BY PROFESSOR A.P. VOL'SKIY

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Translation

Cosmodrome

By Professor A. P. Vol'skiy

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ANNOTATION

[Text] General information is presented on the space rocket launching complexes. The classification and designations of the cosmodromes, their composition and structure are presented. Primary attention is given to the engineering complexes and launching pads, buildings and structures, transport, lifting-positioning and launching equipment, service systems and thermostating. A study is made of the communications between the ground systems and the on-board systems of the booster rockets. General characteristics, the organizational and structural principles of the monitoring and control systems for the technological process operations and the space rocket complex are presented.

The book is designed for engineering and technical workers, the students at the higher institutions of learning and people interested in space rocket engineering.

FROM THE AUTHORS

The book presented to the reader is a first effort to use foreign and Soviet sources in a systematic discussion of the basic organizational principles of the engineering complexes and launching pads of the cosmodromes and the requirements imposed on them, to familiarize the reader with the buildings and structures at the cosmodrome, the structure of the ground units and systems and to demonstrate the variety and complexity of equipment required to assemble, prepare for launch and launch from space rocket systems. General information is also presented about the cosmodromes of the world and brief characterizations of them are given.

Since space rocket engineering is still a relatively new field,up to now there is no standardized terminology either in the Soviet Union or abroad; therefore the terminology of the MALEN'KAYA ENTSIKLOPEDIY KOSMONAVTIKA [Small Encyclopedia of Cosmonautics] (Moscow, Sovetskaya Entsiklopediya [Soviet Encyclopedia], 1970) has been adopted.

The book was written by a collective of authors as follows: A. P. Vol'skiy (the introduction and Chapter 1), A. V. Khaldeyev (Chapters 2 and 6), N. I. Prigozhin (Chapters 3 and 4), I. A. Shuyskiy (Sections 4.6 and 7.2), V. N. Nikolayev (Chapter 5 and Sections 7.1 and 7.3), V. M. Karin (Chapters 8-11).

The authors assume responsibility for the fact that the book is not free of deficiencies, and they will be grateful to the readers for critical comments and suggestions.

INTRODUCTION

On 4 October 1957 with insertion of the first Soviet artificial earth satellite in history into space orbit, the era of cosmonautics was born. As a science, cosmonautics was born far before this date, and by rights its author is considered to be the Russian scientist Konstantin Eduardovich Tsiolkovskiy.

The history of development of cosmodromes is closely connected with the development of cosmonautics. As a compositional part of a united space rocket complex, the cosmodromes must, in accordance with their purpose, meet the requirements imposed on them by the booster rockets and the space vehicles,[1] for the performance of ground preparations, launching and flight control. The structure and composition of the cosmodromes and the structural design of the equipment depend entirely on the structure of the space rocket systems and the goals which have been set for them.

A characteristic feature of the first foreign cosmodromes was the fact that the greater part of them were built on the basis of test areas for combat missiles. The geophysical and meteorological rockets which can be considered as the first generation of space rockets were launched from mobile ground complexes. In 1946, the United States began a program of launching the captured German V-2 rockets to investigate the upper layer of the atmosphere from the White Sands Proving Grounds (New Mexico, United States), which included a gun mount type erector, mobile fueling units, a diesel electric power plant and monitoring and testing equipment. The launches took place from a pad installed on a concrete foundation.

In 1949 the two-stage Bumper-VAK rocket (V-2 and VAK-Corporal) launched from White Sands Proving Grounds reached an altitude of 303 km. The ground units making up the launch complex for this rocket were also mobile.

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[1] By space vehicles here and hereafter we mean both manned spacecraft and various satellites of the earth and other planets.

During the same years the United States built new research rockets of the Nike, Viking and Bumper family, the ground equipment for which was developed in accordance with the same "traditional" system. The Aeroby rockets which found application for many years in studying the upper layers of the atmosphere were usually launched from launchers in the form of towers more than 40 meters high.

The Deacon, Rokun and Fireside rockets (United States), the payload of which included various scientific instruments and experimental animals, constituted a characteristic group. These rockets were launched at an altitude of 30 to 40 km above the earth from balloons with a shaft for the rocket to pass through on launch. Launching the rockets at high altitude offered the possibility of expending less fuel on overcoming the lower dense layers of the atmosphere.

In the Soviet Union research rockets were launched at a launching complex including the gun mount type of erector, the launch pad, tanker trucks, derrick trucks, service platforms, electric power and launch control equipment. In 1949 the first vertical launch of a rocket with research equipment weighing about 130 kg was made from such a complex to an altitude of 110 km.

The launches of the V2A geophysics rockets designed to study the upper layers of the atmosphere, photograph the solar spectrum, perform medical-biological research with animals on board and other scientific experiments became a significant step in the study of outer space in the mid-1950's. The launch complex for the V2A rocket also was mobile and had ground equipment of analogous composition and structure.

The next large-scale achievement of Soviet scientists and engineers was the building of the V5V geophysics rocket and the launch complex for it.

In connection with the International Geophysical Year in 1957, a mobile ground launching complex was built in the Arctic on Kheysa Island (Franz-Josef Land) to launch meteorological rockets. In 1957 to 1965, there were 357 launches from this site. Meteorological rockets were also launched from the launchers of the research ships "Ob'," "Professor Vize," "Voykov" and "Shokal'skiy."

The operation of the first launch complexes made it possible to acquire the necessary experience and proceed with building improved complexes to launch modern space rocket systems.

The cosmodromes providing for launching artificial earth satellites, interplanetary automatic stations and manned spacecraft can be considered as second-generation cosmodromes. Almost all of them were constructed in the second half of the 1950's and the beginning of the 1960's.

After organization in 1958 of the National Aeronautics and Space Administration (NASA) at Cape Canaveral (Florida, USA), the Kennedy Space Center was formed from the Eastern Proving Ground. The launch complexes belonging to the Kennedy Space Center were reequipped to launch various space vehicles using the "Titan," "Atlas," and "Saturn-IB" booster rockets; later launch complexes were built for the "Saturn-V-Apollo" space rocket systems, and so on.

The building of the Baykonur cosmodrome in the mid-1950's became an outstanding achievement of Soviet scientists and engineers. During the construction of this cosmodrome maximum use was made of the achievements of foreign science and engineering. As a result, it became possible to launch artificial earth satellites, manned spacecraft and automatic interplanetary stations giving priority to Soviet cosmonautics.

At the beginning of the 1960's France built its own cosmodrome on the Khammagir Plateau (the Sahara Desert, west of Algeria). The "Diamant" rockets were launched from this site, and the French artificial earth satellites "A-1," "Diapason-1," "FR-1" and so on were inserted into earth orbit from Khammagir.

With improvement of the first phase of the Kuru Test Area (French Guiana, South America) the Khammagir Cosmodrome was closed. In 1970 the "Diamant-B" rocket was used to launch the French "Peol" satellite from Kuru, and in 1971, the "Turnesol" satellite.

England built the Woomera Proving Ground on the south coast of Australia, the appearance of which was connected with the development of English rocket weapons. Geophysics rockets were subsequently launched from this site, and a launch complex was built for the "Europa" rocket, and the Australian "Vresat" satellite was launched using the American "Redstone" booster rocket.

Italian scientists and engineers built a floating cosmodrome from two floating platforms installed on pilings off the coast of Africa, the coastal waters of Kenya; one of the platforms acts as a launch pad, and the other, as the launch command control station. The Italian scientific satellite "San Marco II" was launched from this site using the American "Scout" booster.

Japan has three sites for testing rockets. At one of them, the Utinoura Test Area, the four-stage solid-propellant "Lamda-4C" rocket was used to launch the first Japanese artificial satellite "Osumi." The first artificial satellite was launched in the Chinese People's Republic at the same time.

The "Tkhumba" rocket station was built in India on the geomagnetic Equator. The first high-altitude rocket was launched from that station in 1963, and then regular launchings began using the small high-altitude "Nike-Apache" and "Judy Dart" rockets. The Shrikharikota cosmodrome has now been built in India.

CHAPTER 1. GENERAL INFORMATION ABOUT THE SPACE ROCKET COMPLEX

The space rocket complex is made up of a booster rocket and a space flight vehicle including the space rocket system, and the cosmodrome is made up of a set of ground equipment, buildings, structures and services supporting the pre-launch preparations and launching of the space rocket system, providing trajectory measurements, issuance of commands, reception and processing of telemetric data.

The cosmodrome (in foreign literature, a testing ground or proving ground) is one of the most important elements of the space rocket complex.

1.1. Cosmodrome

The cosmodrome is a complex of specially prepared plots of ground with structures and equipment providing for the assembly, preparation for launch and launching of space rocket systems, measuring their flight trajectories, issuing commands and also the reception and processing of incoming telemetric data. The cosmodrome also includes plots of ground or bodies of water for dropping the spent stages of the boosters and for landing the returning space vehicles (Fig 1.1).

Not only does preparation and launching of the rockets take place at the cosmodromes, but also experimental development of individual systems, testing of various types of equipment, obtaining certain fuel components, the training of service personnel and scientific engineering personnel. The cosmodrome is the scientific-experimental center of the space rocket industry, and some cosmodromes also perform the functions of a production base for rocket engineering.

General Information

Usually the cosmodromes are designed for the preparation and launching of the space rocket systems of various classes and for various purposes. This mission arises from the effort to concentrate scientific-experimental work on the space rocket programs, to make more complete use of the equipment and structures and exclude the necessity for investment of means in additional construction. Many cosmodromes can also serve as military test areas.

In view of this universality of the cosmodromes, they cannot be classified by any defined criteria, for example, by purpose. Thus, the Kennedy Space Center (Cape Canaveral, USA), which is the main NASA launching site and is used to launch space vehicles and test booster rockets in accordance with the American National Space Research Program, is also suitable for developing military boosters and providing flight control for space vehicles for military purposes; the Western Proving Grounds (California), being the primary launching site for space vehicles in the military programs of the United States ("Discoverer," "Midas," "Samos" and so on) is also used to launch artificial satellites for the space research program within the framework of the two-way American-French-Canadian agreements.

It also appears impossible to divide up the cosmodromes with respect to type of orbit into which the launched space vehicles are inserted (equatorial, polar), inasmuch as it is possible in practice to insert space vehicles into polar orbits from any cosmodrome; the same applies to equatorial orbits so long as the power of the booster is sufficient. Here it is possible to talk about the preferred direction of launch determined by the location of the measuring stations and the alienation zones considering safety of the routes. Thus, the system of measuring stations for the Eastern Test Area (Florida) permits space rocket systems to be launched with an azimuth from 44 to 110° and artificial earth satellites to be inserted in orbits with inclination to the plane of the equator from 28°30' to 54°24' with an easterly direction of launch.

The range of launch azimuths usually is selected considering the possibility of expanding it. However, it is necessary to consider that the width of the range of initial inclinations in the orbits of the objects is determined primarily by the geographic latitude of the cosmodrome.

It is also impossible to distinguish the cosmodromes by the length of the flight paths which depend on the class of space rocket systems, which in turn determine the choice of the location where the spent stages of the booster rockets will fall (dry land, ocean). Usually provision is made for the possibility of increasing the length of the paths. Thus, the path of the Eastern Test Area of the United States, initially 8000 km long (from Cape Canaveral to Ascension Island) was increased to 20,000 km as a result of expanding the missions of the cosmodrome.

The expenditures on building cosmodromes are in the billions of dollars, and the annual expenditures on maintaining them are tens and even hundreds of millions. Such expenditures are possible only for the economically developed countries; therefore only a few countries have their own cosmodromes, above all, the Soviet Union and the United States, which have the largest cosmodromes in the world at their disposal. The other countries are forced to combine their efforts both in the execution of space programs and in the building of cosmodromes. For this purpose, the European Rocket Development Organization (ELDO) was formed including England, France, Federal Republic of Germany, Italy, Belgium, The Netherlands, Australia and the

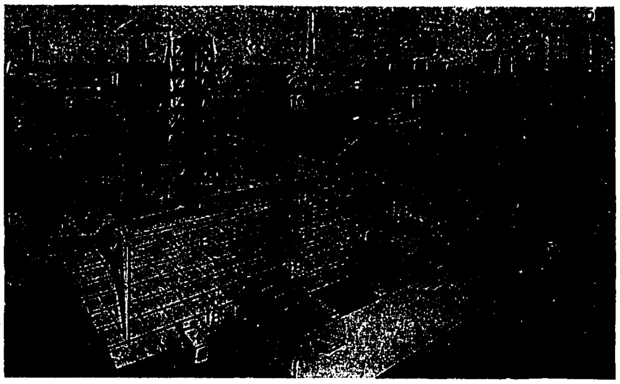

Figure 1.1. Cosmodrome:
А, Б, В -- launch positions; Г -- engineering position; 1 -- cable service tower; 2 -- service tower; 3 -- servicing station for the space vehicle; 4 -- installation and testing facility for the space vehicle; 5 -- installation and testing facility for the booster rockets (vertical assembly building); 6 -- compressor station; 7 -- launch control center; 8 -- oxidant storage; 9 -- reception; 10 -- pool with water for the fire extinguishing system; 11 -- command station; 12 -- gas deflector of the launch system; 13 -- gas discharge channel; 14 -- launch system; 15 -- structure for the guidance instruments; 16 -- caterpillar conveyor; 17 -- radar; 18 -- shelter for service personnel; 19 -- fuel storage; 20 -- hydrogen storage; 21 -- communications lines for the hydrogen evaporation sites.

European Space Research Organization (ESRO) which includes England, France, the Federal Republic of Germany, Italy, Belgium, Denmark, Spain, The Netherlands, Sweden and Switzerland. France has built its own cosmodrome jointly with ELDO, and England, jointly with Australia.

The cosmodromes are unique complexes, the structure and composition of which are influenced by many factors: the geographic coordinates of their location, the volume of the national and international space programs, the purpose and class of the space rocket systems, the level of development of engineering and the state of the economy of the country, the possibility of insuring reliability and safety, and so on. Accordingly, defined recommendations cannot be made which would be considered optimal and "typical" when creating cosmodromes. Therefore, in the further discussion the most characteristic layouts of the cosmodromes, structural designs of the buildings and equipment are presented beginning with world practice which does not, however, exclude other solutions constructed on a theoretically different base.

Placement and Composition

The selection of the placement of the cosmodrome is a problem on international scale, for when launching modern space rocket systems, their flight paths sometimes are as long as half the length of the equator, which involves the interests of many countries. This problem is solved on a complex basis considering the possibility of creating alienation zones in the locations where the rockets are launched, the spent stages fall, where the returned space vehicles land and also considering the necessity for the location of ground stations or ships forming the monitoring and measuring complex along the flight path. Here, the safety arguments are considered in the case of possible emergency when launching the rocket or in the active part of the trajectory.

The cosmodrome flight paths must not interfere with shipping, air traffic or impose losses on any country. Sometimes when space rocket systems are launched warnings are issued to ships and aircraft to stay out of the zones where the spent stages of the booster rockets will fall.

The choice of the location for constructing the engineering and launch positions of the cosmodrome is influenced by the hydrologic conditions of the area, the relief, soil structure, and so on. Usually an even section without great differences in levels is selected, which reduces the cost of building highways, railroads and the aerodromes themselves, and it facilitates the solution of problems connected with transporting large-scale loads. The problem of observing the launch of the rocket is also simplified.

The soil strength and the groundwater conditions must permit buildings and structures to be erected considering the admissible loads and the construction of the deep structures.

The presence of rivers, lakes and other bodies of water required for water supply and fire extinguishing systems is also taken into account. The rivers and canals can also be used as waterways to deliver the large-scale booster rocket stages from the manufacturing plants.

The location of launch and engineering positions, approach routes and transport lines, communication lines and electric power transmissions lines is determined by the zonal layout of the cosmodrome taking into account the requirements of performing the entire technological cycle of preparing the space rocket systems, economy of the engineering-construction and design solutions and also the interests of the development of the economy of the country.

Important factors are the climatic and meteorological conditions in the vicinity of the cosmodrome (the mean annual air temperature, humidity, number of cloudless days per year, and so on), which to a significant degree determine the technical possibilities, influence the operating reliability of the ground systems and also the nature of the buildings and structures. Severe climatic conditions -- a large temperature gradient, high humidity, high winds, and so on -- greatly complicate the operation of the cosmodrome equipment and force complex technical and engineering solutions when building it.

Whereas for safety reasons it is expedient to locate the technical and launch positions of the cosmodromes in lightly populated areas, far from the industrial centers, for economic reasons it is more advantageous to build them in industrial areas, near the plants of the space rocket industry, which permits significant reduction in both the construction cost and the transportation costs connected with delivery of the booster stages, equipment and fuel components.

These contradictory requirements are difficult to reconcile; therefore the problem of selecting a location for building a cosmodrome is a complicated problem, the solution of which is influenced by the possibility of developing new areas, building transportation and communication lines, the necessary industrial enterprises and the provision of communal and domestic services.

The cosmodrome usually includes the following (Fig 1.2):

Engineering facility (engineering complex);

Launch facility (launch complex);

Measuring and command complex;

Search and rescue complex;

Living complex and auxiliary services and systems.

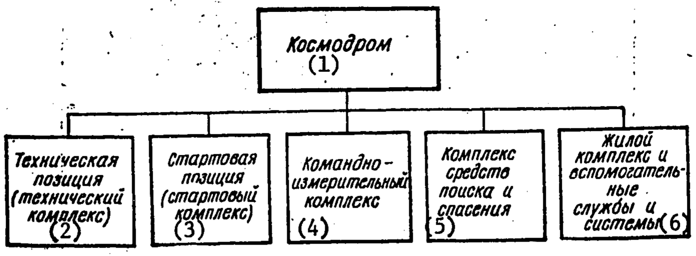

Figure 1.2. Structural diagram of a cosmodrome

Key:

1. Cosmodrome
2. Engineering facility (engineering complex)
3. Launch facility (launch complex)
4. Measuring and command complex
5. Search and rescue complex
6. Living complex and auxiliary services and systems

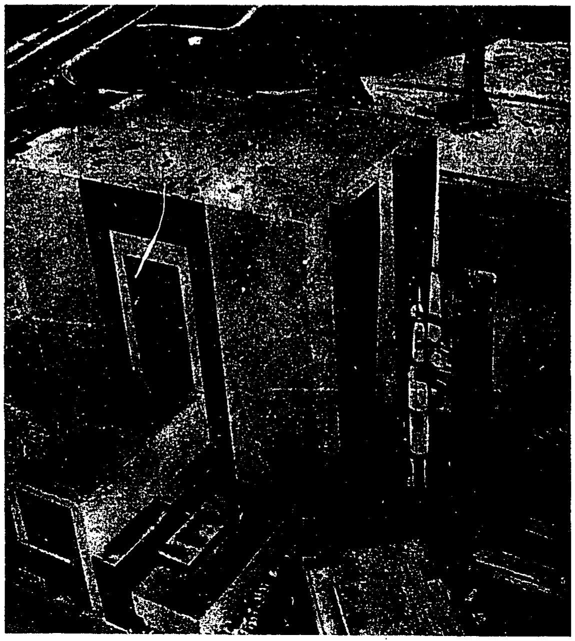

Figure 1.3. Engineering complex

All of the cosmodrome equipment is divided into general engineering and special technological equipment. The general engineering equipment includes electric power, lighting, heating, ventilation and fire fighting equipment, communications, water supply, industrial waste, sewage, elevators, and so on, that is, the equipment of a general industrial profile. The special technological equipment is designed for transporting, transferring, assembly, testing, setting up the launch system, servicing with fuel components and compressed gases, thermostating, preparation for launch, launch and flight control of the booster rockets and the space vehicles.

The engineering complex (TP) is the complex of buildings and structures with general engineering and special technological equipment and the plots of ground with access routes providing for the acceptance, storage, assembly and testing of booster rockets and space vehicles, the servicing of the space vehicles with fuel components and compressed gases and mating them with the booster rockets.

The following basic technological operations are performed at the engineering complex (Fig 1.3):

Acceptance of the stages, modules and individual assemblies of the booster rockets and space vehicles from the manufacturing plants;

Assembly of stages and booster rockets and mating of the space vehicles;

Storage of booster rockets and space vehicles;

Autonomous and complex testing of booster rockets and space vehicles;

Servicing the space vehicles with high-boiling fuel components and compressed gases;

The charging and storage of on-board and ground chemical batteries;

The preparation of the space rocket systems for transportation to the launch complex;

To support the indicated operations, the engineering complex has the following:

An installation and test facility (MIK) for the booster rockets (a vertical assembly building);

An installation and test facility for space vehicles (MIK KO);

A service station for the space vehicle;

A compressor station with receiving area;

A storage battery charging station;

Storage facilities for powdered charges and a building for mating the solid-fuel boosters;

Storage of the booster rockets;

Storage for the mating-installation and the lifting-erecting equipment;

Access routes with unloading platforms and ramps;

Structures with power supply, ventilation, heating, water supply and sewage equipment, fire extinguishing systems, communications systems, and so on;

Administrative and service buildings.

The launch complexes (SP) include a set of buildings with general engineering and special technological equipment and grounds with access routes for delivery of the space rocket systems from the engineering complexes, installation of them in the launch system, testing, pre-launch preparation, servicing with fuel and compressed gases, aiming and launching.

The following basic operations are performed at the launch complex (Fig 1.4):

Installation of space rocket systems in the launch systems;

Assembly of space rocket system (if necessary);

Pre-launch testing of the booster rocket and the space vehicle;

Servicing of the booster rocket with fuel components and compressed gases;

Servicing of the space vehicle with low-boiling fuel components;

Thermostating the elements of the space rocket system and the fuel component;

Boarding of the cosmonauts;

Aiming of the booster rocket;

Launch;

Recording the system parameters of the launch complex during preparation, servicing and launch (the system parameters of the launch complex can also be recorded from the engineering complexes;

Drainage of the fuel components and removal of the booster rocket from the launch system (on postponement of the launch).

In order to support these operations, the launch complex includes the following:

The launching tower with the launching system;

The structures with equipment for storage, servicing and draining the fuel components;

The gas supply and receiving stations;

The facility for neutralization equipment (if the fuel components are toxic);

The refrigerating center;

The measuring station;

Command station (launch control center);

Transformer substation and power supply system;

Lightning arrester system;

Cooling towers and sprinkling basins;

Process water tanks for the fire extinguishing system;

Access railways and hard-topped roads;

Administrative and service facilities;

Enclosures and protection means.

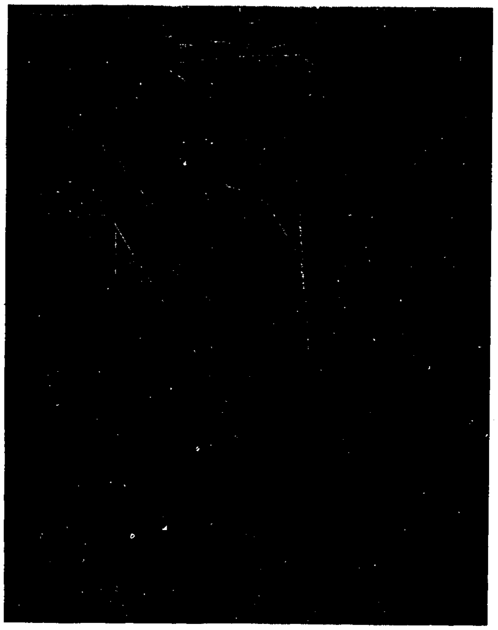

Figure 1.4. Launch complex

The cosmodrome usually has an engineering complex and one or several launch complexes, some large cosmodromes have several engineering complexes for preparing the space rocket systems of various classes.

The measuring and command complex (KIK) is the complex of ground stations and posts or specially equipped ships located along the flight path of the booster rockets and the space vehicles designed for measuring trajectories, sending commands, receiving and processing incoming telemetric data.

The measuring and command complex (Fig 1.5) provides for the following:

Flight trajectory measurements of the booster rockets and space vehicles;

Transmission of commands to the space vehicles to switch on the programs built into the on-board servosystems and mechanisms and commands to alter the program;

Reception of telemetric data from on board the booster rockets and space vehicles;

Telephone or telegraph communications with the cosmonaut;

Reception and relaying of television pictures from on board the space vehicle;

Transmission of the results of the trajectory measurements over the communication lines to the coordinating computer centers;

Processing of trajectory and telemetric data.

The equipment of the measuring and command complex is made up of the radiotelemetric stations, radio receiving and transmitting units, antennas, television sets, lines for automatic processing of the received data and mathematical computers, the unified time service equipment, communications media, electric power sources, and so on.

The search and rescue complex (PSK) for the returned space vehicles (ships) and their crews includes specially equipped ships, aircraft, helicopters, radios, visual observation equipment and other means required to search, detect, service, evacuate the space vehicles and rescue the crew.

The search and rescue complexes (Fig 1.6) provides for the following:

Search and detection of space vehicles;

The operations of opening the vehicle and extracting containers, capsules and modules with scientific equipment;

Disembarking of the crew from the space vehicle (ship) and rendering first aid (if necessary);

Loading the space vehicle on the evacuation transport means or on board a rescue ship;

Transporting the vehicle to the base, and so on.

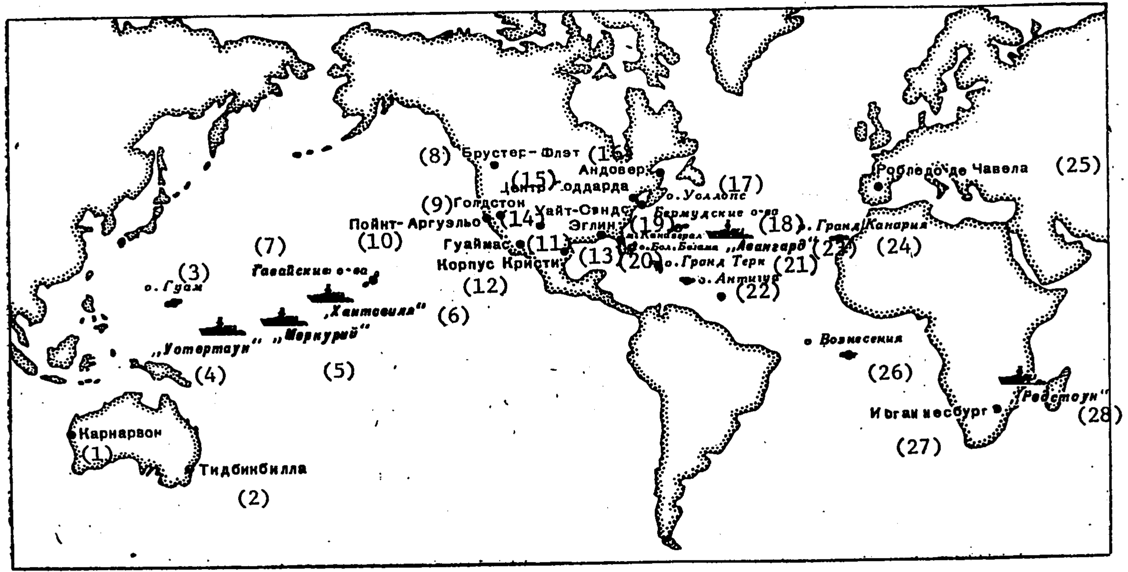

Figure 1.5. Command and measurement complex (location of ground stations and ships, stations for trajectory measurements and repeater stations)

Key:

1.	Carnarbon	11.	Guaymas	21.	Grand Turk
2.	Tidbinbilla	12.	Corpus Christi	22.	Antigua
3	Guam	13.	Eglin	23.	"Avanguard"
4.	"Watertown"	14.	White Sands	24.	Grand Canary
5.	"Mercury"	15.	Goddard Center	25.	Robledo de Chavela
6.	"Huntsville"	16.	Andover	26.	Ascension Island
7.	Hawaiian Islands	17.	Wallops Island	27.	Johannesburg
8.	Brewster Flat	18.	Bermuda Island	28.	"Redstone"
9.	Goldstone	19.	Cape Canaveral		
10.	Point Arguelo	20.	Grand Bahama		

Figure 1.6. Complex of search and rescue means: а -- water landing of the spacecraft crew module; б -- placement of pontoons under the crew module; в -- lifting the cosmonaut aboard a helicopter in a cradle; г -- exit of the cosmonaut on an inflatable raft

The living complex and auxiliary services of the cosmodrome (Fig 1.7) have an administrative and training center with administrative services and a center for training service personnel; the residential city with commercial, communal and cultural-domestic facilities; power supply systems (heat and electric power plants, electric power plants, transformer substations and electric power transmission lines), water supply, communications for all of the cosmodrome services; the storage zone for fuel components and the production of cryogenic components; the repair base and storage facilities; transport lines, and so on.

Basic Requirements Imposed on Cosmodromes

The cosmodromes must satisfy an entire series of operating and technical requirements which include the following:

Insurance of high reliability of the launches and operating safety;

Minimum time for preparing the space rocket systems for launch (a series of launches);

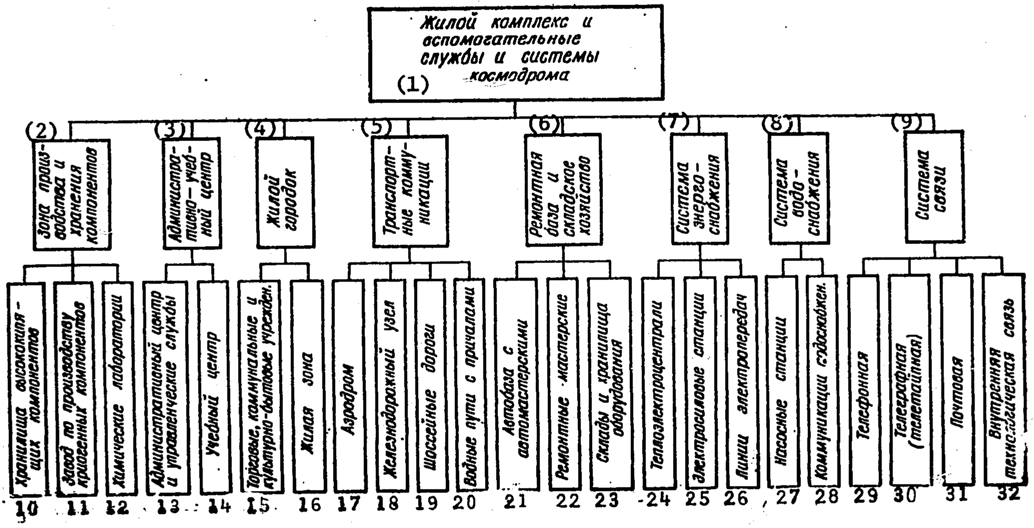

Figure 1.7. Structural diagram of the living complex, auxiliary services and systems of cosmodrome

Key:
1. Living complex and auxiliary services and systems of the cosmodrome
2. Zone for production and storage of components
3. Administrative training center
4. Residential complex
5. Transport lines
6. Repair base and warehousing
7. Power supply system
8. Water supply system
9. Communications system
10. High-boiling component storage
11. Plant for producing cryogenic components
12. Chemical laboratory
13. Administrative center and services
14. Training center
15. Commercial, communal and cultural-domestic institutions
16. Residential zone
17. Airport
18. Railroad junction
19. Highways
20. Waterways with docks
21. Motor vehicle base with workshops
22. Repair shops
23. Warehouses and storage facilities for equipment
24. Heat and electric power plants
25. Electric power plants
26. Electric power transmission lines
27. Pumping stations
28. Water supply lines
29. Telephone
30. Telegraph (teletype)
31. Postal
32. Internal process communications

Minimum number of service personnel;

Preparation for launch and launch at any time of year or day under defined meteorological conditions.

The high reliability of the launches is insured by fail-safe operation of the space rocket system and the ground launching complex.

Reliability is the property of the equipment to maintain its output characteristics (parameters) within defined limits under given operating conditions. From determining the reliability it follows that not only is the system considered unreliable in which mechanical or electrical damage is manifested leading to unfitness of it, but also the system for which the characteristics go beyond the admissible limits.

The reliability of a unit or a system is built in when the system is designed; the most effective methods of improving reliability are selection of the elements of increased reliability, simplification of the system, creation of systems with limited consequences of failures of the elements, redundancy (redundancy of the assemblies and systems), built-in monitoring, automation of checks, and so on. The reliability of the equipment is increased by improving the production technology, automation of the production processes, strict monitoring of production quality, the introduction of special tests with simulation of the operating conditions (usually extreme values of the loads, pressures, vibrations, temperatures, and so on are used).

Reliability is closely connected with various aspects of the operating process: observation of the operating rules excluding the possibility of breakage of the equipment; periodic checks; performance of preventive repair work; maintenance of equipment in technically good working order, and so on.

The preservation of the equipment -- the property of the equipment to remain in working order in storage -- is an important technical concept. Inasmuch as storage is an inseparable part of operation and maintenance, the fitness of the units and systems depends on it to a very high degree.

The characteristics of the possibility of repairing failed systems and units or individual elements of them -- repairability, that is, adaptibility of the equipment to the detection and elimination of failures and also prevention of failures -- has great significance. Frequently when preparing the space rocket systems for launch, it is not the fact of failure of the unit or system itself that causes alarm, but the impossibility of quickly finding the failure and quick elimination of it.

As applied to a cosmodrome it is expedient first of all to consider only the systems and units which have a direct influence on the preparation of the rocket for launch and the launch itself and secondly, to investigate their reliability only from the point of view that they are either in working order or not in working order. Inasmuch as on appearance of the failures in individual elements the systems and units of the cosmodrome as a whole can continue to perform its function, instead of reliability it is more appropriate to talk about efficiency.

By the efficiency of a complicated technical complex we mean the degree of its correspondence to the solution of the stated problems. With this approach the most important criterion is estimation of the completeness of the fulfillment of the mission. However, such factors as awkwardness and complexity of the equipment, the application of expensive deficit components and materials, the requirement of high qualification of the service personnel, high cost of operation and maintenance, and so on, have a high influence on efficiency. At the present time these factors are more and more being taken into account in the development of equipment and organization of operations at the modern cosmodromes.

The insurance of operating safety at the cosmodrome is an important requirement. It is possible to consider that the cosmodrome is an increased danger zone, and in a number of cases, figuratively speaking, a "powder keg": explosives and current sources, fuels and spontaneously combustible components, high pressure lines and toxic working of fluids are side by side here. Therefore inappropriate technical solutions or insignificant violations of safety measures in operation and maintenance can lead to emergencies and even to a disaster.

The measures to provide for operating safety at the cosmodrome can be divided into two groups: the first group includes the measures provided for when designing the structures, the systems in the units of ground equipment and the cosmodrome as a whole; the second group includes the organizational measures providing for observation of safety measures and fulfillment of the behavioral roles of the service personnel.

The first group includes the placement of the buildings and structures of the cosmodrome at a safe distance from each other, the corresponding organization of the technological cycle of pre-launch preparations and launching of the space rocket systems, reliable protection of the structures from fire and the effects of a blast wave, and the presence of means of protecting the service personnel and means of evacuating them in an emergency, exclusion of improper action taken by operators, and so on.

The buildings and structures of the cosmodrome are grouped in zones depending on their functional purpose, the degree of danger involved in the operations and in accordance with the technological process sequence for preparation of the space rocket systems. The launch facility is usually placed at a distance from the other zones and facilities of the cosmodrome in order to protect them from damage in case of the explosion of a rocket during launch or in the initial phase of the trajectory. The service station, the powdered charge storage, the zones for production and storage of fuel components, and so on are located at a safe distance. The launch facility structures are designed for dynamic forces, excess pressure and sound effects. The dynamic forces occur in the case of emergency postponement of the launch (shutdown of the engines) and with respect to magnitude exceed by 1.8 to 2 times the launch mass of the space rocket system. The excess pressure is created in case of an emergency explosion of the rocket system on the launching paid and it is expressed in "TNT equivalents" -- the amount of TNT equivalent to the blast energy. The sound effects arise from operation of the rocket engines of the booster rocket during launch, and they are measured by the magnitude of the sound pressure.

Thus, the launch complex No 39 for the "Saturn-V-Apollo" space rocket system, in accordance with the admissible critical values of the excess pressure and acoustic effects, is broken down into four functional zones: launches, launch support, general purpose and industrial.

The launch zone is delimited by an excess pressure line of a possible explosion of 0.0028 MPa[1] and a sound level of 135 decibels. The launching pads, the direct launch support equipment, automatic and remote control optical and electrical equipment are located in this zone. The distance between launching paids (2670 meters) was selected so that in case of explosion the service personnel and space rocket system on an adjacent pad will not be subjected to above admissible pressures.

The launch support zone is located between the sound effect lines of 135 and 120 decibels. The vertical assembly building, the launch control center, the facility for storing chemicals, the storage battery charging station, and so on are located in this zone. The vertical assembly building is located beyond the reach of large fragments in case a rocket explodes during launch.

The general purpose zone beings with the sound effect line of 120 decibels and reaches the boundaries of the large complex. This zone is relatively safe and is designed for the general engineering equipment structures.

The industrial zone is located within the limits of the general purpose zone and includes the installation and test facility for the space vehicles, the administrative buildings, the pyrotechnical buildings, laboratories, and so on.

The structures are protected, as a rule, by being partially underground, the use of high-strength structural elements, embankments, shielding slabs, and so on. The structures in which there are people during the final operations and launch are especially reliably shielded: these include

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[1] 1 Pa$\simeq 10^{-5}$ kg-force/cm^2; 1 kg-force/cm^2=$9.80665\cdot 10^4$ Pa (exactly)$\simeq 10^5$ Pa= 0.1 MPa.

the facilities for the central preparation and servicing panels and the launch control center.

The launch structures are also shielded from the gas jet of the rocket engine on launch. In cases where it is inexpedient to shield the gas deflector of the launching system, the elements for fastening the rocket during launch and some of the ground cables reliably from the gas jet, they are made to be used only once or for partial replacement (repair) after each launch.

The design safety measures include so-called classification of the facilities, that is, division of the buildings and structures into explosion hazardous, fire hazardous, and so on. For example, the liquid oxygen storage facility of the launch facility is a fire-hazardous structure, and the service tower is explosion-hazardous and fire-hazardous, for the service lines, drainage lines, high pressure lines and electric cables are run along it. Depending on the category, the equipment of these structures has also been developed in the corresponding execution.

For safety, the service personnel are provided with means of collective and individual protection from the effects of toxic vapor, heat and shielding in case of fire. These means are varied and include the equipment and attachments from the stationary shielding structures (bunkers, heat shields, fire-fighting systems, ventilation units, and so on) to the simplest fire extinguishers and individual gas masks.

Special attention has been given to the problems of evacuation of service personnel on occurrence of an emergency, for which provision is made for emergency exits in the facilities, fire escapes, emergency hatches, and the structures of the launch facility have tunnels or underground passages, sometimes running for quite long distances. The greatest difficulty arises in evacuating people from the service tower, the platforms of which are located at a great height. The elevators cannot provide fully for the solution of this problem, for the possibility of their failure as a result of an emergency is not excluded, and descent by ladders is too slow. Therefore, special cable devices, rescue cradles and chutes are used in emergencies. Designs have been developed for these catapults, individual jet packs and even helicopters and dirigibles.

The measures to insure safety of performing operations at the launch facility include the measures to rescue the spacecraft crews. If an emergency develops before the crew boards, high-speed elevators, rescue devices, evacuation systems and other means of leaving the service tower are used (sometimes the same as for the service personnel). Bunkers and other shielding structures have been provided to shelter the crew. In case of an emergency with the booster rocket during launch, the emergency rescue systems of the spacecraft are used which have various structural executions, but one goal -- removal of the compartment of the spacecraft in which the crew is located to a safe distance from the launch site.

Thus, the compartments with crews on the "Soyuz" and "Apollo" space vehicles are separated by solid-propellant engines with subsequent descent of these compartments on parachutes, and the "Vostok" space vehicle had a catapult seat with the cosmonaut in it.

Incorrect action by the operators during the pre-launch preparation is excluded by maximum automation of the preparation process, modularization of the units and systems, sound and light signals, warning inscriptions and all possible forms of monitoring.

The second group -- the organizational measures performed at the cosmodrome -- primarily includes observation of safety measures. For each type of operation there are specific safety engineering rules (for example, inadmissibility of an open flame or the occurrence of an electric spark in the facility where gaseous or liquid oxygen is to be found; forbidding repairs of tanks and lines under pressure, and so on). In addition, there are the general standards and rules of behavior of the service personnel working at the cosmodrome: the only people allowed to perform the various operations are those who have studied the corresponding system or unit and have the necessary training; people not involved in performing these operations must be removed from the area where they are performed. Inasmuch as the operations with respect to preparing the space rocket systems are performed in a strict technological sequence, the violation of this sequence without the permission of the launch director is categorically forbidden.

The preparation time of the space rocket systems for launch is an important operating and technical index of the cosmodrome. For modern space rocket complexes the pre-launch preparation cycle involves the time from several days to 2 or 3 months and depends on the work schedule, the class of rocket and also the flow chart for preparing the space rocket system for launch. In certain cases the preparation time is not limited, for it has no significant effect on the fulfillment of the stated mission. In other cases this time is strictly limited. This arises from the need to launch at given astronomical times (for example, for a flight to the moon or other planets) or after defined time intervals (when docking space vehicles in orbit), or when it is necessary to have the space rocket system ready to launch in the launching system for emergency aid to a manned spacecraft which has gotten into trouble

When planning the preparation time it is considered that on the one hand shortening the length of the cycle can lead to complication of the equipment, the construction of additional structures, the expansion of the working areas and an increase in the number of service personnel and on the other hand, to a decrease in the number of launches from each launch complex and reduction of the equipment loading coefficient. Therefore in the general case, when striving to reduce the launch preparation time of the space rocket system, it is necessary to consider all of these factors.

The number of service personnel at the modern cosmodromes, in spite of the high level of automation and mechanization, will reach several thousands and even tens of thousands of people. This is explained by the great complexity and variety of the ground systems and the rocket systems requiring specialists of different profiles for their servicing. In addition, the buildings, structures and services of the cosmodrome, as a rule, are split up territorially and are sometimes at significant distances from each other, which excludes the use of the same specialists. In striving to reduce the number of service personnel engaged in preparing the space rocket systems, everything begins with the fact that the machine cannot completely replace the human operator, who plays the primary role in the performed operations.

The cosmodrome must provide for launch preparations and launches of space rocket systems at any time of year and any time of day. This arises from the necessity for launching at strictly given astronomical times and the rocket preparation schedule which must not depend on the capriciousness of the weather. Considering that the climatic conditions at the locations of the cosmodromes are frequently severe, this requirement cannot always easily be met.

1.2. Space Rocket System

General Information

The space rocket system (RKS) includes the booster rocket and the space vehicle.

The booster rocket is used to obtain the first and second cosmic velocities[1] and insert the space vehicle into the given orbit. In space engineering only multistage rockets are used, that is, rockets made up of several stages in which the spent stage is separated after using up all of its fuel, and its speed becomes the initial speed for the subsequent stages and the space vehicle (the payload).

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[1] The first cosmic velocity is the least initial velocity which must be communicated to a body at the surface of the earth in order for it to become an artificial earth satellite. It is equal to the angular velocity, and in the absence of an atmosphere it is 7.91 km/sec. The second cosmic velocity is the least initial velocity which must be communicated to the body for it to overcome the earth's gravity on beginning to move near the earth -- it varies with altitude and on being reduced to the surface it is 11.19 km/sec.

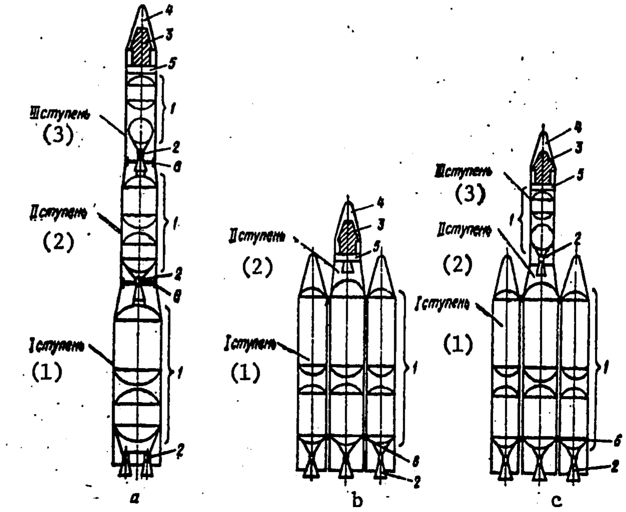

Figure 1.8. Schematic diagrams of a multistage rocket:
a -- with transverse division of the stages (the "tandem" system);
b -- with longitudinal division of the stages (the package system);
c -- a combination system; 1 -- fuel compartments; 2 -- rocket engines; 3 -- payload; 4 -- nose cone; 5 -- control equipment compartment; 6 -- power plants of the stages

Key: 1. 1st stage; 2. 2d stage; 3. 3d stage

Structurally the multistage rocket can be executed with transverse division of the stages (the tandem system), with longitudinal division (the package division) or a combination of these two systems (Fig 1.8).

In the system with transverse division of the stages their engines operate successively; in the system with longitudinal division the engines of the subsequent stage can operate simultaneously with the engines of the preceding stage; in the combined system, both simultaneously and successively. However, in any of these systems when the fuel is used up the spent stage is discarded.

The space vehicle is equipped with a nose cone to protect it from aerodynamic loads occurring when the rocket passes through the dense layers of the atmosphere. Structurally the nose cone, the space vehicle, the engine of the emergency rescue system (if the vehicle is manned) and the last stage of the booster rocket or its connecting element (adapter) constitute a single last stage or top module.

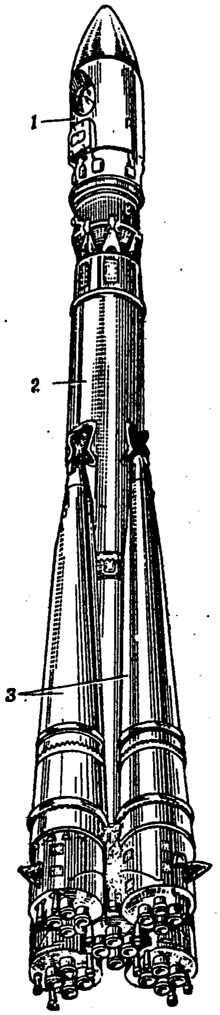

Figure 1.9. Booster rocket and the "Vostok" spacecraft: 1 -- top module with last (third) stage; 2 -- central module (second stage); 3 -- peripheral module (first stage)

The booster rocket of the "Vostok" spacecraft (Fig 1.9) serves as an example of the combination system of joining the stages. It is a three-stage rocket made up of six modules: central, four peripheral and the third stage module. The first and second stages (the peripheral and central modules respectively) are made in accordance with the system with longitudinal division, and the third stage which is installed on the central module, in accordance with transverse division.

In space engineering primarily liquid-propellant rocket engines are applied which use liquid fuel components to create the jet thrust. The solid-propellant engines find application only as individual stages or boosters, and in the space vehicles, for emergency residue systems, soft landings, and so on.

The space booster rockets are distinguished by relatively light construction, the mass of which does not exceed 10 to 12% of the mass of the entirely filled rocket. When creating the structural design of rockets having high strength and rigidity, along with using high-strength light alloys, other solutions are used (maintenance of a defined inside pressure in the rocket tanks using ground pre-launch blowing systems, supporting elements for "suspending" the rocket on the launch system, wind fastenings, and so on).

With respect to launch mass, the space booster rockets are divided into superlight, light, medium, heavy and superheavy. This classification is somewhat provisional; it has no clear bounds and nevertheless has found broad application in the technical literature, especially foreign literature. In the United States the following classification of rockets is used:

Superlight -- with a launch mass up to 50 tons ("Scout");

Light -- with a launch mass to 100 tons ("Thor-Alter," "Thor-Werner");

Medium -- with a launch mass to 300 tons ("Thor-Delta," "Thorad-Delta," "Thor-Agena," "Thorad-Agena," "Atlas-Agena," "Atlas-Centaur," "Titan-1B");

Heavy -- with a launch mass to 1000 tons ("Titan-IIIC," "Saturn-IB");

Superheavy -- with a launch mass of more than 1000 tons ("Saturn-V").

The purpose of the space booster system is determined by the space vehicle. In automatic space vehicles all the operations are performed without the participation of man using equipment and instruments. The manned vehicles are controlled by cosmonauts on board; some of the manned vehicles can also operate in the automatic mode.

With respect to orbit the space vehicles are divided into artificial earth satellites and interplanetary stations. Depending on the purpose of the satellites, they are divided into scientific,meteorological, communications, navigational, and so on (Fig 1.10, 1.11). The interplanetary stations (Fig 1.12) are designed for flight to other planets. Some of them can have the artificial satellites of these planets also in their position.

The structural line of spacecraft has a number of peculiarities connected with the specific factors of outer space — weightlessness, deep vacuum, the presence of meteoritic particles, intense radiation for which the nature of the friction process changes, the phenomena of so-called "cold welding" occur, meteor erosion takes place, and so on.

Space vehicles which must operate for a long period of time under space conditions have systems that insure a defined thermal regime, power supplies for the instruments and equipment and radio communications with the earth. On manned spacecraft, the required atmospheric composition is maintained in the compartments, and conditions required for life support of the crew are created.

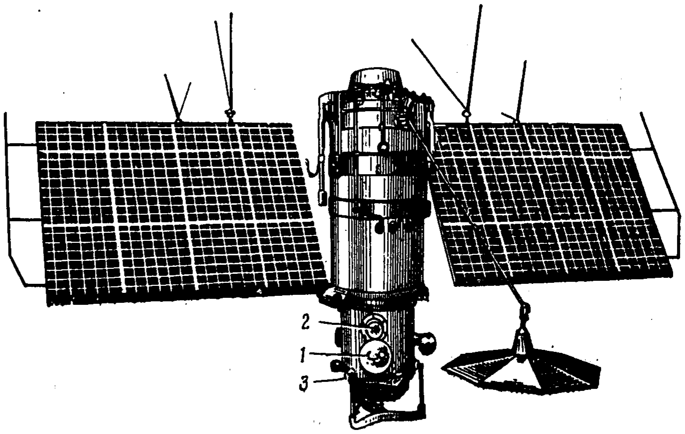

Figure 1.10. "Kosmos" meteorological satellite:
1 -- actinometric equipment; 2 -- infrared equipment; 3 -- television equipment

Usually the entire space vehicle does not descend to the earth, but only part of it -- the descent vehicle -- which contains the crew and some of the on-board systems; the remaining compartments with equipment providing for orbital flight of the vehicle are separated from the descent vehicle at the beginning of the descent trajectory. At the end of descent the speed of the vehicle is reduced, and a further decrease in speed before landing is accomplished usually by a parachute system. On some of the spacecraft ("Soyuz," "Apollo") a soft landing system is included which makes use of powder propulsion units permitting the landing speed (dry land or water) to be reduced in practice to zero.

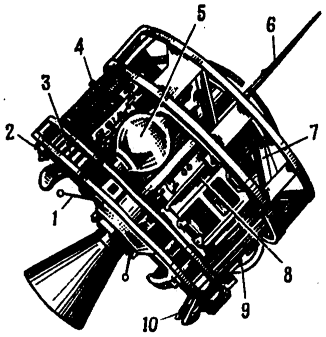

Figure 1.11. "Syncom-2" communications satellite:
1 -- telemetric and command rod antenna; 2 -- jet nozzle of the orientation system; 3 -- nickel-cadmium storage battery; 4 -- radio receiver; 5 -- hydrogen peroxide bottle; 6 -- coaxial communications slotted antenna; 7 -- radio transmitter with traveling wave tube; 8 -- command radio receiver; 9 -- nitrogen bottle of the position control system; 10 — solar indicator

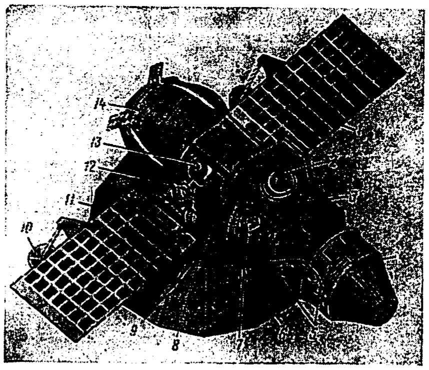

Figure 1.12. "Venera-7" ["Venus-7"] interplanetary automatic station:
1 — solar cell panel; 2 — astronavigational sensor; 3 -- shielding panel; 4 — correcting engine; 5 -- collectors of the pneumatic system with control nozzle; 6 -- cosmic particle counter; 7 -- permanent solar orientation sensor; 8 -- orbital compartment; 9 -- radiator-cooler; 10 -- low-directional antenna; 11 -- high-directional antenna; 12 -- automation module for the pneumatic system; 13 -- compressed gas bottle; 14 -- descent vehicle

The variety of structural designs of spacecraft, in addition to their functional purpose, is also connected with their national origin, with different approaches to the solution of many engineering problems. This has been manifested in preparation for the joint experimental flight in docking in space of the Soviet spacecraft "Soyuz" and the American "Apollo," in July 1975.

For rendezvous, docking and joint flight, the "Soyuz" and "Apollo" spacecraft (Fig 1.13) were developed considering their compatibility. Instead of a "rod-cone" docking unit, androgynous docking units were installed with peripheral location of the locks.

The problem of compatibility of the atmosphere was also solved. Inasmuch as an "earth" atmosphere is used on the "Soyuz" spacecraft, and pure oxygen is used for breathing on the "Apollo" in order to provide for transfer of the cosmonauts from one ship to the other a special chamber was built for pressure equalization (this transfer module was built into the "Apollo").

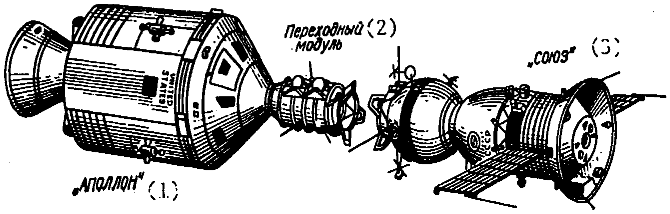

Figure 1.13. "Soyuz" and "Apollo" spacecraft

Key:

1. "Apollo"
2. Transfer module
3. "Soyuz"

Orbital stations play a special role in cosmonautics. The first experimental space station in the world was created by docking the "Soyuz-4" and "Soyuz-5" spacecraft in orbit. The next important step in their development was insertion of the long-term "Salyut" orbital station into artificial earth satellite orbit (Fig 1.14).

The further development of space flights is continuously connected with the creation of large orbital complexes in terrestrial space. The basis for such complexes will be multipurpose orbital stations made up of various purpose modules which will be inserted into orbit by multiple-use rockets and spacecraft and they will be replaced by new ones as they complete their missions. Crew to service the space stations will be delivered and changed analogously.

Recently specialists of many countries have worked on building multiple use space transport systems. The solution to the problem of saving the space rocket systems is being sought in different directions. The possibility of building a multiple use spacecraft with a nonreturnable booster has been established. The efforts to decrease the amount of nonreturnable equipment have led, for example, to the investigation of a transport space system with the multiple use last stage which simultaneously serves as part of the booster rocket and the space vehicle. The possibility of saving and multiple use of the most expensive equipment of the booster rockets has been discussed: the instrumentation of the control and telecommunications systems, the liquid-propellant rocket engines, the mounted solid-fuel modules, and so on.

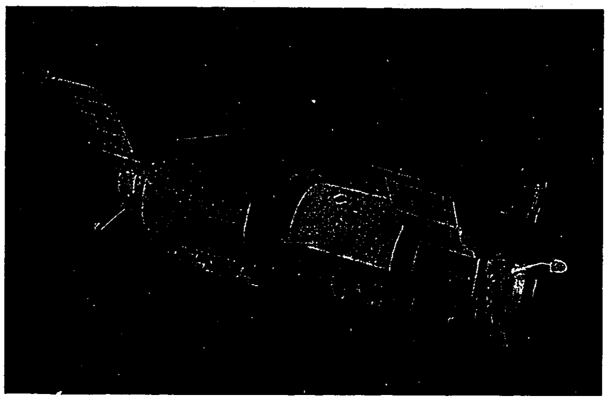

Figure 1.14. Long-term "Salyut" orbital station

American specialists have developed a design for the "Rombus" space transport system which is recovered by parachutes (the recovered vehicle weighs 252 tons); in this case the landing site of the vehicle is planned to be near the launching pads and waterways. After landing, the vehicle will be delivered on a self-propelled caterpillar unit to a barge and transported to the installation and testing facility of the cosmodrome.

The multiple-use space transport systems can be considered as representatives of space rocket engineering of the next generation.

Interrelation of Space Rocket Systems with Ground Complexes

The ground equipment complexes provide for the preparation of space rocket systems in all stages, beginning with transportation from the manufacturing plant to launching the booster rocket.

During the initial period of development of space rocket engineering, the goal was not set of insuring (perhaps, even at the expense of some complication of the space rocket systems) simplicity of operation, convenience of servicing, efficient construction of the units and systems of the ground equipment, or reduction of pre-launch preparation time. This led to serious complications with respect to automating the preparation process and, consequently, required the presence of a large number of units and service personnel.

The experience in developing space rocket engineering has led to the fact that the space rocket system has begun to be developed as a unit whole, which has made it possible to find more efficient solutions to the stated problems.

The requirements and the possibilities of the ground complex are constantly considered from the first structural elements of the space rocket system. Thus, the dimensions of the booster rocket are selected beginning with the optimal ratio between its length and diameter. However, if only this condition is adhered to, the rocket can turn out to have dimensions such that it will be impossible to deliver it to the launch site by the existing means of transportation, and the creation of special transport means will lead to increased cost of the entire complex.

If we begin with an effort to decrease the mass of the rocket structures, it is expedient to make the on-board filling lines and cable networks as short as possible. However, this is not always advantageous for the space rocket complex as a whole, for in this case it is necessary to have access to the filling heads and plugs located at significant height during the pre-launch preparations which complicates operation and maintenance, records a large number of service personnel and complicates automation of the operations. Consequently, it is sometimes more expedient to allow some increase in weight of the structure of the space rocket system and as a result, to insure convenient arrangement in operational respects of the booster rocket elements coupled to the ground equipment.

An analogous situation arises also when selecting the fuel components when it is necessary to consider not only their energy but also their operating characteristics. The choice of fuel components, method of filling and batching has great influence on the structural design of the space rocket systems and its pneumohydraulic system. Thus, when using low-temperature cryogenic components the rocket tanks usually are lined with thermal insulation; although this increases the mass, it makes it possible to use the component in the supercooled form which significantly decreases its evaporation and also prevents air condensation on the tank walls. The filling and servicing conditions have a significant influence on the strength characteristics of the tanks, the structure and dimensions of the drainage and safety valves.

In order to increase the reliability of the launch process it is desirable at launch time to have a minimum number of couplings of the space rocket system to the ground systems. Therefore the majority of ground-on-board couplings are broken in advance, just as before launch, and only those which are required up to liftoff time of the rocket from the launching system are broken directly during launch.

The interrelation of the space rocket systems and ground equipment is complicated and varied, and the mutual effect is large. The proper considerations of all factors determines how effectively the problem of building the space rocket complex with optimal parameters will be solved.

Systems For Preparing the Space Rocket Systems for Launch

The preparation of the space rocket systems for launch includes the following basic steps:

Transport of the elements of the space rocket system to the cosmodrome;

Assembly and testing of the booster rocket and the space vehicle at the engineering complex;

Transport of the booster rocket to the launch complex and installation of the launch system;

Pre-launch preparation of the space rocket system and launch.

The method of assembling the space rocket system, as a function of which it is possible to isolate three process flow charts, has the most significant influence on the entire preparation cycle:

The first flow chart includes the horizontal assembly of the space rocket system and complex testing on the installation and testing setup at the engineering complex; the transportation of the space rocket system in the horizontal position to the launch complex and erection of it to the vertical position on the launch system;

The second flow chart includes horizontal or vertical assembly of the individual stages of the booster rocket in the installation and test equipment, transporting it to the launch complex, assembly of the space rocket system in the vertical position on the launch system and subsequent performance of complex tests;

The third flow chart includes vertical assembly of the space rocket system and performance of complex tests on the installation and test units (the vertical assembly building) at the engineering complex; the transportation of the space rocket system to the launch complex and installation of it on the launch pad (the stationary part of the launch system).

Each of the systems has its advantages and disadvantages, and the application of one system or another is determined by many factors.

In the first system the individual stages of the booster rocket are delivered to the installation and test facility (MIK), where autonomous checkout, assembly in the horizontal position using a coupling unit or installation and coupling dollies, complex testing and coupling of the space vehicle (the last stage) are carried out. The completely assembled space rocket system is transported to the launch complex on the erector. At the launch complex it is put in the vertical position and installed in the launch system.

This arrangement is applicable for space rocket systems, the structural design of which permits transportation of them in the horizontal position (which is determined by the strength capabilities of the rocket and frequently is connected with some increase in its weight). In accordance with this system the assembly and testing of the space rocket system is accomplished in the facility under favorable conditions which will permit convenience of performance of the operations and the quality of them. At the same time there is no necessity for building a high-rise installation and test facility, the creation of a carrier for vertical transfer of the space rocket system and special tracks which is connected with great technical difficulties (in particular, with subjection to significant wind loads). The deficiencies of the system include assembly of the space rocket system in the nonoperating (horizontal) position; the necessity for repeated complex testing in the launch position, for the transfer of the booster rocket from the horizontal position to the vertical position and installation of it on the launch system can be the cause of the occurrence of failures; the coupling of the service, pneumatic and electric lines to the rocket at the launch position, which is connected with deficiencies and operating difficulties, in particular, under unfavorable climatic conditions.

The first preparation scheme is used for the heavy class "Soyuz" Soviet rockets and the American "Scout" rockets.

The second system is used (in American termonology called the "joint preparation method") when the individual stages of the booster rocket and the space vehicle are delivered in a defined sequence from the installation and test facility to the launch site where it is assembled on the launch system using the service tower, lifts or cranes. During assembly, the individual systems are tested and checked out, and on completion, the space rocket system as a whole is subjected to complex testing.

According to this system, only individual stages of the booster rocket are assembled in the estimation and testing facility, which essentially reduces the size and cost of construction of the installation and test facility and excludes the necessity for special transport means to be used for the completely assembled space rocket system. The deficiencies of this system are unimproved test process in connection with the performance of operations in the open air, which lowers the reliability of the preparation of the space rocket system and the fact that the assembly of the space rocket system on the launch system occupies the launch complex for a prolonged period of time, reducing its carrying capacity.

This preparation system is used primarily for rockets with long intervals between launches (for example, the "Europa-II" booster rocket), the medium class rockets (American booster rockets "Chori Delta," "Atlas-Agena," "Atlas-Centaur" and so on), and it is admissible for cosmodromes located in areas with mild climate.

The second system for preparing the space rocket systems for launch became widespread in the United States during the birth of space engineering, and it was inherited from the process used in preparing combat rockets. American specialists consider it expedient to build complexes for space rocket systems by adapting the related launch complexes for strategic rockets with established rules for preparing them and not by adopting new structural designs taking into account the specific nature of space engineering. This approach which was advantageous from the point of view of rapid introduction of the space rocket complex into operation, did not justify itself when the necessity arose for launching various versions of rockets.

By the third system (according to American terminology, "the mobile preparation method") the space rocket system is assembled in the vertical position on the launch platform (the upper part of the launching system) which is transported together with the space rocket system to the launching site; the launch takes place from it subsequently (after installation of the launching pad). This system permits all of the numerous filling, pneumatic and electrical lines located at various levels to be coupled to the rocket at the installation and test facility (the vertical assembly building). In addition, the rocket coupling lines can be led out through the service cable tower installed usually on the launch platform to a convenient service zone which facilitates coupling of them to the ground systems at the launching site. The deficiencies of this system are the construction of an expensive vertical assembly building, the creation of the carrier with complex configuration or transporting the space rocket system in the vertical position from the engineering complex to the launching site and laying a special track which, as already been stated, is a technically difficult problem. The third preparation system is used for the heavy and superheavy class American booster rockets.

In the American literature on space rocket engineering it is possible to encounter a description of the "fixed preparation method" which is a version of the second system and is used for the medium-class booster rockets. Its essence consists in the fact that the individual stages of the booster rocket, bypassing the engineering complex, are delivered to the launch site where the vertical assembly of the booster rocket takes place, it is coupled to the service tower coupling lines, undergoes complex checking and launch.

For super-heavy space rocket systems it is probably necessary to have other assembly and transport systems, for the TNT equivalent and sound effect increase significantly and, consequently, it becomes necessary to place the launch system at a greater distance from the engineering complex. As a result of significant size and weight of such booster rockets, difficulties occur in the application of traditional means for delivering the space rocket systems to the launching site.

Thus, there is an American plan for the use of a marine floating assembly and launching system where the basic element is large, the greater part of which is occupied by the compartment for assembling the space rocket system. During assembly the barge is kept on a special dock, and its decks are kept open. The launch will take place at sea. The bow of the barge where all of the control and launch equipment are located remains in the horizontal position before the launch, the stern is disconnected and put in the vertical position by filling the aft tanks with water, and after launch returns to the initial position.

1.3. Main Cosmodromes of the World

The Baykonur Cosmodrome -- one of the largest cosmodromes in the world (Fig 1.15) -- is located in Kazakh SSR, in a semiarid zone with sharply continental climate (hot, dry summer and cold winter with high winds and insignificant precipitation); it was founded in 1955.

The basis for selecting the construction site for the cosmodrome was its sufficient remoteness from large populated areas, the possibility of insuring safety of the rocket launches, the creation of alienation zones, zones for landing the returnable space vehicles and also the presence of a large number of cloudless days during the year.

The cosmodrome routes extend thousands of kilometers over the territory of the Soviet Union and end in the Pacific Ocean where the last stages of the booster rockets are dropped. Along the routes there are measuring stations and especially equipped ships. The space vehicles are inserted into orbits with an inclination to the plane of the equator from 48° to 81° with easterly direction of the launch. The space vehicles and manned spacecraft usually land in the northeastern regions of the Kazakh SSR.

Launches have been made from the Baykonur Cosmodrome in accordance with the National Program of the USSR for the Study and Use of Outer Space, within the framework of cooperation with socialist countries by the "Interkosmos" program and also in accordance with agreements for joint efforts to explore outer space concluded between the USSR, the United States, France and other countries.

The first artificial earth satellite in the world was launched from the Baykonur Cosmodrome. The flights by cosmonaut Yu. A. Gagarin and the first female cosmonaut V. V. Tereshkova into outer space were made from this same location. It also launched the automatic interplanetary stations "Luna," "Venera," "Maris," "Zond," the space stations and artificial earth satellites of various types ("Kosmos," "Elektron," "Polet"), the satellites of the "Molniya" series for relaying television programs and long distance telephone and telegraph communications.

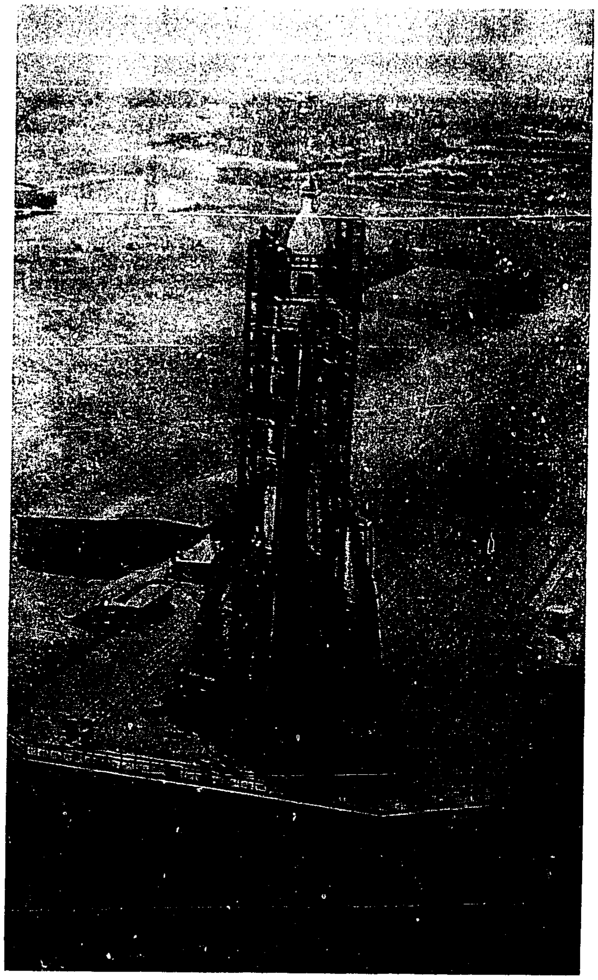

Figure 1.15. Baykonur Cosmodrome (launch site of the "Soyuz" space rocket system

Launches of manned spacecraft "Soyuz" and the orbital stations "Salyut" are made regularly from the Baykonur Cosmodrome.

Space vehicles with French equipment have been launched within the framework of a cooperative program with France.

In accordance with the Soviet-American EPAS program, the "Soyuz" spacecraft was launched from Baykonur Cosmodrome on 15 July 1975, for docking in orbit with the "Apollo" spacecraft.

The "Soyuz" spacecraft equipped with a camera made in the German Democratic Republic was inserted into orbit in September 1976.

The cosmodrome has built a number of launching sites and engineering complexes. One of the most important is the complex from which the three-stage booster rockets with the "Vostok" and "Voskhod" manned spacecraft were launched, and at the present time the "Soyuz" space vehicles are being launched.

The launch structure for this booster rocket is the semiburied type. It has a launch system with ejectable supporting beams. The rocket is "suspended" in the launch system behind the power packs. The space rocket system is delivered to the launching site from the installation and testing unit of the engineering complex where it is assembled in the horizontal position.

In addition to the installation and testing unit, the MIK KO building, the service station for the space vehicles, the storage battery charging station and a number of other buildings and structures are located in the engineering complex. The measuring stations are located here which are equipped with telemetric equipment, television set, antennas, radio receiving and transmitting units.

The living quarters of the cosmodrome in which there is a complex for training the cosmonauts (classrooms for exercises of the crew in accordance with the technical and scientific training program, a sports complex with a swimming pool, laboratory for preparing the cosmonauts for flight, a medical complex) and also an institute, technical high school, schools, club, stadium, television broadcast center, and so on are located.

The cosmodrome is connected with other plants in the country by air, highway and railroad transportation. The cosmodrome territory also has a branch network of highways and railways.

The eastern test area (before 1965, the Atlantic Missile Range) is the largest American cosmodrome. It is located at Cape Canaveral and Merrit Island (in the state of Florida), and it has a territory of about 400 km^2 (Fig 1.16). The basis for the selection of this site was its adequate isolation, which guaranteed launch safety and offered the possibility of further expansion of the territory. In addition, the convenient location of the islands of the West Indies and the South Atlantic made it possible to install monitoring and measuring complexes on them to observe the flight of the rockets.

The range track about 20,000 km long runs above the Atlantic and Indian Oceans to the Prince Edward Islands, and has 15 measuring stations equipped with optical, telemetric and radar units. The rockets are tracked also from ships and aicraft and from more than 100 individual ground observation stations.

The system of tracking stations existing in the eastern test area permit launches with an azimuth from 44 to 110° and insertion of the artificial earth satellites in orbits with an inclination to the plane of the equator from 28°30' to 52°24' with easterly direction of the launch. Launches of artificial earth satellites both into equatorial and polar orbits are possible from the test area, but insertion into polar orbits is connected with the performance of the heading maneuver in the active section of the booster rocket flight. Much greater expenditures of the energy reserves of the space rocket system are required to achieve polar orbits than equatorial orbits.

The test area is located in a highly swampy, flat area with rock occurring at a depth of about 50 meters; the air temperature fluctuates from 0 to +50°C during the year; powerful hurricanes and typhoons are possible with a wind speed of up to 55 m/sec.

This test area has all forms of communications (air, sea, railroad, motor vehicle). The booster rockets are transported predominantly by air and water; the light class booster rockets and their elements are transported on aircraft, and the heavy class booster rocket stages are transported on barges and ships.

Along the coast line of Cape Canaveral and the southern part of Merrit Island there are 20 launch complexes, of which 12 belong to the Eastern Test Area and 8 belong to the Kennedy Space Center. The launch complexes of the Eastern Test Area are designed for launching various space vehicles using the "Atlas," "Titan" and other booster rockets and the Kennedy Space Center, using the "Atlas-Agena," "Saturn-IB," and "Saturn-V" booster rockets. In addition to forming space research, the Eastern Test Area is used widely to test American combat missiles: more than 200 flight tests and several thousand bench tests are run on the rockets yearly at the test area. The service personnel, including the tracking stations, number more than 20,000.

The Kennedy Space Center (Fig 1.17) is the main NASA test area and is designed for launching space vehicles and testing booster rockets in accordance with the American National Space Research Program.

The mission of the center includes the following:

Planning launches of NASA space vehicles;

Assembly, testing, check out and launching of space vehicles;

Coordination of operations performed by the joint programs with the Eastern Test Area;

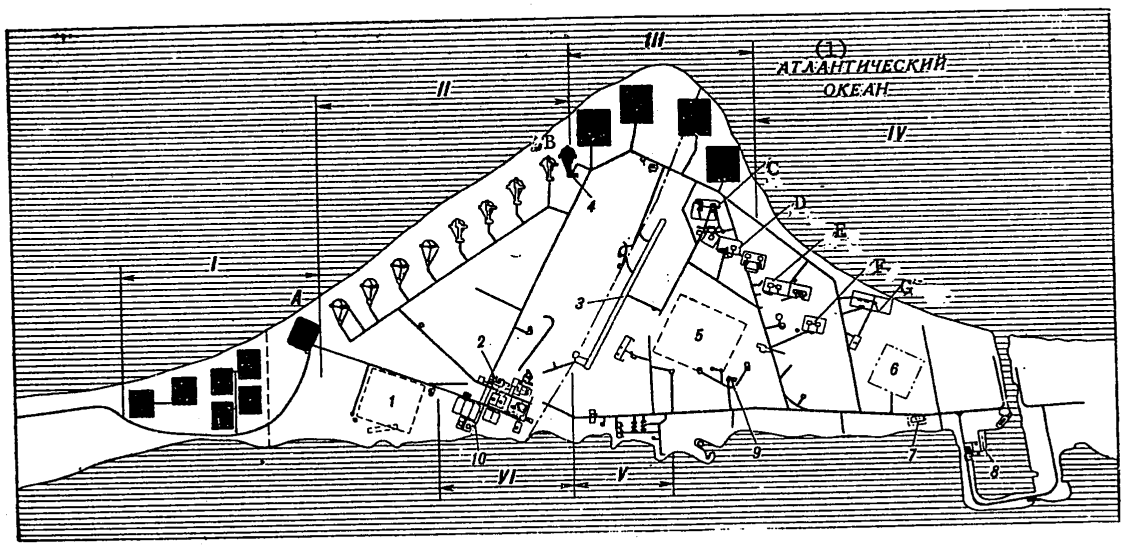

Figure 1.16. Eastern test area of the United States:
Zones: I -- heavy-class rockets with a thrust of 450-1150 tons; II -- intercontinental ballistic milles ("Atlas," "Titan," the "Dyna-Soar" rocket plane); III -- superheavy class missiles with a thrust of 1700 to 4500 tons; IV --medium-class rocket; V -- fuel component storage; VI -- industrial. Launch complexes: A -- "Saturn" booster rocket; B -- "Mercury" space rocket system; C -- "Minuteman" missiles; D -- "Thor" rocket; E --"Redstone" and "Jupiter" rockets; F -- "Pershing" missiles; G -- "Polaris" missile; 1, 5 -- receiving structures; 2 -- rocket flight control center; 3 -- railroad; 4 -- beacon; 6 -- building with transmitters; 7 -- oxygen plant; 8 -- port structures; 9 -- General Electric guidance system; 10 -- Bell Telephone guidance system.

Key:
1. Atlantic Ocean

Performance of scientific research and experimental design work in the field of developing methods of launching space vehicles, the design of new launching complexes and also modification of the existing launching equipment;

The study of the possibility of launching rockets from orbit and servicing them in orbit;

The planning and design of storage and operational equipment for new fuel components;

The training of scientific and technical personnel, and so on.

The ballistic characteristics of the center (the directions of the booster rocket flight paths, the range of launch azimuths, the inclination of the orbits) are analogous to the characteristics of the Eastern Test Area, and the rocket flights are observed by common monitoring and measuring complexes.

For communications with the plants of the space rocket industry, the same means are used as at the Eastern Test Area. The staff of the center numbers about 2800 people.

Although the Eastern Test Area and the Kennedy Space Center are territorially joined and interact with respect to certain problems, they are two administratively independent organizations which have different equipment and solve independent problems in the interests of the U.S. Air Force and NASA, respectively.

The Western Test Area (until 1965, the Pacific Ocean Missile Range) is located on the Pacific coast of the United States, north of Los Angeles (Fig 1.18), and it includes the Vandenberg Air Force Base, the Point Mugu Marine Test Area, the Point Arguelo Test Area and an inland test area, of which only the Vandenberg Air Force Base and the Point Arguelo Test Area are used to launch space rocket systems. The Vandenberg Base (the missile testing range) works on the development and testing of ground equipment for the air force missiles, training of launch crews to service the booster rockets, the creation and testing of antimissiles and launching of military satellites into polar orbits ("Discoverer," "Midas," "Samos" and so on). The Vandenberg Base has three launch complexes for the "Atlas" rockets, two for "Titan" rockets, one for "Scout" rockets and 14 pads for launching "Minuteman" missiles. The Point Arguelo Test Area is used for launching artificial earth satellites into polar orbits. About 140 launches are made annually from the Western Test Area.

The track of the test area which is more than 16000 km runs over the Pacific Ocean and is divided into three test areas: the Hawaiian Islands, Kwagelein Atoll and Eniwetok Atoll. The monitoring and measuring means are located in these areas, including 10 measuring stations equipped with optical, telemetric and radar equipment. Ships and aircraft are also used for rocket flight tracking.

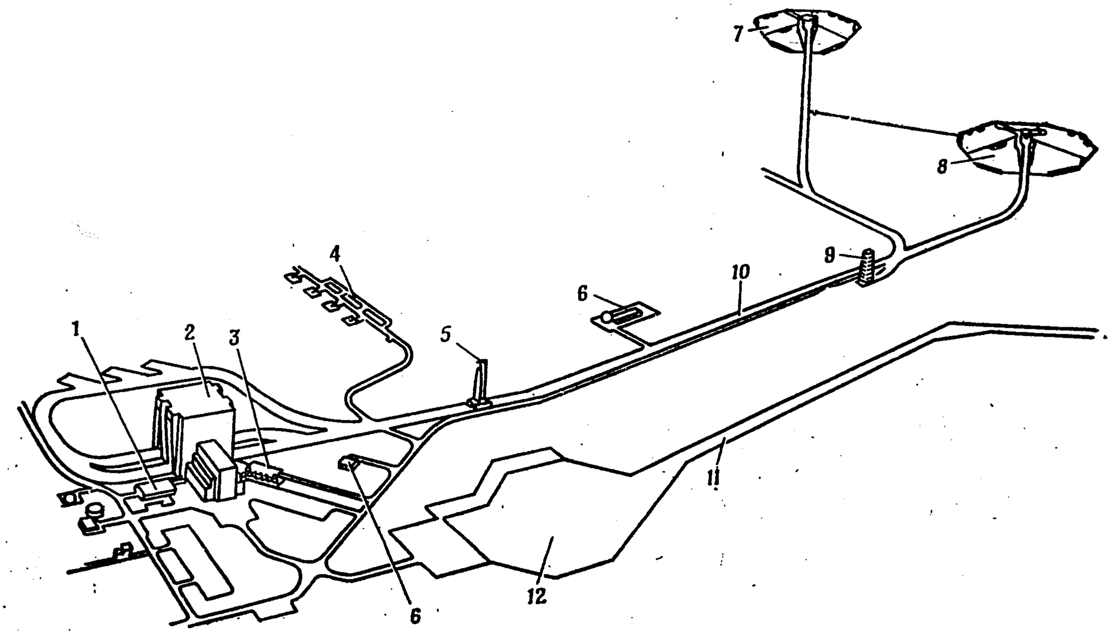

Figure 1.17. Kennedy Space Center (layout of the placement of the structures for preparation and launching of the "Saturn-V-Apollo" space rocket systems):
1 -- facilities for service personnel; 2 -- vertical assembly building; 3 -- launch control center; 4 -- warehousing facilities; 5 -- launching platform with service cable tower; 6 -- receiver for compressed gases; 7, 8 -- launching pads; 9 -- mobile service tower; 10 -- track for caterpillar carrier; 11 -- water canal; 12 -- dock with mooring walls.

The admissible launch sector is bounded by azimuths of 301° (the upper bound) and 170° (lower bound). The central track runs along the 261° azimuth. The orbits of the launched satellites have inclinations from 34°2' to 90° (when moving west) and from 81°48' to 90° (when moving east).

The test area occupies a territory of about 400 km^2 (the continental section). It is located near large enterprises which build rockets and is connected with industrial areas by waterways, railroads and air service. The total number of personnel working at the test area exceeds 17,000.

The Western Test Area has a number of advantages over the Eastern Test Area. For example, artificial satellites passing over the poles of the earth can be launched from it, which makes it possible to study almost the complete surface of the earth, including the northern regions. The trajectories of the booster rockets, the active section, run over the ocean; no pieces of dry land are encountered until Antarctica itself. This makes it possible to insert artificial earth satellites into polar orbit without risk that the spent stages or failing rocket will fall on populated areas and also to use coastal waters for separation of the launch boosters.

The test area on Wallops Island (United States) which is part of the Wallops Test Station is one of the principal NASA bases for launching research rockets and artificial earth satellites (Fig 1.19. The test area was built in 1945 by the Langly Scientific Research Center (the National Consultation Committee on Aviation -- the predecessor of NASA) to test unmanned vehicles and study the aerodynamic problems of flight. With the formation of NASA the test area was reorganized into an independent center.

The Wallops Test Station is located on the eastern coast of the United States 260 km southeast of Washington and is made up of three zones: the basic zone which was the former air force base, the zones on Wallops Island (8 km long and 0.8 km wide) and the continental zone which is located 3.2 km west of Wallops Island.

In the basic zone are the administrative and functional branches, the experimental design office, laboratories, the launch control center, the communications center and telemetric data reception center, one of the stations for transmitting commands and receiving data from the "Tiros" meteorological satellites and airports. The zone on Wallops Island includes six launch complexes equipped with equipment for assembly, preparation and launching of the rockets and also for observation of the flight. The tracking stations, the radar complex and the experimental flight base of the Lincoln Laboratory are located in the continental zone.

The vehicles can be inserted into orbits with inclination from 37° to 54° basically by the "Scout" booster rocket.

The track of the test area runs over the Bermuda Islands where tracking stations are located which are equipped with measurement means and receiving radio telemetric stations. The launch sector is bounded by the azimuths of 67° (upper bound) and 143° (lower bound).

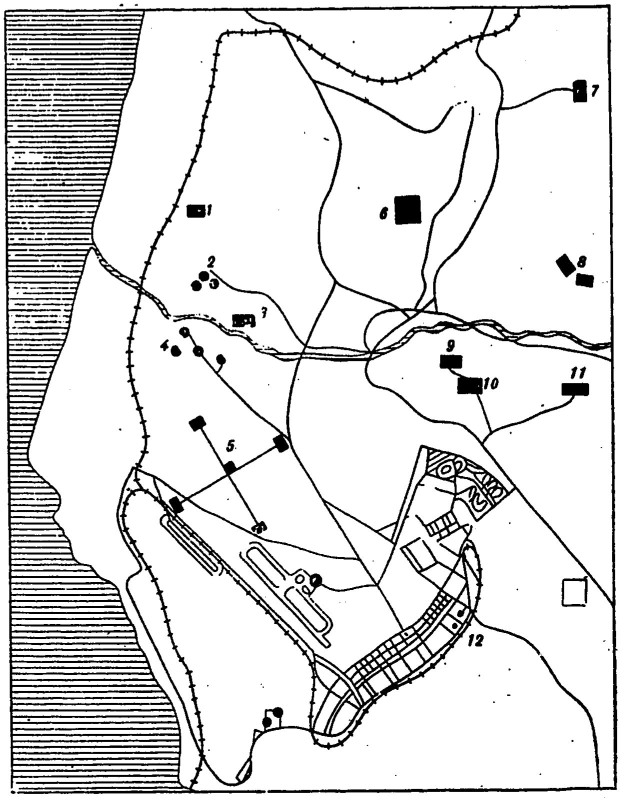

Figure 1.18. Western Test Area of the United States (location of the launch complexes at Vandenberg Base):
1 -- flight control center for the "Atlas" rocket; 2 -- installations for launching the "Atlas" rocket; 3 -- flight control center for the "Thor" rocket; 4 -- devices for launching the "Thor" rocket; 5 -- devices for launching the "Titan" rocket; 6 -- telemetric station; 7 -- tracking station; 8 -- control center; 9 -- station for sending signals regarding emergency elimination of rocket; 10 -- liquid oxygen plant which produces 50 tons a day; 11 -- liquid oxygen plant which produces 25 tons a day; 12 -- test area for teaching the techniques for recovering the nose cones.

The test area on Wallops Island is used for flight testing of individual structural elements and equipment of the vehicles developed by NASA and also for launching research rockets and launching certain artificial satellites, including those built by other countries.

There are more than 400 launches a year at this test area. During its existence it has launched more than 6000 research and experimental rockets of various classes. Its service personnel number 500-600.

The Kuru Test Area (Fig 1.20) which is under the joint control of France and the European Rocket Development Organization(ELDO) is located on the Atlantic coast in French Guiana 32 km from Cayenne (almost on the equator -- 5° north latitude). The test area has three launch complexes: for high altitude rockets, the French "Diamant-B" booster rocket, and for the "Europa-II" booster rocket (the ELDO organization).

The launching complex for the "Europa-II" booster rocket is oriented along the "north-south" line, but launches are possible to orbits with a declination from 0 to 100°. The "Europa-II" booster rocket was built on the basis of the "Europa-I" rocket launched from the English-Australian Test Area in Woomera. The move from the Woomera test area to the Kuru Test Area was made because with latter is located closer to the equator and is more favorable for inserting a payload into stationary orbit (the "Europa-II" rocket is designed for launching communications satellites into stationary orbits).

Although the Kuru Test Area is located in a wet tropical climatic zone with prolonged rainy periods, the rocket equipment has not been modified, for the launches are undertaken only during the dry seasons. In addition, the greater part of the time the stages of the rocket and the payload are in air conditioned facilities.

The first stage of the "Europa-II" booster rocket is delivered by water to the test area port; the upper stages and the payload are delivered by air to the airport at Cayenne, and then by motor transportation to the test area. The port can take ships with deep draught only during high tide which comes at 14-day intervals, which limits the capabilities of the test area.

The tracking units (radar, telemetric data reception stations, movie theodolites and other equipment) are located both in the test area itself and at other locations.

According to schedule two launches of the "Europa-II" booster rockets must take place each year.

The permanent personnel of the test area number 600 to 700.

The English-Australian rocket test area in Woomera (Fig 1.21) is located in the vicinity of Woomera (southern Australia). The dry land part of the test area track runs 200 km over the lightly populated parts of Australia and can be extended 4400 km into the Indian Ocean. Experimental launches of the English "Blue Streak" booster rockets and the "Europa" rockets and also launches of research rockets to the upper layers of the atmosphere take place from the test area.

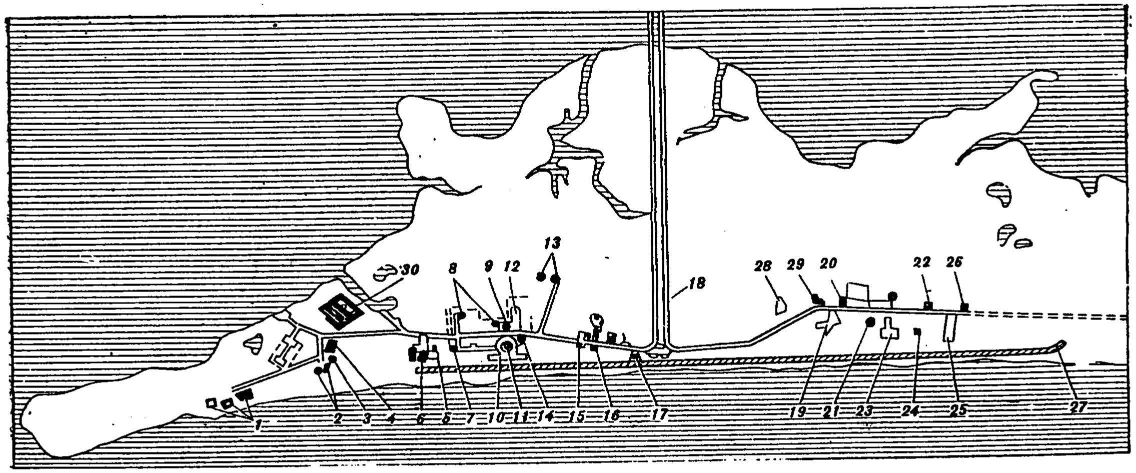

Figure 1.19. Test area on Wallops Island:
1 -- radar for extratrajectory measurement; 2 -- cameras; 3 -- radio transmitter building; 4 -- station for emergency detonation of the rocket; 5 -- launch pad No 1 for launching the high-altitude "Aeroby" rocket; 6 -- control station for launching pad No 1; 7 -- building for assembling rockets launched from launching pad No 1; 8 -- powdered charge storage; 9 -- storage for inflammables; 10 -- launching pad No 2 for firing high-altitude rockets used as the first stage of the "Honest John" and "Arcas" rocket; 11 -- control station for launch pad No 2; 12 -- storage for solid-propellant boosters; 13 -- tracking radar; 14 -- control tower; 15 -- storage; 16 -- installation and test facility for the space vehicles; 17 -- tracking station; 18 -- road and dike connecting the island to the mainland; 19 -- launching pad No 3 for launching the "Scout" booster rocket; 20 -- building for assembling the second and fourth stages of the "Scout" booster rocket; 21 -- control station for the launching pad No 3; 22 -- building for assembling the first and third stages of the "Scout" booster rocket; 23 -- launching pad No 4 for launching the "Little Jo" rocket; 24 -- cameras; 25 -- launching pad No 5 for launching the "Trailblazer" and "Shotput" rockets; 26 -- building for assembling rockets launched from launching pad No 5; 27 -- dike; 48 -- building for assembling the "Scout" booster rocket; 29 -- launching complex No 6 for the "Scout" booster rocket; 30 -- liquid fuel storage.

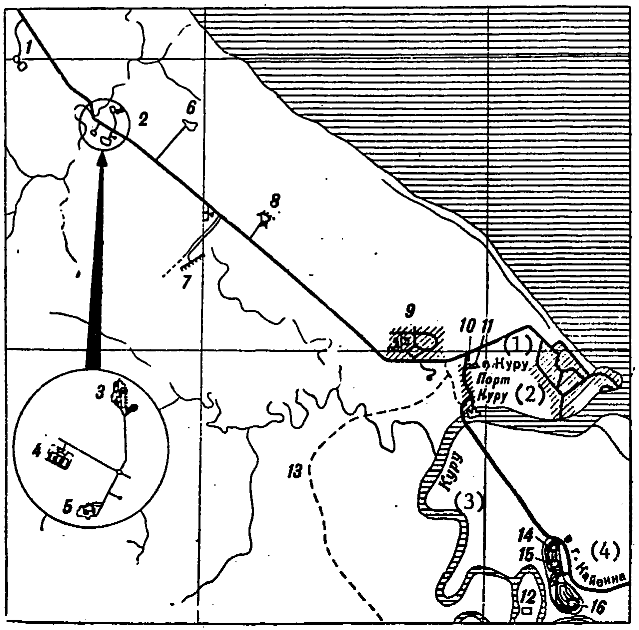

Figure 1.20. Kuru Test Area:
1 -- Iris and Diana radar; 2 -- launching complex for the "Europa-II" rocket booster; 3 -- launching pad; 4 -- storage for toxic fuel components; 5 -- buildings for repairing stages; 6 -- launching complex for the "Diamant-B" booster rocket; 7 -- powdered charge storage; 8 -- launching complex for high-altitude rockets; 9 -- engineering facility; 10 -- electric power plant; 11 -- plant for making liquid oxygen; 12 -- radio repeater station; 13 -- aqueduct (water supply system); 14 -- "Bretan" radar; 15 -- movie theodolite; 16 -- telemetry reception station.

Key:

1. Kuru
2. Port Kuru
3. Kuru River
4. to the city of Cayenne

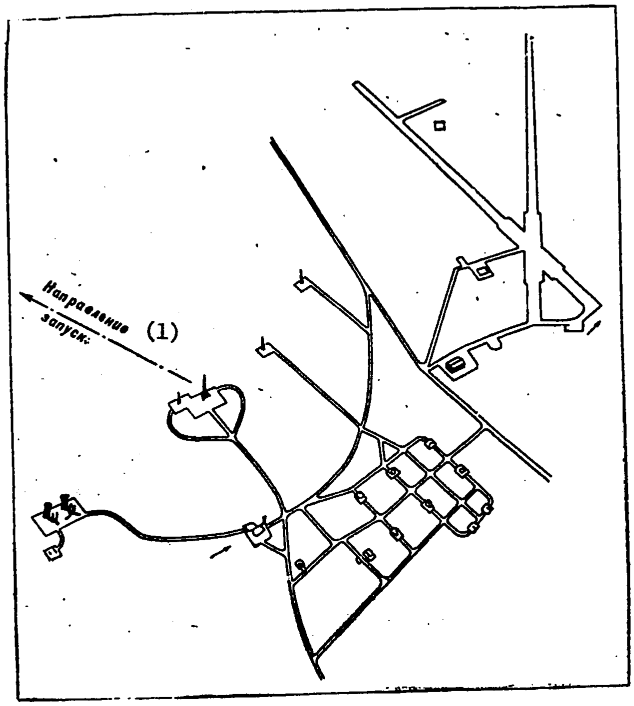

Figure 1.21. Woomera Test Area (plan of the launching pad area)

Key:
1. direction of launch

The main part of the work at the test area is testing combat missiles. The test area is used by the United States and certain other NATO countries.

The test area is equipped with six launching pads. Along the flight path are more than 200 measuring and monitoring stations and two telemetric systems.

The dry climate and the presence of a large number of cloudless days during the year are characteristic of the test area, which facilitates the launching of the booster rockets.

The Woomera Test Area has 6000 personnel. The administrative agency of the test area -- the Scientific Research Center for Armament Development -- is located in Salisbury.

CHAPTER 2. ENGINEERING COMPLEX

2.1. Purpose, Structure and Composition

The engineering complex is one of the most important elements of the cosmodrome. It is an engineering section with buildings and structures containing general engineering and special technological equipment designed for acceptance, storage, assembly and testing of the booster rockets and space vehicles and also for making adjustments on them (Fig 2.1).

The final assembly of the booster rockets and space vehicles, autonomous and complex testing, the servicing of the space vehicles and booster stages of the rocket with high-boiling fuel components and compressed gases, coupling of them into a united space rocket system and preparation of the system for transportation to the launching site all take place in the engineering complex. The engineering complex is an intermediate link between the manufacturing plant and the launching site in the united cycle of preparing the space rocket system for launch.

The cosmodrome can have one or several engineering complexes. Usually the engineering complex is built beginning with the conditions of preparing space rocket systems of a defined class and purpose considering the modifications of them, variation in composition and expansion of the mission, but they also provide for working with different space rocket systems.

Some cosmodromes have individual engineering complexes for booster rockets and space vehicles, each of which includes the installation and testing capacity, the required buildings and structures. These engineering complexes can be removed significant distances from each other (up to several kilometers).

On installing the engineering complex, we begin with the necessity for removal of it to a safe distance from the launch complexes of the cosmodrome, but the possibility of decreasing the length of the special path from the engineering complex to the launching site for the transport and erecting unit is taken into account in order to reduce the cost of construction of the unit, to reduce the time required to transport the space-rocket system and exclude the application of thermostating during the transport time.

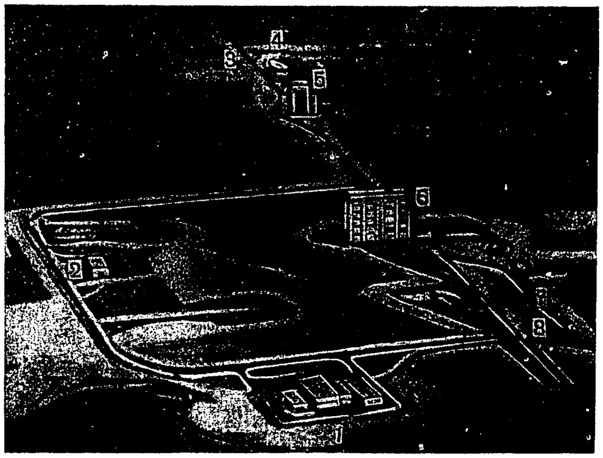

Figure 2.1. Engineering complex:
1 -- booster rocket storage; 2 -- building for preparing the solid-propellant booster; 3 -- railroad for transporting the space rocket system to the launching site; 4 -- storage of the liquid fuel components; 5 -- building for coupling the solid-fuel booster; 6 -- installation and testing facility; 7 -- pad for the launching platform; 8 -- hard topped road.

For the performance of all of the operations of preparation, assembly and testing of booster rockets and space vehicles the engineering complex has the following buildings and structures:

The installation and testing facility for the booster rocket (the vertical assembly building);

The installation and testing facility for the space vehicle;

The service station for the space vehicle;

The compressor station with receiver;

The storage battery charging station;

The booster rocket storage;

The ground equipment storage, and so on.

For rockets with solid propellant boosters and powder charge engines, the engineering complex also includes powder charge storage (facility for pyrotechnical devices) and a building for coupling the solid-propellant boosters. Sometimes these structures are isolated in a separate zone, the so-called "pyrotechnical facility." The engineering complex also includes the electric power or transformer substation, boiler room, cooling tower, water tower, air conditioning and installation facilities, administrative and service buildings, communications junctions, security structures, and so on.

All of the buildings and structures of the engineering complex are connected by railways or hard topped roads; some of the engineering complexes have waterways or valves for delivering the booster rockets and their stages and also docks and mooring walls for unloading. The railroads are equipped with ramps and the necessary loading and unloading means.

The class of space rocket system, the method of assembling it and preparation for launch have a significant effect on the composition and structure of the engineering complex.

The engineering complexes for the light and medium class rockets occupy relatively small areas; their structures are small in size and universal with respect to purpose (for example, it is possible to combine the installation and testing facility for the boosters and the space vehicles, the installation and testing facility for the boosters and the rocket storage, and so on). The engineering complexes for heavy and superheavy class rockets occupy areas of several square kilometers, and the installation and testing facilities measure in the hundreds of thousands of square meters.

The method of assembling the space rocket system and the flow chart for preparing it for launch have the greatest influence on the structure of the engineering complex. If the space rocket system is assembled at the launching site, then only the buildings for repairing the stages and space vehicle are built in the engineering complex, and in this case its role is minimal; when assembling the space rocket system in the engineering complex, the composition of the buildings and structures and equipment are significantly complicated, and its role becomes appreciably more important.

Let us consider in more detail the purposes and the composition of the basic buildings and structures of the engineering complex.

The installation and testing facility (MIK) for the booster rocket is the main structure of the engineering complex equipped with equipment that provides for acceptance of the stages, modules and individual assemblies of the booster rockets from the manufacturing plants, unloading them, unpacking them, storage, horizontal or vertical assembly, autonomous and complex testing, checking for seal, coupling the space vehicles (nose cones) and transfer to the transport and erection unit (Fig 2.2).

The installation and test facility can be made up of either one hall or several halls (spans). The so-called unpacking facility designed for receiving individual compartments, modules and assemblies of large booster rockets, removing the packing from them and preliminary assembly and also storage of the rockets is adjacent to the basic building at some of the

MIK facilities. Depending on the size and class of the booster rocket, the installation and testing facility can assemble and test one or several rockets, for which there are work areas set up with the necessary equipment.

Figure 2.2. Installation and testing facility for booster rockets (Baykonur cosmodrome)

The MIK hall or spans are equipped with bridge cranes, the number and capacity of which depend on the adopted process.

In order to assemble and move the modules and stages of the booster rockets from one span to another inside the installation and test facility there are railroad tracks, and to move the assembled space rocket system to the launching site there is a special channel or railroad track, the dimensions and structural design of which are determined by the structural design of the transport and direction unit.

The installation and test facility is equipped with electric power, lighting, heating and ventilation equipment, fire extinguishing, water supply, industrial waste systems, communication means and other general engineering equipment.

The electric power equipment is designed for supplying the ground equipment, the measuring system and the systems for remote and automatic control of the industrial current.

For maintenance of the defined air temperature inside the MIK there is a central heating system, an air conditioning system, an exhaust ventilation system for the entire enclosure and local intake ventilation for cooling the operating equipment. For cooling the vacuum pumps, the ground electrical equipment, the fire extinguishing system and other technical and domestic needs the installation and testing facility has water supply system, and to get rid of used water and other fluids, an industrial waste system. The MIK facility is equipped with telephone, headphone and loud-speaker communications.

The special technological equipment of the MIK facility includes the pneumatic vacuum and the monitoring and testing equipment, the ground electric supply system for providing specialized currents, the transport, lifting and transfer, installation and coupling equipment, service means, and so on.

For pneumatic testing of the stages of the booster rockets, charging the on-board tanks and checking the seals of the signs and compartments the MIK has pneumatic vacuum equipment, pneumatic panels, pneumatic shields and columns through which the compressed gases are fed to the work areas through hoses and lines. The compressed gases come to the MIK facility from the compressor station in the engineering complex or from the common gas supply system of the cosmodrome.

In the installation and test facility the booster rocket is subjected to autonomous and complex testing. The autonomous testing is checking the individual systems, assemblies and units in order to determine the correctness of their functioning; the complex testing is a single operation performed to check the proper operation of all systems of the booster rocket.

All the tests are performed using the monitoring and testing equipment, which includes the control system panels, guidance, telemetry, temperature and pressure monitoring, and so on.

The monitoring and testing equipment is located in separate facilities (the so-called panel facilities) coupled to the MIK facility by cable channels.

The measurement and control systems are provided with direct current and nonstandard alternating current by the special current ground electrical supply system (SNEST), which includes converters, current distributors, remote control panels, a cable network, and so on.

The test for equipment includes means of hauling the stages, modules, compartments of the booster rockets, the nose cone and elements of them within the boundaries of the engineering complex (the cosmodrome), and it includes dollies, specially equipped railroad cars, platforms and carriers. Various loading means are used for the lifting and transforming operations in the MIK facility.

All of the assembly operations in the installation and testing facility are performed using installation and coupling equipment (MSO).

The installation and testing facility has service means which provide the operators and assemblymen with access to the hatches and joining locations of the booster rocket during assembly and test.

The vertical assembly building (Fig 2.3) is a version of the testing and assembly building and is used for the "mobile method of preparation" of the space rocket system for launch. The space rocket system is assembled in the vertical position on the launching platform (the upper part of the launching system) from which it will subsequently be launched; the launching platform with the assembled space rocket system is delivered to the launching site by the carrier.

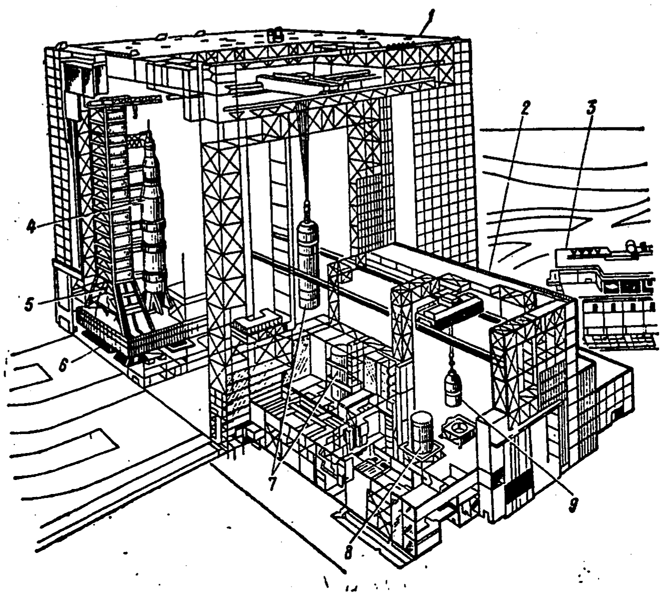

Figure 2.3. Vertical assembly building (Kennedy Space Center): 1 -- high part (long span); 2 -- low part (small span); 3 -- command post building; 4 -- space rocket system; 5 -- service cable tower; 6 -- caterpillar carrier; 7 -- upper stages of the rocket (one is in the checkout process and the other is being moved by crane); 8 -- instrument compartment; 9 -- nose cone.

The vertical assembly building has high and low parts. The high part is designed for the acceptance of the first stage of the booster rocket, testing it, assembling the space rocket system and preparing to ship it to the launch site. The low part is used for the acceptance, assembly and testing of the upper stages of the booster rocket and the nose cone and has several compartments. The upper stages are installed in the work areas, they are completely assembled and tested, and then they are delivered to the high part and coupled to the first stage.

The installation and testing facility for space vehicles (MIK KO) is used to accept the space vehicles from the manufacturing plants, unload them, store them, assemble them, check for seal, subject to electrical testing and also for the assembly and testing of the nose cones (see Fig 2.4). The installation and test facility for the space vehicles is a building which usually is smaller in size than the booster rocket installation and test facility and is made up of one or several halls (spans). The height of the MIK KO depends on the dimensions of the space vehicles and the nose cones and the method of assembling them. The MIK KO facility has railroads for delivering the objects, lifting cranes for moving them inside the facility and for performing installation-assembly and loading and unloading operations.

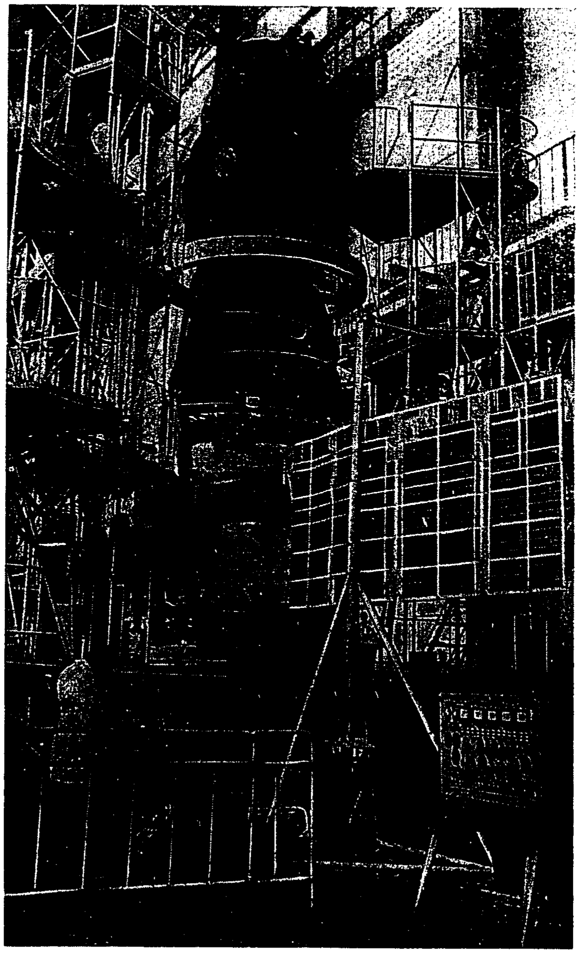

Figure 2.4. Installation and test facility for space vehicles

The monitoring and testing equipment and the current sources usually are placed in special facilities or rooms (panel rooms), the number of which depends on the composition of the space vehicle systems and the dimensions of the test equipment.

The work areas of the MIK KO are equipped with the required pneumovacuum, lifting and transfer and installation and coupling equipment, the monitoring and testing equipment, service means, electric power supply and sources of special currents, telephone, headphone and loudspeaker communications. For removal of heat released when testing the on-board equipment, liquid (ZhSOTR) and air (VSOTR) systems for maintaining the thermal conditions have been designed.

The MIK KO can have several work areas equipped both for like and different space vehicles with respect to structural design and purpose.

For testing the space vehicles and their compartments for seal, the set of pneumovacuum equipment includes barochambers installed either in the MIK KO facility itself or in a separate building. The barochambers or pressure chambers, depending on the placement of the objects in them, can be horizontal or vertical.

The installation and testing facility for space vehicles must satisfy higher requirements with respect to cleanness, which arises not only from the production culture, but also the functional peculiarities of the operation of space vehicles. Dust and dirt or foreign objects getting into the space vehicle can cause serious interference with the operation of the equipment and life support of the crew members in space under weightlessness conditions. Therefore the entrance doors to the MIK KO are made sealed or with air locks, and the ventilation systems are equipped with filters. Sometimes the MIK KO facility is a conditioning system which, in addition to maintaining a defined temperature and humidity, also provides for cleanness of the air. In some cases, the access of the service personnel to the space vehicle is through a so-called "clean chamber" having two compartments: the first, in which the operator leaves his work clothes, and the second, where he dons specialized clothing. Before entering the spacecraft the operator's clothing is cleaned with a vacuum cleaner. A small excess air pressure is constantly maintained in the "clean chamber" which prevents dust from getting in it from the outside (from the MIK KO enclosure).

The service station is designed to service the space vehicles and the last (booster) stages of the booster rockets with high-boiling fuel components and compressed gases. The station has facilities for filling the sustainer, braking, and correcting engines, the orientation engines and the propulsion engines and also the tanks of the last (booster) stages of the booster rockets with fuel, oxidant and gases (nitrogen, helium, and so on).

The service station is usually a separate building which is built at a great distance (up to several kilometers) from the other buildings and structures of the engineering complex for safety reasons.

The service station is made up of the service hall (boxes), the storage facility for the components and the compressed gases, a pumping station, a batcher, a refrigeration center, panels, and so on.

The station can have one or several servicing halls (boxes). In the first case the rocket systems are filled with all the fuel components and compressed gases in a common hall; in the latter case, a separate box is provided for each component; for safety reasons the boxes are separated by sealed doors.

A railroad track is laid through the entire station on which the space vehicle or nose cone is delivered in a car or on a carrier. If the station has one hall, then connecting lines are joined to the space vehicle (nose cone), through which the fuel components and compressed gases are fed simultaneously or in succession. At a service station which has several halls (boxes), the serviced vehicle (nose cone) is moved on a railroad car or carrier from one box to another. Here, in the first box the rockets are filled with fuel, in the second box, with compressed gas and in the third, oxidizing agent.

The service areas, the filling heads and connecting lines are serviced from platforms and structures which are part of the service stations; sometimes the railroad car or carrier service means are used for these purposes.

The control of all of the service operations is from the panel rooms where there are panels for the remote and automatic control systems, the monitoring and signalling equipment; the servicing operations are recorded on a display and by the instruments of the corresponding monitoring systems.

The service station is equipped with powerful intake-exhaust ventilation, an industrial waste system, fire-fighting systems which are made in fire and explosion safe execution from materials resistant to aggressive components and their vapors. Especially strict safety measures are taken at the service station.

The storage facility for the fuel components is usually arranged in separate structures joined to the service station by a trestle (or channel) through which the feed lines are laid.

The compressor station is a structure in which the set of equipment, control means and monitoring and measurement means provide for compressed air, nitrogen or helium. The air compression units include one or several compressors and devices for cooling, drying and cleaning the air.

The compressor station has a receiver -- a series of tank batteries for accumulation and storage of the compressed gases -- with pressure regulating equipment.

The gases are fed through pipeline systems to the buildings and structures of the engineering complex and at some cosmodromes having a single compressor station, also to the structures at the launching site.

The storage battery charging station is used to prepare and charge storage batteries used as on-board sources of electric power for the space vehicles and booster rockets.

The storage battery charging station is placed, as a rule, in a separate building and is set up with equipment which provides for preparation and transfer of electrolite, charging and discharging of the batteries, monitoring of them before installation on the space vehicle and also special coolers (in order to decrease the spontaneous discharge of the batteries).

So-called conditioning of the batteries takes place at the station, consisting in performing several "charge-discharge" cycles, which promotes the acceptance of high electric power reserve.

The powdered charge storage (the facility for pyrotechnical devices) is provided for only at the space centers where rockets and space vehicles including solid-propulsion boosters, powdered charge engines, emergency rescue engines and other pyrotechnical devices are tested. The storage facility is usually a separate building removed for safety reasons from the other buildings and structures of the engineering complex.

The pyrotechnical devices are placed in storage on dollies or mounts; for loading and unloading operations cranes or manual hoists are provided. In order to maintain a defined air temperature in the facility and exclude sharp temperature gradients (to avoid the formation of cracks in the charges) the storages are built buried in the ground or with embankments; the large storage facilities are equipped with air conditioning systems.

All the storage equipment is made in the explosion-proof execution, and it is carefully grounded to avoid the accumulation of static electricity; a lightning arrester system is provided for protection from atmospheric electricity.

The building for coupling the solid fuel boosters is a simplified vertical assembly building and has large and small spans equipped with bridge cranes. The rocket is moved to the large span on a carrier in the vertical position on the launch platform, and sections of the solid-propellant boosters are brought to the small spans. After assembly of the booster sections they are coupled to the rocket by using the crane in the large span. The same safety requirements are imposed on the building for coupling the solid-propellant boosters as the powdered charge storage facility.

Inasmuch as the coupling building is an expensive structure, sometimes the solid-propellant boosters are coupled in the installation and test facility for the booster rockets with observation of the necessary safety measures.

The booster rocket storage is a building equipped with bridge cranes and railroad tracks for delivering the assembled booster rockets.

Usually the rockets are stored on hangar warehousing dollies or on carriers and railroad units on which they are delivered to storage; in this case there is no necessity for cranes which significantly simplifies the construction of the storage.

The storage facility for the ground equipment units can consist of several buildings and sheds for storing mobile service units, installation and coupling, lifting and transfer equipment and transport means. The large units (the service cable towers, caterpillar carriers, and so on) are stored, as a rule, in specially equipped open areas.

2.2. Testing Booster Rockets and Space Vehicles

The volume and sequence of testing the space rocket systems at the engineering complex are determined by the class of the booster rocket, its structural peculiarities, the method of preparing the space rocket system for launch, the flight program and other factors. However, independently of this there is a defined procedure for performing such tests.

Testing Booster Rockets

Usually the booster rocket comes to the installation and test facility in the form of individual stages, compartments, and modules, and only the super-light and light classes of rockets come fully assembled. Before testing the rocket or individual stage, an external inspection is performed to see that there is no damage to the structural elements of the rocket, lines, cable network and instruments installed on the rocket.

After the external inspection, pneumatic tests are made (Fig 2.5), in which the following are checked:

The seal of the pipeline and fitting connections;

The seal of closure of the filling, drainage and discharge files;

Adjustment of the reducers, and so on.

During pneumatic tests, compressed air with a dewpoint of no more than -55°C at atmospheric pressure is used which does not have mechanical impurities or vapor of any substances. The presence of mechanical impurities can lead to foreign particles on the sealing surface of a valve or reducer and to loss of their seal; the presence of foreign particles in the tank with hydrogen peroxide can cause decomposition of the peroxide. In order to remove impurities and oil from the air, it is passed through filters and moisture and oil separators.

The use of air with an increased moisture content is inadmissible, for as a result of lowering of the temperature during reduction, ice crystals and frost precipitate out of the air, which can cause plugging of the gas feed system and loss of seal in the pneumatic equipment.

The electrical testing of the booster rocket is usually carried out in several steps.

Figure 2.5. Booster rocket at the MIK [installation and test facility]

Autonomous tests are being run on the on-board instrument by using special panels either on the rocket or after removal of the instruments from the rocket; the instruments are adjusted and checked out under flight conditions (by sending programmed instructions), and their operating characteristics are also recorded. After autonomous testing the instruments are installed on the rocket or a stage of it and are connected to the on-board cable network. If during testing it becomes necessary to change the orientation of some of the instruments (the hydraulic instruments, the sensitive elements of the range automation, and so on), they are installed on special supports or benches beside the rocket and are connected to the on-board cable network by jumper cables.

Autonomous testing in the complex rocket system is carried out using panels which enter into the set of equipment for complex checking and launching of the rocket, for autonomous checking of the operation of the instruments of the control system and the auxiliary systems connected to the on-board cable network. If the autonomous tests have demonstrated that all of the rocket systems operate normally, we resort to complex testing with simulation of the regular and emergency operating conditions.

In the case of complex testing, instead of the engine automation, a simulator is connected which is structurally part of the control panel. This is explained by the presence in the engine of assemblies for one-time use (diaphragms, pyrocartridges) and other elements and also a simulator of the on-board batteries is connected to supply the on-board networks from ground power supplies.

On completion of the complex testing, all the instruments are initialized.

At the present time broad use is being made of test automation both during autonomous testing of the instruments of the control system and the auxiliary systems combined with the complex booster rocket system and during complex testing. Here the instructions to change operations are issued by the programming mechanism, and a test is run by the "yes-no" system: if the parameter is in the normal range, an instruction is sent out for further performance of the operation; when the parameter goes beyond the limits of the norm, the tests are automatically halted with indication of the failed system element on a special display.

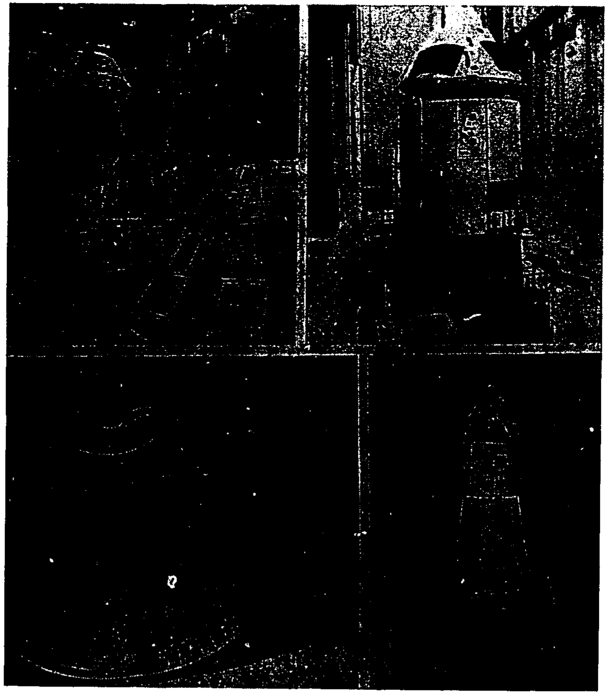

Figure 2.6. Spacecraft in the MIK KO [installation and test facility for space vehicles]

Testing Space Vehicles

The following operations are performed with the space vehicles in the engineering complex: assembly, pneumovacuum testing, electrical testing, servicing and finalizing operations (Fig 2.6).

The volume of installation and assembly operations depends on in what form the space vehicle arrives at the engineering complex at the MIK KO [installation and test facility for space vehicles]: completely assembled or in compartments. In the first case the space vehicle is completed (some of the precision instruments, the power supplies, antennas, solar cells and other external elements extending beyond the transport dimensions are installed), and the technological attachments and fittings are removed (the transport bands, protective covers, fasteners, and so on); in the latter case the space vehicle is assembled from the individual compartments.

One of the most responsible operations is the pneumovacuum testing. Inasmuch as a space vehicle can be in orbit for a prolonged period of time in a deep vacuum and any disturbance of its seal can lead to failure of the equipment, a change in operating conditions of the on-board systems and, in the final analysis, to failure to fulfill the mission stated for the space rocket system, the seal of the space vehicles is checked with special care.

The pneumovacuum tests (up to 50% of the time is spent on them) are performed twice: after delivery of the space vehicle to the engineering complex and before servicing it (in the former case the seal can be broken during transportation and loading and unloading operations; in the latter case, during the installation-assembly operations and electrical testing).

The test process is set up in such a way that it is possible to detect a possible loss of seal in the earliest stazge of preparation of the space vehicle. At the present time the following methods of testing space vehicles for seal are used:

In a pressure chamber;

By the pressure drop;

By evacuation with respect to the rise in pressure;

By the method of accumulation at atmospheric pressure;

Using a helium leak detector.

In the first procedure the space vehicle or element of it is placed in a pressure chamber (Fig 2.7) in which rarefaction is created. The tested vehicle is filled with helium, and by the increased helium content in the pressure chamber during a defined time (the magnitude of the leak) the failure of the seal is determined by a helium leak detector connected to the pressure chamber.

If it is impossible to place the vehicle in the pressure chamber because of its large size or the tested element is inside the vehicle, the sizes of the admissible leaks are quite large and the test pressure exceeds atmospheric, then the seal is checked by the pressure drop (Fig 2.8). In this case the tested element is filled with compressed air and the amount of the pressure drop is recorded over a defined time interval by a manometer [pressure gauge].

Evacuation by the rise in pressure is used for systems operating with external excess pressure; the failure of the seal is determined by the rise in pressure in the evacuated system in a defined time interval.

The accumulation method is used to test systems inside the compartments not subject to evacuation and having small magnitudes of admissible leaks. With this method, helium is fed to the system, which will penetrate into the sealed volume of the compartment through microleaks; the helium concentration in the compartment is measured using a helium leak detector and, by comparing it with the standard helium-air mixture, the seal of the system is determined.

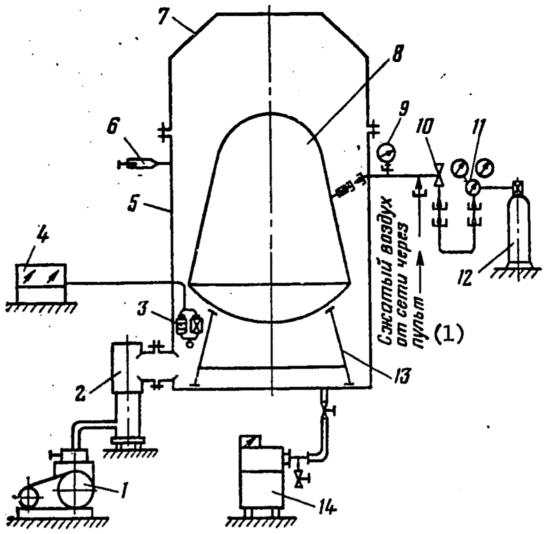

Figure 2.7. System for checking a vehicle for seal in a pressure chamber:
1 -- vacuum pump; 2 -- gate valve; 3 -- thermocouple manometric sensor; 4 -- vacuum meter; 5 -- pressure chamber; 6 -- valve; 7 -- hood of the pressure chamber; 8 -- tested vehicle; 9 -- pressure gauge; 10 -- valve; 11 -- reducer; 12 -- helium tank; 13 -- mount; 14 -- helium leak detector.

Key:

1. Compressed air from the network through the panel

The helium leak detector procedure (sometimes called the "probe" procedure) is usually used in cases where it is necessary to determine the location of the leak. For this purpose the tested vehicle is filled with a mixture of helium and air or nitrogen under excess pressure, and its outside surface is "probed" by the helium leak detector. On appearance of helium on the surface of the tested vehicle (which indicates the presence of a leak at this location), the indicator of the leak detector (the indicating instrument) is deflected, and the tone of the sound signal changes.

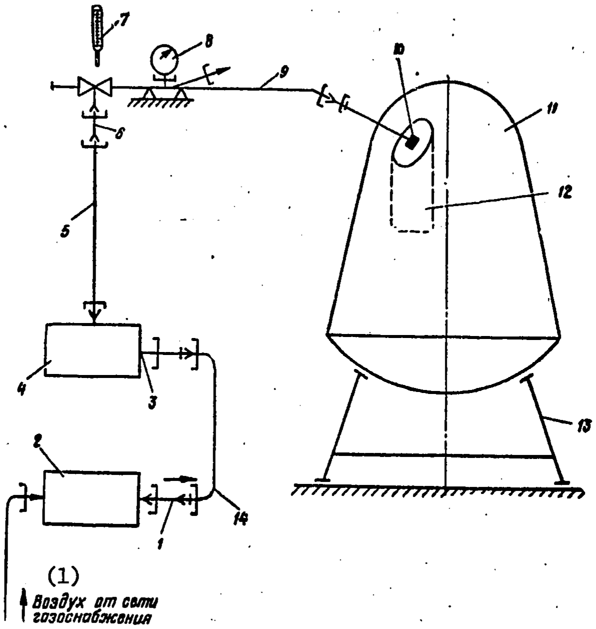

Figure 2.8. System for checking the seal of a vehicle by the pressure drop:
1, 6 -- adapter; 2 -- distribution board; 3 -- connection; 4 -- pneumatic panel; 5,14 -- hoses; 7 -- thermometer; 8 -- pressure gauge; 9 -- pipeline; 10 -- valve; 11 -- tested vehicle; 12 -- container of the vehicle; 13 -- mount

Key:
1. Air from the gas supply network

The volume and sequence of the electrical testing of the space vehicles depend to a high degree on their purpose, structural design and flight program. Usually these tests include several steps:

Checking the initial condition of the on-board systems;

Complex testing of the systems with simulation of the regular and proposed (unauthorized) operating conditions in the automated mode;

Complex testing with simulation of the possible manual control conditions of the on-board system;

Testing in a specially equipped "echo-free" chamber (a facility that does not reflect radio waves), which excludes the appearance of distorted radio signals; these tests are used on space vehicles the flight program of which provides for docking with other vehicles;

Complex testing jointly with the booster rocket with simulation of the regular and emergency situations on insertion of the vehicle into orbit.

On completion of the electrical tests, the test landing of the cosmonaut is made (for manned spacecraft) in which the functioning of the systems connected directly with the life support of the crew and convenience of execution of the operations in the cabin are checked.

At the service station the vehicle is filled with fuel components and compressed gases, and before that the thermal regulation systems are filled in the installation and test facility for the space vehicles.

The finalizing operations include assembly of the top module, coupling it to the booster rocket, checking out the circuits of the pyrocartridges for separation and ejection of the nose cone and the communications circuits of the on-board cable network of the space vehicle with the last stage of the booster rocket and also the circuits for communication of the on-board cable network with the first stage of the booster rocket.

The coupling of the top module to the booster rocket and all subsequent operations are performed usually in the installation and test facility for the booster rockets.

2.3. Means of Assembling Space Rocket Systems

Independently of the method of assembling the space rocket system -- horizontal or vertical -- all of the installation and assembly operations are performed by cranes. In the vertical method of assembly, one crane is used, and for horizontal no less than two (when working with two cranes exact determination of the center of gravity of the lifted load is not required, it is always between the suspension point).

The installation and test facilities of the modern space centers are equipped with 250-300 ton bridge cranes with the lifting height to 140 m. In the presence of several spans in the installation and testing facility, the service zones of the cranes in the spans overlap each other.

Inasmuch as the space rocket systems and their elements belong to the category of the specially responsible loads, and filled with fuel components (even partially) and having the powdered charges in them, they are explosion-hazardous, increased reliability and safety requirements are imposed on the cranes of the MIK and MIK KO facilities:

Insurance of complete operating safety excluding the possibility of damaging the loads or injuring service personnel;

The presence of basic and installing (reduced) speeds of raising and lowering the hook, movement of the dolly and movement of the crane beam;

Smooth (without jerks) variation of speed;

The presence of a united control panel permitting one operator to control the loading and unloading process and also to realize continuous observation of the load;

Lowering of the load only in the operating conditions of the motor; free lowering in the braking mode is not permissible;

The presence of two brakes on each engine, and so on.

During installation and assembly the following are used:

Equipment for transporting the compartments and stages of the booster rocket within the boundaries of the MIK (the hangar warehousing dollies, the installation and coupling dollies and the transport units);

The installation and coupling equipment (the coupling unit, the assembly stocks, the test benches, the manipulators);

The lifting and transferring equipment (traverses, lift attachments, rigging);

Service means (service areas and beams, ladders, mounts, and so on).

Sometimes some of the units combine several functions, for example, it is possible not only to transport the booster rocket compartments and stages on the installation and coupling dollies through the installation and testing facility, but also to assemble them; the assembly stocks can also include service means.

The structural designs of the installation and coupling equipment for the booster rockets are varied. The simplest are the installation and coupling dollies, on the logements of which compartments are stacked in the horizontal position; in order to match the ends of the compartments, the logements can be raised, lowered, rotated around the longitudinal axis and displaced both in the lateral direction and along the longitudinal axis as a result of movement of the dollies themselves along the railroad tracks of the MIK. The drives for the logements can be hydraulic, electrical and mechanical. The joining units and the assembly stocks are structures with displacement mechanisms providing for all the necessary degrees of freedom. The vertical assembly stands are large-scale structures including the coupling mechanisms, rotating devices and service platforms.

The lifting and transfer equipment includes various attachments: from small suspensions for lifting containers with elements of the space rocket system to large cross beams for lifting compartments, stages and the completely assembled rocket. The cross beams are longitudinal (arranged along the hull of the rocket) and transverse (arranged across the hull); the transverse cross beams are simpler with respect to structural design.

The service means are divided into stationary and mobile. The stationary means include various platforms on columns and walls of the installation and test facility; the mobile means include the ladders, gangways, service units, which when necessary can be taken up, freeing the space for other equipment. Some of the service units are equipped with winches and other attachments with small load capacity for supplying the instruments to the hatches of the space rocket system.

The installation-coupling and lifting-transfer equipment for the space vehicles depends to a great extent on their structural design and method of assembly: horizontal, vertical or combination. With the first method the space vehicles are assembled on a horizontal stock, coupling units, installation and coupling dollies when working with large spacecraft and stations or if the MIK KO facility is not very high. With the second procedure the space vehicle is installed on the installation dolly, a mount or stand, and all of the assembly operations are performed in the vertical position. With the combined method of assembly, part of the operations are executed in the horizontal position, and part in the vertical position.

Special stands for assembly, testing and servicing of the space vehicles have become very widespread (Fig 2.9). Usually this type of stand has several levels of stationary and movable service platforms for the tested equipment and access to the various zones of the vehicle. Sometimes the stand has more complex structure with a rotating device and inclinding supporting frame equipped with electric or hydraulic drive, which permits rotation of the object around the vertical axis, inclination of it at the required angles and movement to the horizontal position with insurance of subsequent joining of the nose cone (it is hauled to the bench on the installation and coupling dollies). This type of stand is called universal and can replace an entire series of units and attachments: manipulator, service unit, stock for assembly of the top module and so on.

The set of installation and coupling equipment also includes the installation attachments, the manipulators and various tilting devices. The tilting, that is, the movement of the vehicle (or a compartment of it) from the horizontal to the vertical position and back is an especially responsible operation. This operation is performed by using a tilting manipulator or tilting unit and crane or by two cranes. In the first case the vehicle (compartment) is suspended on the cross beam with respect to the center of gravity, which permits it to be brought from one position to the other; in the second, the vehicle is placed with the lower section in the manipulator, and the upper (by means of the cross beam) is suspended on the crane and by alternate lifting and displacement of the crane hook, it is brought from the horizontal position to the vertical position; in the third case, after suspending the vehicle by the cross beam on two cranes and raising the hook of one of them before complete unloading of the other, the vehicle is brought from the horizontal position to vertical.

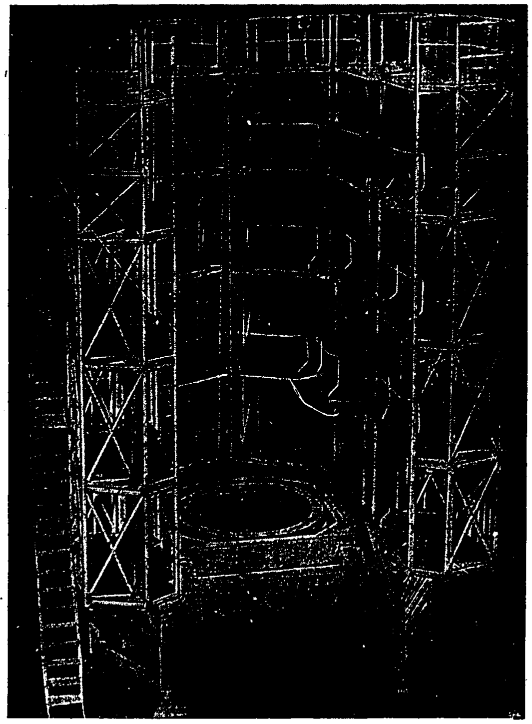

Figure 2.9. Vertical assembly and testing bench

The space vehicle is rarely coupled directly to the booster rocket; usually it is first assembled into the top module, that is, it is covered with the nose cone and it is fastened to an intermediate element (an adapter, frame, and so on), which is a fitting of the last stage of the booster rocket.

There are several methods of assembling the top module. In one of these methods the vehicle is fastened by an adapter on a stock or all-purpose bench, and the nose cone is fitted on the space vehicle on the installation and coupling dollies; after assembly the top module is disconnected from the stock (bench), and it is moved to the side on the dollies. If the nose cone is made up of two halves (shutters) with a longitudinal slit, it is assembled on a horizontal assembly bench. In this case the lower half of the nose cone is placed on the bench, and then the vehicle is placed in it, and the vehicle is covered with the upper half of the nose cone.

During horizontal assembly, the top module is coupled to the booster rocket using the longitudinal or transverse cross beams fastened at the corresponding points of the module, and in vertical assembly, by means of the transverse cross beam.

2.4. Engineering Complex for the "Saturn-V-Apollo" Space Rocket System

The engineering complex of the "Saturn-V-Apollo" space rocket system (part of launch complex No 39 of the Kennedy Space Center) is made up of the engineering complex itself (see Fig 2.10) and an industrial area at a distance of 11.2 km (see Fig 2.11). The basis for its development is the third system for preparing the space rocket systems for launch (the "mobile preparation method") -- vertical assembly of the space rocket system in the engineering complex, performance of complex testing, transporting the space rocket system to the launch site in the vertical position and subsequent launching.

The center of the engineering complex is the vertical assembly building, around which the building with the equipment for air conditioning, water supply, electric power, the compressor station with receiver, the electric substation, the storage battery charging station, cooling tower, water tower, and so on are located. The launch control center building is adjacent to the vertical assembly building. The areas for parking the caterpillar carriers and the launch platforms with the service cable towers are at some distance.

The engineering complex has access routes with unloading platforms and ramps. For transporting the space rocket system from the vertical assembly building to the launching site, a special reinforced concrete channel 39.5 meters wide is laid; the same channel is used to connect the areas for parking the caterpillar carriers with the areas where the launching platforms are placed. For the delivery of the booster rocket stages to the space center there is a water canal with a receiving dock.

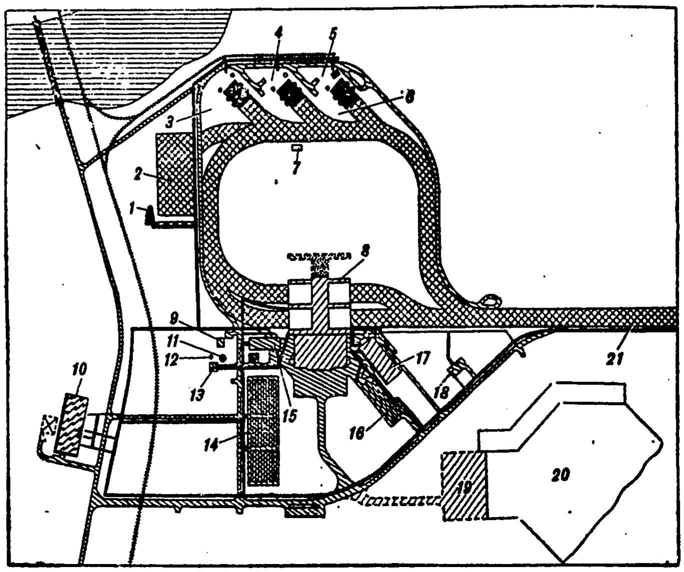

Figure 2.10. Engineering complex for the "Saturn-V-Apollo" space rocket system:
1 -- waste water purification station; 2 -- area for parking the caterpillar carrier; 3 -- area for placing the launch platform No 1; 4 -- area for placing launch platform No 2; 5 -- area for placing launch platform No 3; 6 -- area for installation of the service cable tower on the launch platform; 7 -- storage battery charging station; 8 -- vertical assembly building; 9 -- cooling tower; 10 -- electric substation; 11 -- reservoir; 12 -- water tower; 13 -- building for storing chemicals; 14, 16 -- automobile parking; 15 -- building with equipment for air conditioning, water supply and electric power; 17 -- launch control center; 18 -- compressor station with receiver; 19 -- receiving dock; 20 -- water canal for delivering stages of the booster rocket; 21 -- channel for transporting the space rocket system to the launching site.

The assembly and testing of the space vehicles are carried out in the industrial area where the installation and testing facility for the space vehicles (the buildings for assembly and checkout of the "Apollo" spacecraft), the buildings for testing the life support systems for the "Apollo" spacecraft and the systems for supporting reentry of the spacecraft into the atmosphere, the assembly of the parachute structures of the landing system, the preparation of the pyrotechnical devices, and so on, and also the computer center, the dispatch panel, administrative and service buildings are located. All of the buildings and structures have

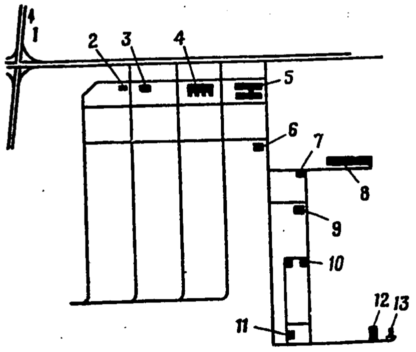

Figure 2.11. Industrial area (arrangement of the basic buildings and structures):
1 -- road to the engineering complex; 2 -- assembly dispatch station; 3 -- computer center; 4 -- building for the administrative divisions and services of the Kennedy Space Center; 5 -- installation and testing facility for space vehicle (building for assembly and testing the "Apollo" spacecraft); 6 -- building for assembling the parachute structures of the landing system; 7 -- building for testing the life support systems for the "Apollo" spacecraft; 8 -- building for testing the systems to support entry of the "Apollo" spacecraft into the atmosphere; 9 -- building for testing the auxiliary equipment systems; 10 -- building for testing the systems operating on spontaneously combustible fuel components; 11 -- building for testing the fuel element systems; 12 -- pyrotechnical building; 13 -- warehouse.

access routes with areas for unloading equipment and parking motor vehicles. A concrete paved highway connects the engineering facility and the industrial area.

The vertical assembly building permits assembly and testing of four booster rockets with the spacecraft simultaneously (in the future, six booster rockets).

The building is made up of two basic spans: a large (the high part) and small span (low part). The large span 158x135 meters in size and 160 m high has four compartments (with the possibility of building on two more compartments) for vertical assembly of the space rocket systems. As the basic bearing structures of the bridge and monorail cranes and also other lifting devices providing for the transporting and erecting of the booster rocket stages, spacecraft and other systems for installation there are six towers in which the laboratories, the panel rooms, the warehouses with equipment, and so on are located. The small span 135x84 m in size and 64.3 meters high has eight compartments for testing and preparing the upper stages of the booster rocket for assembly; there are two-story buildings adjacent to it for testing and preparation of the instrument compartment of the rocket for assembly.

In the vertical assembly building five bridge cranes have been installed (two with a capacity of 250 tons, one with a capacity of 175 tons and two of 15 tons each); eight monorail cranes with a capacity of 5 tons each and more than 50 other lifting and transport units, including 16 high-speed elevators have also been installed.

The rocket stages are serviced from the work platforms advanced from the walls of the compartments, and a large span, also from the service cable tower which has 17 work platforms and 9 remote platforms.

The vertical assembly building is planned in accordance with the technological flow chart for preparation of the rocket (Fig 2.12).

The first stage of the booster rocket delivered by water to the space center is transported to the large span after it is put in the vertical position and transferred to the caterpillar carrier. It is then installed on the launch platform (the upper part of the launching system). The electrical, pneumatic and hydraulic lines are connected to the stage, and the electric circuits, the instruments, the seal of the engine, the oxidant and fuel lines and the lines of the pneumatic systems are checked out.

The second and third stages of the booster rocket and also the instrument compartment are transported to the small span on the carriers. In the small span they are installed in the horizontal position on dollies and checked out. On completion of checkout the stages are delivered in turn to the large span and coupled to the first stage. The lines are connected to them and the complex testing of the booster rocket as a whole begins.

The command module and the lunar module of the "Apollo" spacecraft undergoing testing and checkout in the MIK KO facility were first joined to an adapter, after which they were delivered to the vertical assembly building where they were coupled to the booster rocket (Fig 2.13).

After assembly, the space rocket system is finally checked out; then the caterpillar carrier is run under the launch platform with the service cable tower installed on it, and the entire system is transported to the launch complex.

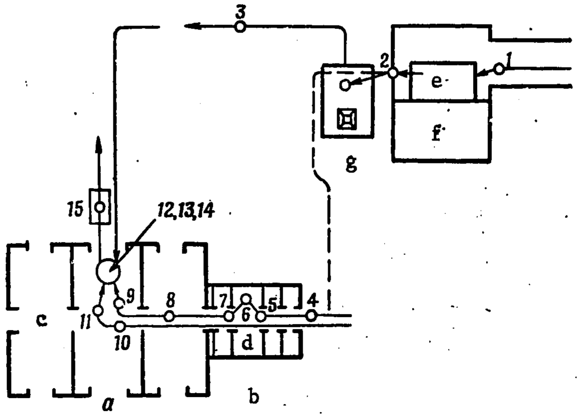

Figure 2.12. Technological flow chart for the assembly of the "Saturn-V-Apollo" space rocket system:
a -- large span of the vertical assembly building; b -- small span of the vertical assembly building; c -- compartment for vertical assembly; d -- compartment for preparation and testing of the upper stages; e -- barge for delivery of the first stage of the booster rocket; f -- barge unloading zone; g -- caterpillar carrier; 1 -- first stage of the booster rocket on the barge; 2 -- erecting the first stage to the vertical position; 3 -- delivery of the first stage to the large span and installation of it on the launch platform; 4 -- upper stage (second and third) on the barge or carrier; 5 -- lifting of the upper stage and installation of it in the operating compartment; 6 -- testing of the upper stage; 7 -- installation of the upper stage on the transport dolly; 8 -- movement of the transport dolly to the large span; 9 -- installation of the second stage on the first (or the third on the second); 10 -- payload; 11 -- installation of payload on the booster rocket; 12 -- testing the first stage; 13 -- installation of first stage stabilizer; 14 -- final testing of the space rocket system; 15 -- transporting of the space rocket system on the caterpillar carrier to the launching site.

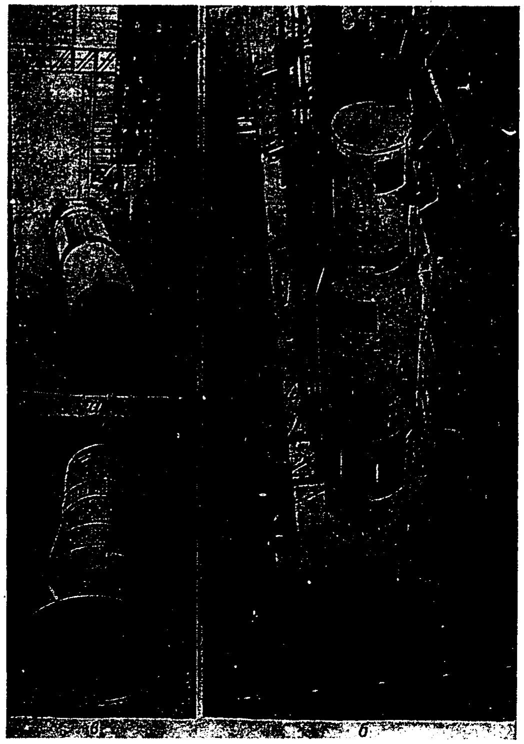

Figure 2.13. Assembly of the "Saturn-V-Apollo" space rocket system in the vertical assembly building:
a -- second stage in the small span; b -- assembled booster rocket on the launching platform; c -- payload

CHAPTER 3. LAUNCH COMPLEX

3.1. Purpose, Structure and Composition

The launch complex is a plot of ground which is prepared in engineering respects with buildings and structures equipped with systems and units designed for acceptance of the space rocket system from the engineering complex, pre-launch preparation and launching.

At the launch complex the space rocket system is installed (and at some launch complexes it is first assembled) on the launching system, the pre-launch testing, filling with fuel components and compressed gases, aiming and launch are carried out. The operations performed at the launch complex are the concluding phase of preparing the space rocket system.

The launch complexes are built considering their use for rockets of a defined class, which conditions their specific nature. The structures and equipment of the launch complex depend on the structural design of the space rocket system. Some launch complexes can provide for the preparation and launching of various space rocket systems that are similar with respect to class.

The structure and composition of the launch complex are determined by the class of space rocket system, the flow chart of the preparation system, the purpose of the space rocket system, the structural-compositional layout of the booster rocket, the composition of the space vehicle systems, the planned number of launches, the duration of the pre-launch preparations, and so on.

The class of space rocket system has a great deal of influence on the structure and composition of the launch complex. With an increase in size and mass of the rocket not only do the dimensions of the ground structures and equipment increase, but significant qualitative changes appear.

For rockets of light and medium classes, the number of structures is minimal, the greater part of the equipment is made movable, and only certain systems and units are made stationary. For heavy class rockets the number of buildings and structures increases, the spacing between them is increased, their dimensions and complexity of structural design increase. For protection from the excess pressure of a possible explosion and the sound effects the structures are built with embankments or buried and semiburied, and the unit systems a re made basically stationary. This is especially characteristic for rockets of the superheavy class, although part of the units (the launch system and the service towers) can be movable.

The structure and composition of the launch complex are determined to a great extent by the technological flow chart used for the system of preparation of the space rocket system for launch. Certain characteristics of launch complexes are presented in Table 3.1 for various preparation systems.

Depending on the number of launching pads, the launch complexes can be single or paired, which is connected with the performance of a series of launches after short time intervals and also with arguments of fitness: in case of failure of one of the launching pads when there is a rocket emergency, it is possible to launch from the other pad.

A single launch complex (Fig 3.1) has all of the necessary equipment for preparation and launching the space rocket systems; the paired launching complex (Fig 3.2) can be both entirely autonomous and have the common technological structures and systems (launch control center, systems for storing and servicing fuel components, gas supply station, refrigeration center, and so on). The paired launch complex is more economical than the single one, for the same systems are used, but it is more vulnerable in case of a possible rocket emergency on the launching system or in the initial segment of the trajectory.

The distances between the launching pads and the structures located on them are selected beginning with the conditions of safety of the ground systems and the space rocket systems in case of an emergency and with consideration of the sound effects. Sometimes these spacings are decreased in order to reduce the length of the coupling lines and to decrease the cost of construction, which excludes the possibility of parallel preparation of a rocket on an adjacent pad.

Depending on the structural design of the launching structure, the launch complexes are divided into ground, semiburied and scaffolding type. The ground launching complexes usually used for light and medium class rockets, all the basic equipment and, above all, the launch system with gas deflector are located on the surface of the ground (at "zero" level); the semiburied launch system with gas deflector is partially buried, and there are gas removal channels for removal of the gases; at the scaffolding type launch complexes, the launching system and also some of the equipment (service tower, the service cable tower, the erector, and so on) are placed on a scaffolding. The last two types of launch complexes are basically used for heavy and medium-heavy class rockets.

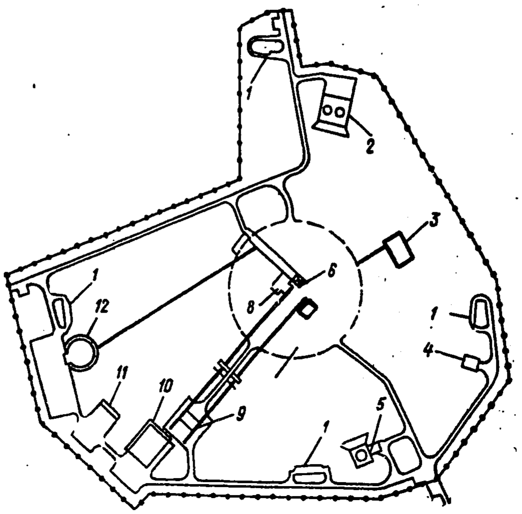

Figure 3.1. Single launch complex:
1 -- camera; 2 -- fuel storage (liquid hydrogen); 3 -- pool with water; 4 -- fuel storage; 5 -- oxidizing agent storage (liquid oxygen); 6 -- service tower; 7 -- launch area; 8 -- launching pad; 9 -- crane for installing the stages on the launching pad; 10 -- auxiliary equipment building; 11 -- compressor station; 12 -- launch control center.

In addition to the class of the space rocket system and method of preparing for launch, the relief of the terrain (the presence of ravines, deep slopes and so on) can have a significant influence on the choice of one type of launch complex or another.

The buildings and structures of the launch complex are designed for an excess pressure from 0.1 to 1 MPa, or more. Out of all the structures, the command station is the best shielded (the launch control center), for in addition to the monitoring and testing equipment and the launch and checkout equipment there are also service personnel in this station.

The launch complex is equipped with special technological and general engineering equipment.

The special technological equipment is designed for pre-launch preparation of the space rocket systems and launching of them. It includes the following:

The transport equipment for delivering the booster rockets, their stages and space vehicles and also transporting them within the boundaries of the launch complex;

Table 3.1. Some Characteristics of Launch Complexes

System of preparation of the space rocket system for launch (1)	Booster rocket (2)	Cosmodrome (test area) (3)	Launch complex (4)
First system	"Vostok" "Vostok" "Soyuz"	Baykonur	"Soyuz"
Second system ("matched method")	"Thor-Delta"	Western Test Area (ZIP)	
	"Thorad-Delta"	The same	
	"Thorad-Agena"	The same	
	"Atlas"	The same	
	"Atlas-Agena"	Kennedy Space Center	12, 13
	"Atlas-Centaur"	The same	36A, 36B
	"Thor-Delta"	The Same	17A, 17B
Second system ("fixed method")	"Titan-II"	Eastern Test Area (VIP)	19
	"Titan-IIIA"	The same	20
	"Saturn-I" "Saturn-IB"	Kennedy Space Center	34
	"Saturn-I" "Saturn-IB"	The same	37
	"Scout"	Wallops Island	3

Table 3.1 [continued]

Method of assembly and installation on the launching system	Service tower	Launch structure	Launch system
(5)	(6)	(7)	(8)
Horizontal assembly in the installation and test facility at the engineering complex, erection to the vertical position using an erector	Stationary with ejectable service beams	Semiburied with trough deflector	With ejectable supporting beams
On the launching system by service tower cranes	Rolling	Scaffolding type	Rotating launching pad with trough deflector
The same	The same	The same	The same
The same	The same	The same	The same
The same	The same	The same	The same
On the launching system by service tower mechanism	Rolling on railroad track	The same	The same
The same	The same	The same	The same
On the launching system by cranes	Rolling	The same	Launching pad
On the launching system by rotating service beams	Stationary, rotating	Scaffolding type with wedge deflector	
The same	The same	The same	
On the launching system by cranes of service tower	Rolling on railroad track	The same	
The same	The same	The same	
Horizontal assembly on the beam of the launching system, installation at a defined angle to the horizontal using the beam	The same	Ground launch structure	Stationary special beam

Table 3.1 [Continued

System of preparation of the space rocket system for launch (1)	Booster rocket (2)	Cosmodrome (test area) (3)	Launch complex (4)
Third system ("mobile method")	"Saturn-V"	Kennedy Space Center	39
	"Titan-IIIC"	Eastern Test Area	40, 41

The loading and lifting equipment for lifting and transfer operations during transporting, assembly, transferring and servicing the space rocket system;

The lifting and erecting equipment -- special units for erection or assembly of the space rocket system at the launching system and also for removal of the systems in case of an aborted launch;

The launch systems for acceptance of the space rocket system and maintaining it in the launch position, providing for supplying electrical, fueling, pneumatic, drainage and other lines to it and performing the pre-launch preparation, aiming and launching;

The service means for insuring access of service personnel, supplying instruments and attachments to the hatches of the space rocket system in vertical position on the launching system and also to the points at which the ground lines are coupled;

The fuel servicing equipment -- units and systems for transporting and storing the fuel components and compressed gases, filling the space rocket system with them and drainage of the fuel components in case of an aborted launch;

The thermostating systems for insuring the given thermal conditions of the space rocket system elements and maintaining the required temperature of the fuel components;

The aiming system for controlling the verticalization of the space rocket system and guide it along the azimuth;

The remote and automated control systems for the technological process operations which control the launch system, the direction unit, the systems for fueling the booster rockets and other equipment used in the pre-launch operation of the space rocket system;

Table 3.1 [continued]

Method of assembly and installation on the launching system (5)	Service tower (6)	Launch structure (7)	Launch system (8)
In the vertical assembly building of the engineering complex	Withdrawable on a ground (caterpillar) running gear	Scaffolding type with launch bench and wedge deflector	Movable caterpillar running gear
The same	Rolling on railroad track	The same	Movable on railroad track

Electric power equipment for supplying the space rocket system, the ground equipment and the remote and automatic control systems for supplying the ground equipment units with special current;

The monitoring and testing equipment for performing the monitoring and checkout testing of the instruments, units and systems of the booster rocket and also coupling the booster rocket and the space vehicle;

The checkout and launch equipment (the ground part of the launch and flight control systems of the space rocket system) to provide for pre-launch preparation and giving launch instructions;

The auxiliary equipment (the mobile and stationary water, gas and foam fire extinguishing systems, the systems for neutralizing the fuel components, and so on) for performing auxiliary operations, the necessity fo which appears during the course of the pre-launch preparation of the space rocket system of on occurrence of emergencies.

The general engineering equipment is designed to maintain the space rocket system and the specialized technological process equipment in constant readiness for operation and also to create normal operating conditions for the service personnel. It includes the following:

A water supply system for supplying the general engineering and specialized technological system with water, the fire extinguishing systems of the buildings and structures, the systems for flushing the spilled fuel components away, and so on, and also for supplying drinking water (usually of a higher degree of purity) and water for domestic needs;

The circulating water supply system for cooling the refrigerators, air conditioning systems, diesel engines and other units; in such systems, the water is used again after cooling and purification, which permits decreased water consumption from the water supply sources;

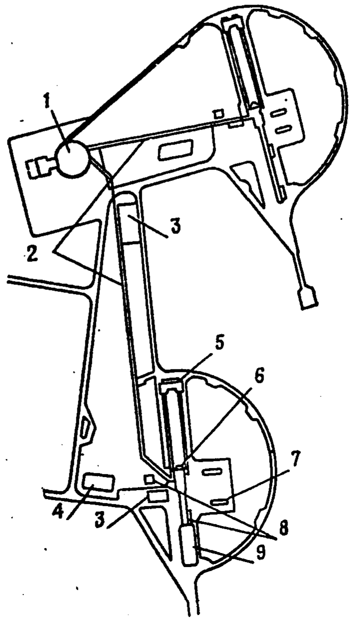

Figure 3.2. Paired launch complex (with autonomous areas): 1 -- launch control center; 2 -- cable channel; 3 -- liquid hydrogen, gaseous helium and nitrogen storage; 4 -- liquid oxygen storage; 5 -- movable service tower; 6 -- launching pad; 7 -- fuel storage; 8 -- air conditioning unit; 9 -- loading and unloading platform

The industrial waste (sewage) system for collection and removal of contaminated waste water beyond the boundaries of the launch complex (cosmodrome), purification of waste water and decontamination before discharge into bodies of water;

A fire protection system to eliminate centers of fire, which can occur in the structures of the launch complex and also as preventive means for preventing possible fires when the rocket is launched or during other operations;

The power supply system for the units and systems of the launch complex to receive industrial alternating current both from the electric power transmission lines and from diesel electric power plants;

The heating system to provide and maintain the required temperature and moisture of the air in the buildings and structures using water heating from the boiler room of the launch complex or the engineering complex; air and electric heating systems are also used;

Ventilation systems for insuring purity of the air in the facilities and structures; especially powerful systems are installed at the structures where increased gas concentration is possible (the fuel component storage, the facilities of the launch structure under the pads, the neutralization facilities, and so on); the systems are usually autonomous for each structure;

The system for gas analysis of the facilities to determine the concentration of the oxygen vapor in the structures of the launch complex where formation of it is possible;

Lightning suppressors to protect the rocket when installed in the launching system and the ground equipment units of great height from atmospheric electricity, for which lightning arresters (divergers) are installed on the launching pad and on the service tower;

Communications means (telephone, headphone) for two-way communications between the system operators and the operations director; loudspeaker communications for the operations director to give instructions on preparing the rocket.

The following structures have been designed for the installation of special technological and the general engineering equipment at the launch complex:

The launch structure;

The structure for the systems to store, fill and drain fuel components and compressed gases; for the thermostating systems (the refrigeration center);

For neutralizatio equipment;

For fire-fighting equipment;

Evaporation areas;

Pools for drainage of untreated or contaminated high-boiling fuel components;

Spraying basins;

Command station (launch control center);

Railroad access routes on hardtop roads;

Railroads for the moving service tower;

Channels;

Boiler room;

Automobile parking area;

Administrative and service facilities;

Security means, and so on.

The launch structure is the center of the launching site, around which the remaining buildings, structures and equipment are arranged. This is the most complex structure with respect to design and the most saturated with equipment. Not only is the launch system located here, but also the service tower and the service cable tower, the elements of the thermostating and fire extinguishing systems, the equipment for coupling the "ground-on-board" communications, the ground rescue means, the monitoring and testing equipment and the checkout and launching equipment. Access routes for the transport and installation unit and the connecting lines approach the launch structure.

The ground launch structures are in the form of a concrete slab on which the fastenings of the launching system and service units are located. In order to protect the instruments and equipment from the gas jet of the engines, special locations and shelters have been provided, and the cables and other lines are laid in channels and service tunnels (the service tunnels are channels which are used for people to pass through).

The launch structures of the semiburied type have several levels on which different equipment is placed (the so-called facilities under the pad, that is, the facilities located below the "zero" level) and there are gas removal channels to remove the gas jet.

The launch structures of the scaffolding type are steel or reinforced concrete scaffolds, in the upper part of which the launching system is placed, and in the base, a stationary or movable gas deflector.

The structures for the fuel component storage, filling and drainage systems are made, as a rule, buried or semiburied with the necessary shielding from the effects of shock waves (in case of explosion of a space rocket system), and they are removed a safe distance from the launch system. Each fuel component has its own storage with tanks for storing the components, pumping units, fill and drain lines, tanks for drainage, heat exchangers, tanks with compressed gases and the service system panels. The storages are connected with the launch structures by service tunnels and passages with filling and drain lines. These structures also include auxiliary facilities: ventilation, power supply boards, pumped water supply, the spare parts facility, lockers, shower, and so on.

The structures for the compressed gas storage and filling systems are analogous with respect to their structural design to the above-presented structures and they are used for the compressor stations, receiver, pneumatic equipment and gas distributing boards. They are also joined to the launch structures by service tunnels and channels with pipelines.

The structure for the thermostating systems (the refrigeration center) has compressors, condensers, evaporators, heat exchangers, pumps, tanks with heat-transfer agent and other equipment. The refrigeration center can be made either in the form of a separately standing structure of located in the launch facilities under the pad.

The structure for the neutralization equipment of the space rocket systems with toxic fuel components is designed for neutralization means, the composition of which usually includes containers with neutralization solutions, water reservoirs, pumping units, lines, and so on. This structure has an industrial waste system, and it can be executed in the form of a separate building or be part of the service equipment structures.

The structures for fire-fighting equipment are frequently structurally joined to the launch structure, and in a number of cases they are joined to the structures for the water supply system.

The evaporation areas are used to evaporate cryogenic fuel components (liquid oxygen, hydrogen, and so on) after they are drained out of the rocket tanks or in case of accidental spills. These are shallow concrete walls to which lines run from the fuel component storage and from the launch structure. Each fuel component has its own evaporation area; for safety purposes the areas are separated from each other by significant distances.

The basins for draining the untreated or contaminated high-boiling fuel components usually are removed to significant distances from the launch structure and even can be placed outside the boundaries of the launch complex.

The sprinkling basins are used to cool the water in the circulating water supply system and are pools with fountain-like structures. After cooling the water again is returned to the units and systems (compressors, air conditioners, refrigeration units, and so on). Cooling towers are also used to cool the water in the launch complex.

The command station (the launch control center) is equipped with the monitoring-testing and the testing-launching equipment, the equipment for remote and automatic control of the technological process operations and also the communications systems, television and air observation systems. The command stations are usually made in the form of buried bunkers with several levels. This is the most shielded structure. At some launch complexes the command stations are used only for monitoring and testing equipment, and the launch checkout equipment is placed in remote command stations located at a significant distance from the launch complex (including also the engineering complex).

The railroad and hardtop road access routes are designed for transporting the space rocket systems from the engineering complex to the launch complex. The design of these accesses depends on the structure of the transport-installation unit. For transporting space rocket systems of the heavy and super-heavy classes on a caterpillar carrier, a reinforced concrete road of box cross section with two tracks is provided. In order to move the other units, automobile roads are built.

3.2. Operations Performed at the Launch Complex

The nature of the operations and sequence of the pre-launch preparation of rockets of various classes have many common features and are distinguished only by the duration of the operations, the technical means of supporting them and some specifics caused by the peculiarities of the structural design of the booster rocket and the space vehicle.

The following are performed at the launch complex:

Adjustment operations with the ground equipment for maintaining the launch complex in constant readiness;

Operations with respect to preparing the launch complex to accept the space rocket system;

Installation of the space rocket system on the launch system;

Assembly of the space rocket system;

Aiming of the space rocket system;

Supplying of the service units and connection of the "ground-on-board" communications;

Pre-launch checkout of the equipment and systems of the space rocket system;

Filling the space rocket system with fuel components and compressed gases;

Thermostating the elements of the space rocket system and the fuel component;

Boarding of the cosmonauts (when preparing manned spacecraft);

Launch of the space rocket system;

Post-launch operations;

Drainage of the fuel components and removal of the space rocket system from the launch system in case of an aborted launch.

During the period between launches or during prolonged storage, adjustment operations are made with the units and systems insuring constant readiness of the entire complex of ground equipment for operation with the space rocket system.

The preparation of the launch complex for acceptance of the space rocket system is a matter of bringing the units and systems into operating condition from storage. During the preparation process, the storage tanks are filled with fuel and oxidant, and the receivers with compressed gases, the fuel components in the storages are thermostated, autonomous checks are run on the process units and systems without the space rocket system and then with simulators on the on-board systems of the space rocket systems.

The installation on the launch system is preceded by delivery of the space rocket system on the erector in the horizontal or vertical position or delivery of individual stages of the booster rocket and the space vehicle on the transport dollies from the installation and testing facility to the launch complex. By using the erector the space rocket system is moved to the vertical position so that it will be above the launch system, the mechanisms of launch system or the erector (or both);its supporting elements are brought closer until they make contact with the supports of the launch system. Then the space rocket system is made fast with wind and storm fastenings, after which the grapples of the erector are released, and the boom is lowered to the horizontal position.

When using the "fixed"(or combined) method of preparation of the space rocket system, the booster rocket is delivered to the launch complex by individual modules, and it is assembled on the launch system in the vertical position using cranes or service towers.

The aiming of the space rocket system is made up of a set of operations providing for orientation of the space rocket system and the control system sensors with respect to the ground geodetic grid. The accuracy of insertion of the space rocket system into the given trajectory depends on the initial orientation of the gyroscopic instruments of the flight control system with respect to the direction of the ground meridian at the time the space rocket system is located in the launch system. For this purpose, before the launch the gyrostabilized platform of the autonomous control system is oriented in a defined way in space with respect to the coordinate axes of the launch system defined during geodetic preparation of the launch.

The aiming of the space rocket system is achieved by verticalization -- a set of operations with respect to assignment of the space rocket system in the launch system to a strictly vertical position using the supports or jacks of the launch system and azimuthal aiming -- matching of the stabilization plane of the space rocket system with the launch plane by rotating the space rocket system in the horizontal plane using the rotary of the launch system or corresponding orientation of the individual elements of the on-board control system of the space rocket system.

In order to aim the space rocket system it is necessary to carry out a geodetic launch preparation and obtain the initial data, that is, determine the coordinates of the launch system and the reference directions.

In order to service the space rocket systems and connect the "ground-on-board" communications to the space rocket system, service units are brought in. The pneumatic lines are connected to the ground sections of the pneumatic fittings installed on the rocket; the fueling and drainage hoses are connected to the fueling and drainage heads and the on-board couplings; the electric cables are connected to the on-board plugs and plates.

Some of the space rocket systems come to the launch complex with coupled ground lines and cable towers; in this case the lines are coupled to the corresponding parts located in the launch structure.

The pre-launch (both autonomous and complex) checks of the equipment and systems of the rocket are made using the monitoring-testing and launch checkout equipment.

After performance of the autonomous and complex tests, decoding and analysis of their results, the tanks of the space rocket system are filled with fuel components, and the bottles with compressed gases.

The thermostating of the rocket system elements includes supplying heated or cooled air (air thermostating) to maintain the given temperature of the equipment, fuel components, on-board power supplies, and so on using a special ground air thermostating system or by feeding a heat-exchange agent (liquid thermostating) from the ground system to the space vehicle heat exchanger.

The cosmonauts board the space vehicle from the beam or service tower elevators. Before entering the spacecraft, a "clean chamber" can be installed on the platform through which the cosmonauts and service personnel must pass.

Before launching the rocket system, the following operations must be performed: uncoupling and removal of all lines, except those which participate in the launch; the service units are removed to a safe distance; service personnel not involved with the launch are sent to a safe zone or shelter; the fire-fighting equipment is put into full readiness.

During launching of the rocket the following operations are performed: blowing of the fuel tanks of the booster rocket; starting the control system instruments; uncoupling the "ground-on-board" communications; starting the rocket engine and bringing it to the operating state; separation of the rocket system from the launch system.

All of the operations with respect to pre-launch preparation and launching of the rocket system are performed by instructions from the remote control system for the technological operations and the launch-checkout equipment, and they are recorded on the launch panel by a set of readiness transparencies. The majority of operations are performed automatically or remotely. The necessity for service personnel to be located next to the rocket system is eliminated in this case.

The post-launch operations include external inspection of all of the equipment of the launch complex, checking the functioning of the systems and units, replacement of the assemblies planned for one-time use, drainage of the ground lines, and so on. After performance of the post-launch operations the launch complex is put in storage.

The drainage of the fuel components and removal of the space rocket system from the launch system take place in case of postponement of the launch for any reason. These operations include bringing up the service equipment to the rocket system, evacuation of the cosmonauts, coupling of the fuel and oxidant system lines, thermostating, checking the communications systems, television observation, switching on the ventilation and gas analysis systems, and so on. After performance of the indicated operations, it is permitted to proceed with drainage of the fuel components initially from the rocket tanks and then (after assembly of the lines) drainage of the remainder of the fuel from the lines and the combustion chambers of the engines. The remains of the cryogenic components are evaporated, and compressed gases are removed from the on-board bottles to the receiver.

After draining the fuel components and removing the compressed gases, all lines are disconnected from the rocket system, the erector is brought up to the launch complex, it is put into operating position on the launch structure and the service equipment is removed. Then the rocket system is removed from the launch system and it is transported to the engineering complex.

3.3. American Launch Complexes

Let us consider the launch complexes in the example of two American complexes.

Launch complex No 37 of the Kennedy Space Center (see Fig 3.3) is a paired (it has two launching pads), scaffolding type and it is designed for preparation by the "fixed method" and launching the "Saturn-I" and "Saturn-IB" booster rockets.

The launch sites are 240 meters from each other. They have launching pads, buildings for equipment and service cable towers, one common movable service tower, one launch control center. They are supplied with fuel components and compressed gases from centralized storage.

The launching pad is a square steel structure 14.3 meters on a side and with eight supports with grapples which hold the rocket system to launch time and a wedge type steel gas deflector lined with refractory brick which can service both launching pads. After launch the gas deflector is removed over long rails for repair and restoration work. In order to facilitate servicing, triangular platforms are installed around the pad, forming an area of 16.8x16.8 meters together with the pad.

Beside the pad there is an equipment building which has three ground and several underground levels. The electric generators, the checkout equipment, and the distribution boards of the electric and pneumatic systems are located in it.

The service cable tower with the fuel and oxidant feed lines, electric power lines, the cable network of the checkout equipment, and so on, is installed on the equipment building. The tower is a steel structure 82 m high with a 9.7x9.7 meter base (if necessary the tower height can be increased another 15 meters).

The movable service tower 114 meters high weighing 3175 tons is mounted on dollies and can be moved along the rails at a speed of up to 0.2 m/sec. After delivering the tower to the launch site, it is removed by hydraulic jacks from the dolly and is installed on a specially prepared foundation. A 60-ton crane is installed on the tower which can lift all the stages of the booster rocket and the space vehicle; there are two hoists, two platforms for installing the equipment and several service platforms.

The launch control center designed for controlling all operations of prelaunch preparations is located at a distance 400 meters from the launching pad, and it is a two-story, circular dome-shaped reinforced concrete blockhouse with wall thickness of 1.5 meters and covered with dirt on the outside. The control center is designed for a shock wave pressure in front of 5 MPa, and it guarantees safety of the service personnel in case of an emergency with the rocket system on the launching pad.

The tracking equipment for rocket flights and equipment for telemetric measurements are placed on the first level of the launch control system, and on the second level (in the main room), the launch control panel and equipment for observation and communications.

Liquid oxygen is stored in two tanks: the basic capacity 484 m3 designed for fueling the rocket and the auxiliary tank of 108 m^3 for makeup.

The fuel (of the kerosene type) for filling the first stage is stored in a 167 m^3 tank, and it can reach both of the launch platforms on the same lines.

Fuel (liquid hydrogen) for filling the second stage is stored in tanks with a capacity of 470 m^3, and is fed to the tanks by extrusion.

The liquid oxygen-hydrogen storages are separated by safe distances from the launching pads, and from each other.

BY PROFESSOR A. P. VOL'SKIY

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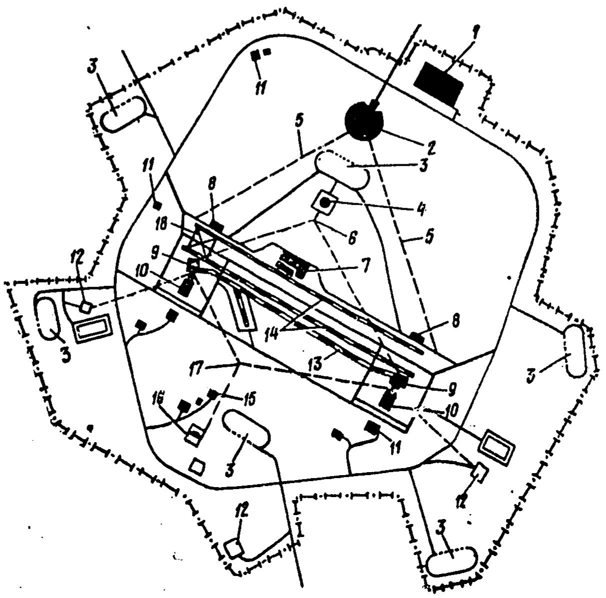

Figure 3.3. Launch complex No 37 of the Kennedy Space Center (United States):
1 -- service building; 2 -- launch control center; 3 -- cameras; 4 -- oxidant (liquid oxygen) storage; 5 -- cable service tunnel; 6 -- lines of the liquid oxygen service system; 7 -- compressed gas receiver; 8 -- facilities for the regulators and valve blocks of the underground lines; 9 -- launching pads; 10 -- buildings for equipment and service cable towers; 11 -- ventilation holes; 12 -- tanks for draining liquid hydrogen; 13 -- rails for removing the gas deflector; 14 -- rails for the service tower; 15 -- fuel storage; 16 -- fuel (liquid hydrogen) storage; 17 -- lines of the liquid hydrogen service system; 18 -- service tower

The high-pressure gas supply includes nitrogen and helium systems. The former is made up of the liquid nitrogen storage with a capacity of 132 m^3, a battery of tanks (receiver) and a gas generator for obtaining gaseous nitrogen. The gaseous nitrogen is used to purge the systems for filling the fuel and other equipment, checking out the high pressure lines, and so on. The second system has 18 tanks 5.6 m^3 in volume each for storing helium. Gaseous helium is used for mixing liquid oxygen in the tanks of the rocket system in order to prevent the formation of layers with different temperature. In order to obtain high-pressure helium, compressors are used.

The launch complex also includes the technical water tank of 112 m^3 and a reservoir for the fire extinguishing system with a capacity of 40,000 m^3 with several pumps with a total output capacity of 2 m^3/sec.

The carrying capacity of the complex with a 90-day cycle for preparation of the "Saturn-IB booster on one launch site is 6 launches a day.

The launch complex No 39 of the Kennedy Space Center (Fig 3.4) of the scaffolding type with two autonomous launching sites is designed for preparing the launch of the "Saturn-V-Apollo" space rocket system by the "mobile method."

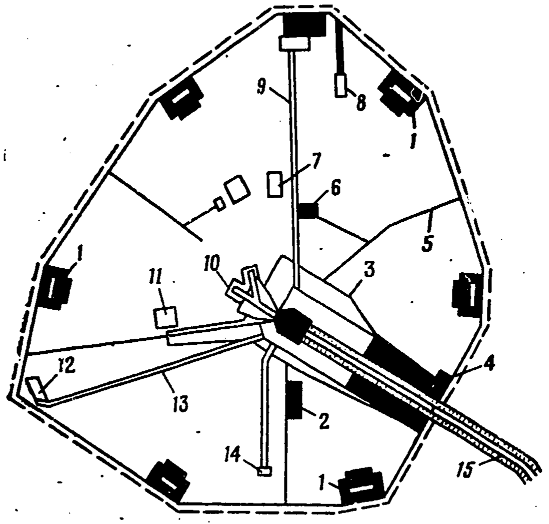

Figure 3.4. Launch complex No 39 of the Kennedy Space Center (United States):
1 -- remote and movie cameras; 2 -- automobile parking; 3 -- launch bench; 4 -- monitoring and launching station; 5 -- gas supply system pipeline; 6 -- building with equipment for determining the azimuth of the rocket; 7 -- pool for draining the fuel; 8 -- pumping station for hot and liquid nitrogen; 9 -- lines for the fuel and liquid hydrogen filling system; 10 -- sites for placement of the gas deflector; 11 -- fire extinguishing system reservoir; 12 -- liquid oxygen pumping station; 13 -- pipelines of the liquid oxygen filling system; 14 -- ventilation device; 15 -- channel for caterpillar carrier.

The launch complex No 39 is unique both with respect to size and with respect to saturation with equipment and technical solution. The units and systems of the complex (for example, the service cable tower, the service tower, the caterpillar carrier, and so on) are the largest not only in the United States. The "Apollo" spacecraft were launched from this complex, which delivered American astronauts to the moon and also the "Apollo" spaceship for rendezvous with the Soviet spacecraft "Soyuz" according to the EPAS program.

The launch site of the complex has in plan view the shape of an octahedron with transverse dimension of 900 meters. At the center of the site is the launch bench (Fig 3.5) — a reinforced concrete structure 103 meters long, 97.5 meters wide and 14.6 meters high. Along the axis of the bench a gas removal channel is built 137 meters long and 17.7 meters wide, on the rails of which the wedge gas deflector is moved. A channel for the caterpillar carrier approaches the bench. The launch platform with the space rocket system installed on it and the service cable tower is delivered to the launch bench by means of it.

Inside the bench there is a bunker of automation communication systems (the communications junction), facilities for the air conditioning system, high pressure gauge storage, an underground filter for the astronauts and service personnel, and so on. Switchboards have been placed at the communications junction to which the communications line from the launch control center is connected. Equipment is found here to simulate the functioning of the booster rocket, including the processes of filling during the prelaunch preparations when the rocket system has not been installed on the launch bench.

In the air conditioning facility there is equipment for supplying air and nitrogen at a controlled temperature and humidity to the space rocket system.

The gas storage area has bottles with nitrogen and helium under a pressure of 42 MPa for purging tanks and the instrument compartment; the nitrogen reserve is 85 m^3, and helium is 255 m^3.

The shelter for the astronauts and service personnel (for 20 people) is in the form of a dome 12 meters in diameter, and it is lined with steel plates 0.9 meters thick. The walls and door of the shelter are designed for protection against a blast wave with excess pressure of 3.5 MPa and G-loads to 75. The concrete door of the shelter 0.2 meters thick is suspended on coil springs which damp the G-loads. A bent inclined stainless steel chute 60 meters long leads to the shelter. It begins at the launch platform and ends 12 meters under the surface of the launch pad. The chute allows the personnel to descend at a speed of 20 m/sec with braking at the end of the pad by using materials with different friction coefficients and special rubber.

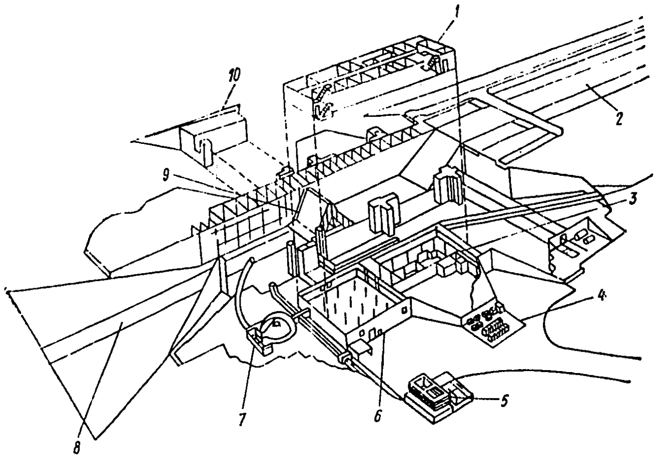

Figure 3.5. Launch bench:
1 -- second level of the communications junction; 2 -- entrance to the bench (channel for the caterpillar carrier); 3 -- first stage of the communications junction; 4 -- transformer substation; 5 -- refrigeration unit; 6 -- facility for the air conditioning means; 7 -- emergency bunker; 8 -- gas discharge channel; 9 -- gas deflector; 10 -- compressed gas receiver.

There is a cableway on the launch stand to rescue the astronauts and service personnel from the upper levels of the service cable tower and the service tower. The car on the cableway (for 9 people) reaches ground level (a distance of about 600 meters) in 30 seconds.

Six supports are mounted on the upper level of the stand (see Fig 3.6) to install the launch platform, and there are four supports for installing the movable service tower. There are also elevators, ladders, service platforms, mechanisms for running the fuel and pneumatic lines, the air conditioning system lines, electric power cable and monitoring and measuring equipment.

The launch platform serves as the location for the assembly, testing and monitoring of the space rocket system,[1] and it has a mechanism for fastening it to the caterpillar carrier, the supports and the terminals on the stand. On the upper plate of the platform grapples are mounted which hold the rocket system and there are also three service cable masts and a service cable tower. In the center of the platform there is a hole for passing gases formed on launching the rocket.

The service cable tower has nine beams with different lines for testing, filling and servicing the booster rocket and the space vehicle, platforms on which the filling, pneumatic, electrical and monitoring and measurement equipment is located and also elevators for delivering the astronauts to the spacecraft.

The platforms and trusses of the tower are removed from the rocket system at various times of pre-launch preparation, and part of the trusses, during the launch process.

The movable service tower is designed for placement of the pneumatic and hydraulic equipment, an electric power supply system, air conditioning, communications and fireproof shielding, and it has several working platforms insuring access of the service personnel to the rocket system.

The caterpillar carrier is used to deliver the launch platform with the rocket system and the service cable tower to the launch site and install them and the movable service tower at the launch stand; the carrier has autonomous electric power supply and is controlled by an operator in one of two cabs on opposite sides of the chassis.

The liquid oxygen filling system is made up of the spherical tank with perlite thermal insulation about 3400 m^3 in volume at a distance of 450 m from the launch stand, a pumping station for supplying oxygen to the

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[1] Inasmuch as in subsequent chapters a detailed description is presented of many of the systems and units of the "Saturn-V-Apollo" space rocket system, only a general characteristic of the equipment is presented in this chapter.

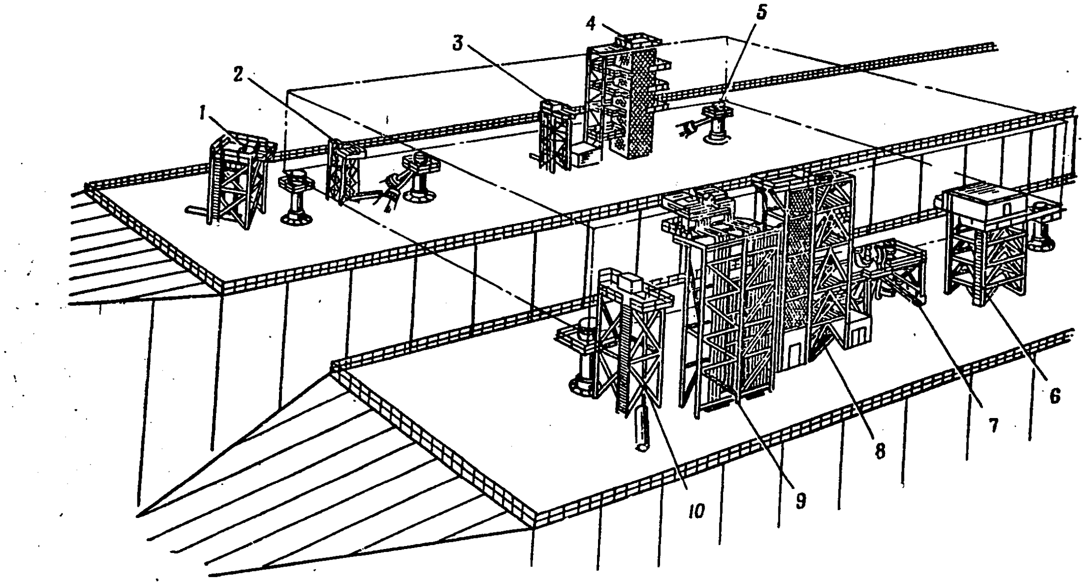

Figure 3.6. Arrangement of the equipment on the launch stand:
1 -- liquid and gaseous hydrogen feed; 2 -- pneumatic system feed; 3 -- fuel feed; 4 -- service platform of the first stage engine; 5 -- supports for the launch platform (a total of six); 6 -- electric line approach; 7 -- access to auxiliary equipment; 8 -- service platform; 9 -- air conditioning system access; 10 -- liquid nitrogen feed.

rocket tanks and fueling and topping off lines with distributing fittings for each of the three booster rocket tanks.

The pumping station has two high-output pumps (one reserve) for servicing the rocket tanks and two low-output pumps (one reserve) for makeup. The liquid oxygen is fed from the tank to the pump input by displacement by gaseous oxygen generated during the filling and the topping off process in a special gas generator-heat exchanger.

The system for fueling (kerosene type fuel) the first stage has a storage with 355 m^3 tanks also located at a distance of 450 meters from the launch stand, a pumping station and the feed lines with various fittings.

The liquid hydrogen fueling system is made up of a spherical tank 3230 m^3 in capacity with perlite-vacuum thermal insulation located near the fuel storage, the filling and topping off lines with vacuum thermal insulation and distributing fittings for each of the two tanks. The liquid hydrogen is fed from the storage to the rocket tanks by displacement by gaseous hydrogen generated during the filling and makeup process in a special gas generator-heat exchanger.

The gas supply system includes conversion-compressor equipment and high-pressure compressed gas batteries located in the bunkers of the launch stand and in the vicinity of the vertical assembly building; the high-pressure gaseous hydrogen storage battery and distributors and also underground bunkers for storing gaseous nitrogen and helium under a pressure of 40 MPa. Various blowing systems require about 85 tons of liquid nitrogen and 80,000 liters of helium.

Nitrogen is used in the environmental monitoring system as a protective inert gas when filling with cryogenic fuel components and working gas, when filling with hydrocarbon fuel and in the pneumatic drives of the cantilevers of the service cable tower; for purging the electric plugs, for blowing the fuel tanks and purging various systems.

Helium is used to blow off the fuel tanks of the space vehicle, for blowing the liquid hydrogen tanks, blowing and creating an inert atmosphere in the system for filling the stages with liquid hydrogen and also as the working gas for the pneumatic cylinders for removing the ground feed hydrogen lines.

At launch complex No 39 a great deal of attention has been given to the selection of safe distances between the structures and the launch platforms. The planning of the complex provides for maintaining the structures and units of the ground equipment of the launch platform (with the exception of the launch system, the launch structure and the service-cable towers) in the case of possible explosion of the booster rocket on an adjacent site.

The preparation time for the "Saturn-V-Apollo" rocket system at the launch complex was 2 weeks. The carrying capacity of launch complex No 39 is on the average 6 to 8 launches a year, but it can reach 12 launches per year.

CHAPTER 4. SPECIAL TECHNOLOGICAL EQUIPMENT

4.1. Means of Transporting the Space Rocket Systems to the Cosmodrome

The space rocket systems are transported from the manufacturing plants to the cosmodrome by railroad, automobile, air and water transportation (Fig 4.1). The application of one type of transport means or another is determined by such factors as the class of rocket, its dimensions and mass, strength characteristics, transport distance, delivery times, and so on. The overall dimensions in mass of the space rocket systems, which on modern rocket systems is of significant magnitude (diameter several meters, length tens of meters and mass tens and hundreds of tons) have a significant influence on the choice of the transport means. It is necessary to transport such loads not by one of the existing forms of transportation; therefore the rocket systems are delivered to the cosmodrome, as a rule, in parts, so-called portable elements (individual stages, compartments, modules and assemblies), the size and weight of which permit them to be hauled.

All forms of transport means have restrictions with respect to the overall dimensions of the hauled loads. For traffic safety on railroads, considering the structures next to the tracks, the bridges and oncoming traffic, the dimensions of the hauled loads must not exceed defined amounts.

When moving by motor transportation, the possibility of safe passage under electric lines, across bridges with upper structure and viaducts, on city streets, and so on are taken into account.

When shipping by air, the size of the load is limited by the sizes of the cargo compartments and the carrying capacity of the aircraft.

When shipping by water the size of the load is limited by the size of the vessel and locks, the height of bridge spans, and so on.

All forms of transport means have certain restrictions with respect to load capacity and speed.

The choice of transport means is also influenced by the G-loads created by them. The rocket calculated for large loads which are active in flight is, as a rule, limited in taking loads occurring during its ground operation in order to exclude excessive weight. In particular, this pertains to loads acting in the transverse direction, which gives rise to the necessity for taking special measures; the introduction of shock absorbers and unloaders on the transport means, installation of additional supports, reduction of the transport speed, and so on. The number of transport supports is determined by the structural design of the rocket, the location of the supporting chords and the maximum loads. The optimal version is two supports of which one is designed for taking the transverse loads during transport and the other, the transverse and longitudinal loads; one of the supports must be movable to compensate for thermal deformations. In order to exclude significant bending of the rocket under the effect of its own weight and the forces of inertia during transportation, an additional intermediate support that is adjustable with respect to height with counterweights or springs (the so-called calibrated support) is installed. Sometimes a support is also installed under the top module for transport purposes; frequently this support plays the role of the forward support when installing the rocket system on the launch system.

Special railroad cars, collapsible car bodies, gondolas, carriers, standard freight flatcars, and so on are used to transport the compartments and modules of space rocket systems by railroad.

Special railroad cars (Fig 4.2) have been developed on the basis of the general-purpose cars, and they have the corresponding equipment for loading and unloading the compartments (modules). Their bodies are equipped with thermal insulation to protect the transported cargo from solar radiation and significant temperature gradients.

The collapsible car bodies are made of individual sections of side and end walls and covers based on standard railroad flatcars; here the compartments of the rocket are placed on the car supports by a crane with the top off. According to the foreign press the opening tops of the cars have been designed in two halves which when closed, converge at the top, forming a sealed waterproof joint, and a cover has also been designed in the form of a corrugated strip which is rolled onto a drum at the end of the car when it is opened.

Gondolas covered with shields or a tent with supports installed on the floor are also used to transport elements of the space rocket systems.

Multiaxle railroad carriers (Fig 4.3) with increased carrying capacity and lower level of the freight platform by comparison with regular cars are used to haul heavy, large compartments. At the present time there are carriers available with a capacity of up to 230 tons, and carriers are being built with still greater capacity.

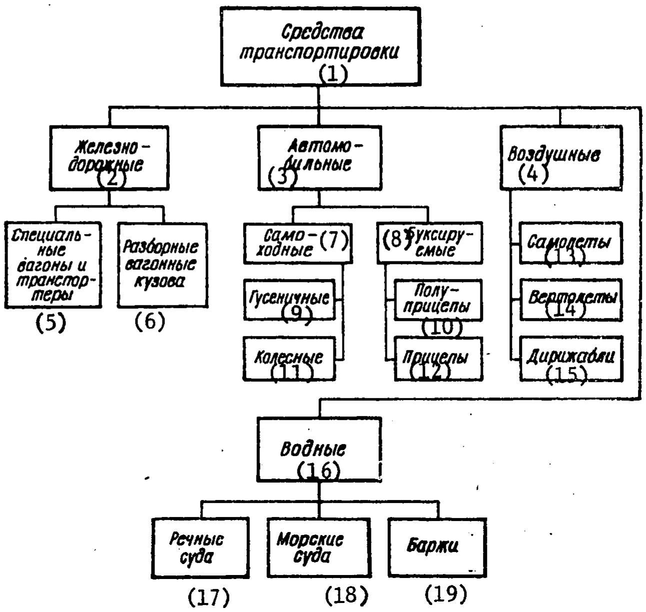

Figure 4.1. Means of transporting space rocket systems

Key:

1. Transport means
2. Railroad
3. Motor
4. Air
5. Special cars and carriers
6. Collapsible car bodies
7. Self-propelled
8. Towed
9. Caterpillar
10. Semitrailer
11. Wheeled
12. Trailer
13. Aircraft
14. Helicopters
15. Dirigibles
16. Water
17. River ships
18. Maritime ships
19. Barges

Containers are also used to transport the rocket system elements. This is especially important when hauling space vehicles and their compartments, for the container reliably protects the compartments from dust, dirt, mechanical damage or solar radiation.

The cars (flatcars, carriers) with elements of the space rocket systems along the main railroads usually follow with speeds adopted for these railroads, which imposes defined requirements on the structural design and strength of the transported compartment. When transporting space rocket systems, jolts and impacts occur; therefore the railroad means are equipped with shock absorbers (coil springs, plate springs, and so on) which take the jolts and shocks. The American specialists have developed a shock absorbing system which uses inflated rubberized pads which convert the impact loads to contact pressure of insignificant magnitude distributed over the surface of the compartment.

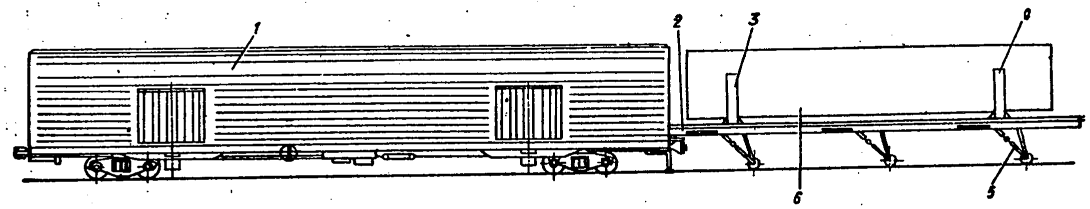

Figure 4.2. Railroad car with telescopic frame:
1 -- body; 2 -- telescopic frame; 3 -- forward support; 4 -- rear support; 5 -- folding support (legs); 6 -- transported load

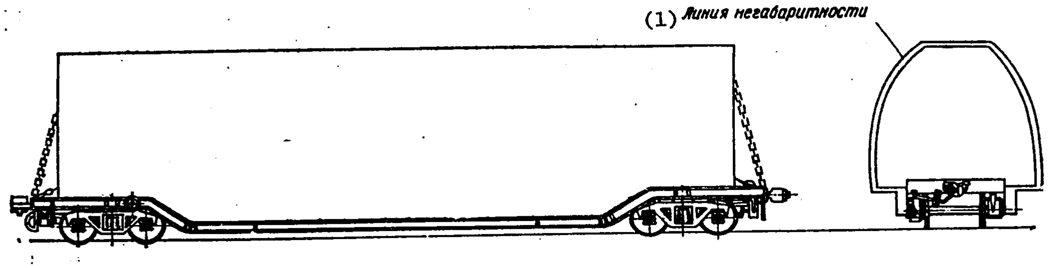

Figure 4.3. Railroad carrier

Key:
1. out-size line

The towed dollies, trailers, and so on are used to haul the elements of the space rocket system by motor transportation.

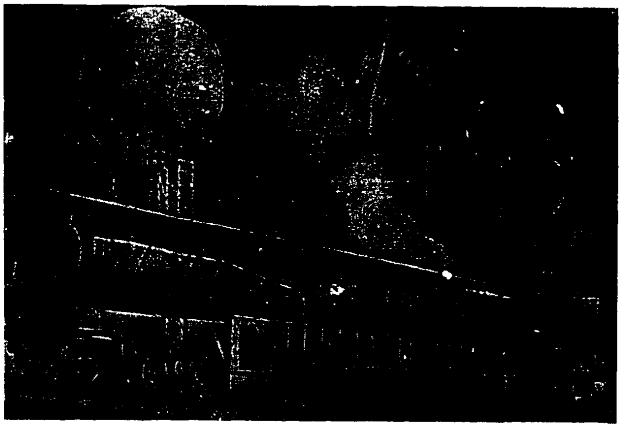

Figure 4.4. Ground dolly

The towed dollies, depending on the method used to couple them to the tractors, are divided into trailers and semitrailers. The length of the dollies can reach 60 meters. A dolly-trailer for transporting a rocket stage is shown in Fig 4.4.

The trailers are units with lowered cargo platforms designed to haul heavy and large pieces of freight, including the elements of space rocket systems.

The application of motor transport means is limited by size and weight of the hauled load. Therefore these meansare more frequently used for hauling within the boundaries of the cosmodrome (for delivering the compartments and modules of the rockets from the airports, from the docks of the waterways, when transporting between structures at the engineering complex, and so on).

In order to transport the space rocket system and its elements by air, aircraft, helicopters and dirigibles are used. The large dimensions of the cargo compartments, the large carrying capacity and high flight speeds of modern aircraft permit delivery of large elements of space rocket systems significant distances in short times.

When loading the compartments and modules of the space rocket systems on the aircraft frequently the so-called craneless procedure is used consisting in the fact that the ground dollies and special frames (corsets) equipped with wheels with compartments and modules located on them are loaded into the cargo compartments of the aircraft using winches. The containers with the space vehicles are also loaded analogously.

The fastening assemblies of the elements of the space rocket system in the aircraft are designed for transverse and longitudinal hauling which can reach significant magnitudes during an emergency landing of the aircraft.

As a result of lack of seal of the cargo compartments of the aircraft the "breathing" valve must be opened on the transported module or container before flight so that the inside cavity will be connected with the cargo compartment cavity; otherwise when the aircraft descends "cratering" of the module (container) is possible as a result of insufficiently rapid equalization of the pressures in it and in the cargo compartment of the aircraft.

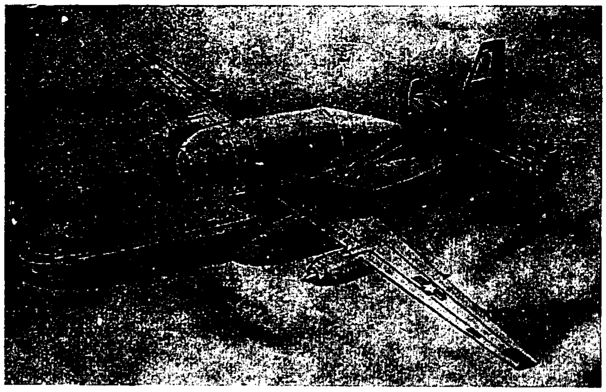

Figure 4.5. Transportation of the S-IVB stage of the "Saturn-I" rocket on an aircraft

Transportation by air is widespread in the United States where aircraft are capable of hauling rocket elements weighing up to 45 tons and up to 3 meters in diamete in the cargo compartments. The transportation of even larger loads is possible, but in this case the aircraft must be modified significantly or the load is placed outside the cargo compartment by fastening it over the aircraft wing using a streamlined container (see Fig 4.5). Fig 4.6 shows the unloading of a compartment of the "Apollo" spacecraft (the compartment is transported without a container) through the cargo hatch of the aircraft; Fig 4.7 illustrates the loading of a booster rocket on an aircraft, and Fig 4.8, unloading the S-IVB stage of the "Saturn-I" rocket from an aircraft by splitting its fuselage into two parts.

Figure 4.6. Unloading a compartment of the "Apollo" spacecraft from an aircraft

There are plans for using dirigibles to transport the rocket elements. By comparison with the aircraft, a dirigible can lift loads of significantly greater size and weight; it requires a landing site that is small with respect to size and simple with respect to design. The use of dirigibles is prospective, for it permits transport of any load unlimited distances and with minimum G-loads.

The water transport means usually are used to deliver stages of especially powerful booster rockets. The advantages of water transportation are small G-loads, the possibility of transporting rocket stages of large mass (more than 150 tons), and the deficiency is low speed of movement.

Water transportation is widely used in the United States, which is explained by the location of many of the manufacturing plants and the space centers along the Atlantic and Pacific coasts and on large rivers. Self-propelled and towed barges, river and maritime ships, floating docks and special floating platforms are used for water transportation (Fig 4.9).

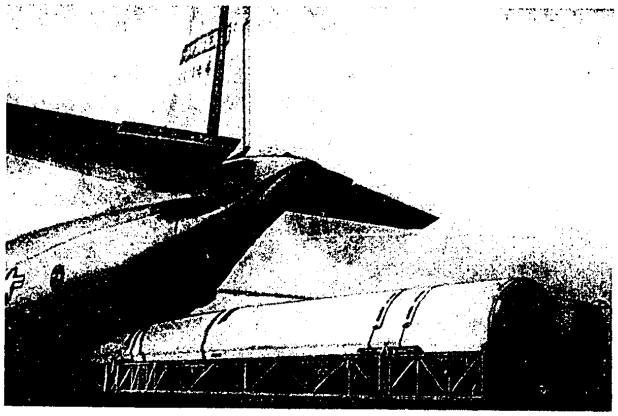

Figure 4.7. Loading a rocket on an aircraft

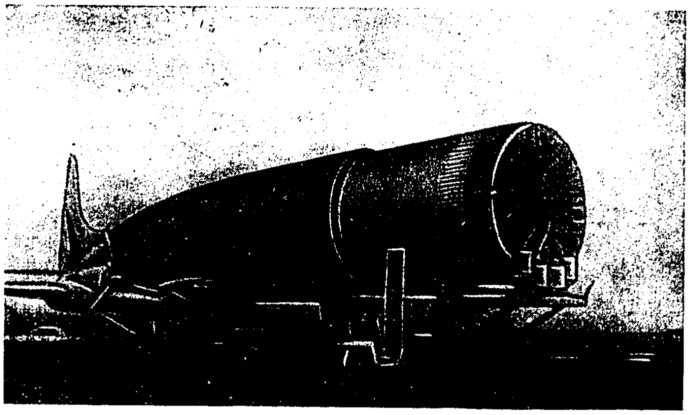

Figure 4.8. Unloading the S-IVB stage of the "Saturn-I" rocket from an aircraft

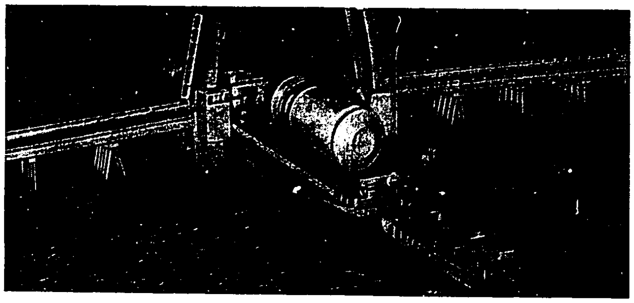

Figure 4.9. Transporting a rocket stage by water

4.2. Transport Equipment

Ground and rail transport means are used to transport space rocket systems and their elements between individual structures of the cosmodrome.

With respect to structural design the ground means (Fig 4.10) are analogous to the transport units for delivering the elements of the space rocket systems to the cosmodrome. Some of the dollies are also used to erect the space rocket systems to the vertical positon; in this case they perform the functions of lifting-erecting units and are called erector dollies.

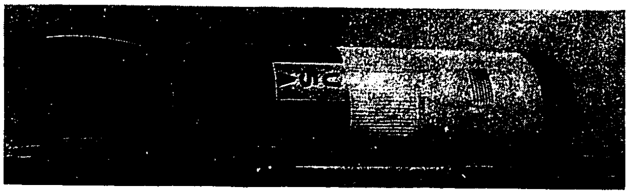

Figure 4.10. Ground carriers for delivering the S-I stage of the "Saturn-V" booster rocket

The railroad transport means can be in the form of dollies on standard railroad flat cars, carriers with lowered cargo platform, erector dollies, carriers for vertical transport of the rocket system, and so on.

Thus, the railroad carrier for transporting the "Titan-IIIC" booster rocket in the vertical position has four chassis with autonomous drives, a control mechanism and electric power cables, and it can move with a speed up to 8 km/hr over a double-track path 8.4 meters wide using two diesel electric locomotives with a single control system. Each chassis of the carrier is made up of four dual-axle dollies joined together by two cross members and a basic frame.

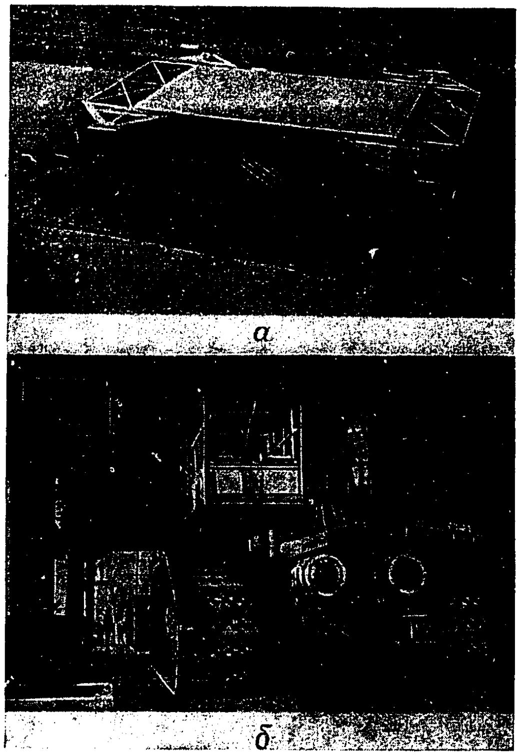

Figure 4.11. Self-propelled caterpillar carrier for the "Saturn-V-Apollo" space rocket system:
a -- general view; b -- at the launch site (the supports of the launch system can be seen on the left)

The self-propelled caterpillar carrier (Fig 4.11) is used to transport the transport-launch platform with the "Saturn-V-Apollo" rocket system and the service cable tower located on it to the launch stand. It is also used to deliver the movable service tower to the stand and return it to the site where it is kept between launches.

The carrier is a girder structure 40 meters long, 34.7 meters wide and weighing 2700 tons mounted on hydraulic jacks with four paired caterpillar dollies, and it has a carrying capacity of about 5500 tons. The power supply for the electric motors of the caterpillar dollies comes from diesel generators installed on the frame.

The maximum speed of the unloaded carrier is 3.2 km/hr, loaded it is 1.6 km/hr in the horizontal section of the track and 0.8 km/hr in the section with a slope of up to 5°. The stabilization system insures accuracy of horizontal positioning of the launch platform of ±5'.

On arrival at the launch complex the platform with the rocket system and the service cable tower is moved by hydraulic jacks from the carrier to the supports of the launch stand. The movable service tower is moved analogously.

4.3. Lifting-Erecting Equipment

The lifting-erecting equipment is designed to erect the space rocket systems to vertical position on the launching structure and for removal of them in case of an aborted launch and also (in some cases) for transporting the space rocket system to the launch site, assembly and servicing during preparation of it for launch.

Different lifting and erecting equipment with respect to structural design is used at the launch complexes. This equipment includes various special machines which, depending on their purpose, are called transport-erection units or erectors.

The transport-erection unit (the gun mount type erector) is designed to transport the fully assembled space rocket system to the launch complex and erect it to a vertical position. Such units can be made with railroad, wheeled and caterpillar running gear.

The railroad erector for the "Soyuz" space rocket system (see Fig 4.12) is made up of the base frame with railroad trucks; the side arms or wings of the frame with the self-propelled mechanism for winding the erector, hydraulic supports for suspension and horizontal leveling of the forward part of the erector and the control cab; the booms with logements and fasteners; the hydraulic mechanism for raising the boom to the vertical position mounted on them.

By using a diesel locomotive, the erector with the space rocket system is transported from the engineering complex to the launch complex. At 20 to 30 meters from the launch system the transport train is halted, uncoupled and the diesel locomotive is moved aside, after which the mechanism for moving at low speed is used to bring the erector up to the launch system. The hydraulic supports attached to the "wings" of the frame are moved from the transport position to the working position 1.5 meters before halting the erector, and they are lowered on the supporting brackets of the launch structure.

The erector boom with the rocket system is suspended above the launch system and, lowering or raising the hydraulic supports and the hydraulic cylinders of the boom lift mechanism, regulating the turn buckles (moving the erector forward or backward), the axis of the space rocket system is lined up with the axis of the launching system. Then the trusses of the launching system are brought up to the rocket system and, lowering the erector with the help of the hydraulic supports, it is suspended on the structural elements on the trusses. Then the boom of the erector is lowered to the horizontal position, first releasing the cantilevered tail

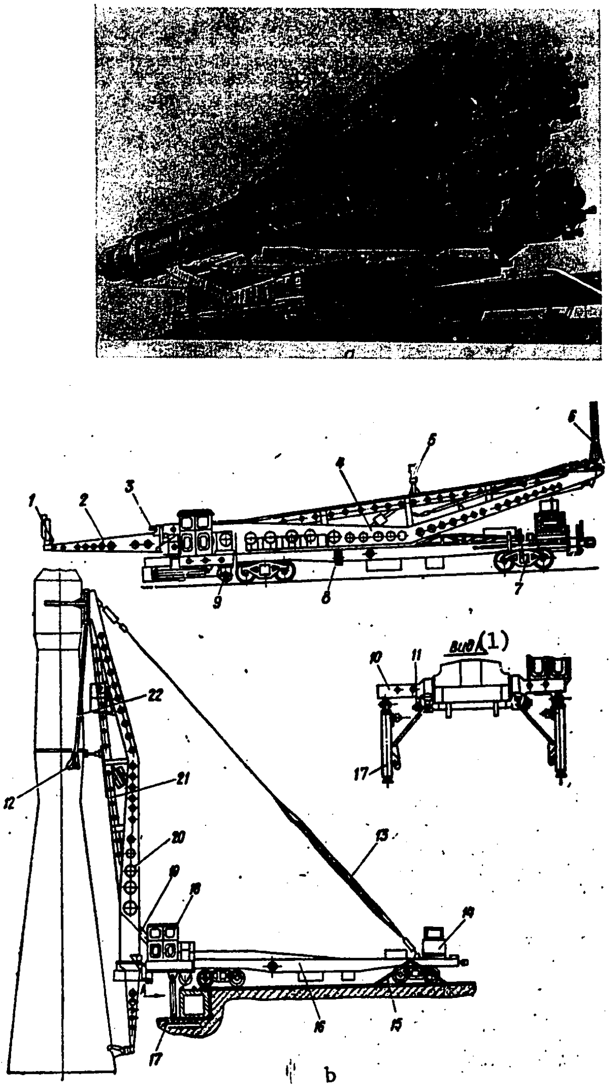

Figure 4.12. Gun mount type erector:
a -- general view; b -- diagram; 1 -- lower logement; 2 -- folding arm of the boom; 3 -- arm lock; 4 -- boom; 5 -- calibrated support; 6 -- upper grapple; 7 -- truck; 8 -- cable coil; 9 -- winding mechanism; 10 -- "wing" of the frame; 11 -- tension bolt; 12 -- suspension shackle; 13 -- guy; 14 -- pump; 15 -- fastening rod; 16 -- frame; 17 -- hydraulic support; 18 -- control cab; 19 -- hydraulic cylinder for raising the boom; 20 -- shackle; 21 -- boom tie rod; 22 -- suspension rod

Key: 1. A view

section of the boom which is fastened in hinges and the erector is taken out of the launch system.

The gun mount type erectors have their origin in the birth of rocket engineering; their structural design has been developed, and they are reliable in operation. The relatively small dimensions (determined by the diameter and length of the rocket system) and light weight (exceeding the weight of the rocket system by a total of 2 or 3 times) of these erectors has insured them quite broad application in rocket engineering.

The stationary and semistationary erectors are placed near the launch system.

The stationary erectors with lifting truss (Fig 4.13) are designed for assembling the rocket system on the truss in the horizontal position and subsequent installation of the assembled rocket system together with the truss in an inclined position. The "Scout" rocket system is installed on the launch complexes of the Western Test Area and the test area at Wallops Island by this system.

The stationary erectors with lifting service tower are used to erect the transport dolly together with the rocket stage to the vertical position. The first stage of the "Titan-II" booster rocket is lifted to the vertical position by this scheme on the launch complex No 19 of the Eastern Test Area.

The semistationary erectors with lifting frame of the transport unit (Fig 4.14) are used to erect the rocket to the vertical position with the help of the hydraulic lifter of the frame of the transport-erection dolly. The frame of the dolly is hinged with the launching pad.

The semistationary erectors with lifting platform provide for erection of the space rocket system to the vertical position using a boom and the railroad transport-erector dolly. The boom of the erector has the form of a platform with rails, and it is located at the launching site so that the railroad transport-erection dolly can be rolled on the platform. The dolly is made up of the running gear, frame, supports and fasteners, a remote mechanism for opening the fastening clamps to release the rocket system after it is installed in the launch system.

The stationary erectors have the same advantages as the erectors with the gun mount type lifting boom. In addition, it is possible to consider among their advantages the possibility of automating the process of installing the rocket system on the launch system and short installation time.

Some of the service towers (Fig 4.15) placed at the launch complex near the launch system are equipped with cranes with a set of attachments for assembling the rocket system by parts. The application of the cranes permits the rocket system or its stage to be moved from the horizontal position to the vertical position by simple technical means, but it significantly increases the duration and labor consumption of the operations required to assemble the rocket system.

This system is used on the launch complexes No 34 and 37 of the Kennedy Space Center when assembling the "Saturn-IB" rocket with the space vehicles.

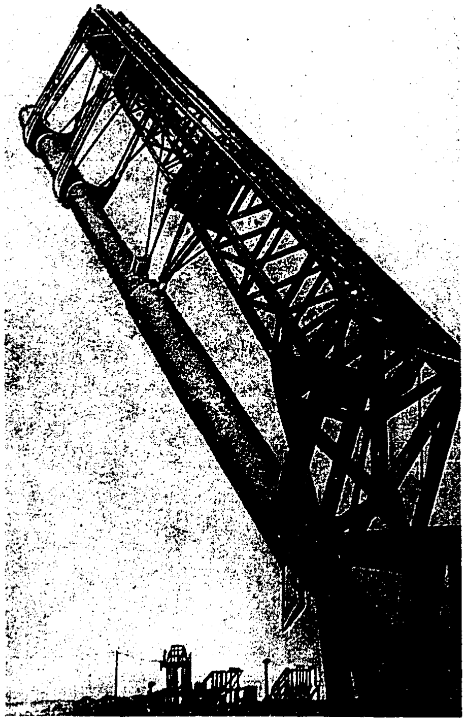

Figure 4.13. Stationary erector with clamping of the rocket at the top (for the "Scout" booster rocket)

4.4. Launch Systems

The launch system which provides for the acceptance, erection, verticalization and launching of the rocket is also used to bring various lines to the rocket system, service it, rotate it and provide azimuthal guidance, and it is the base on which the service cable tower, the cable masts, the supports of the erector and other equipment are mounted. Some of the launch systems can provide for transportation of the space rocket systems and erection of it to the launch position.

Therefore, the launch system not only depends on the structural design of the other units coupled to it, but directly influences their structure. The structural design of the launch system is determined by its primary function -- support of the launch -- and it is developed considering the class of rocket, its power system and the gas dynamic characteristics of the engine.

Beginning with the power system of the space rocket the launch systems can be built to support the space rocket on the end and with suspension on the supporting elements; the most widespread are the launching systems of the first type. In order to hold the rocket against wind loads, fastening assemblies are provided on the launching pad (levers, clamps and locks).

When the rocket is launched, the gas jet is deflected by the gas deflectors. The distance from the engine nozzles to the gas deflector and the angle of encounter of the jet with the deflector walls determine the structural design of the deflector, the dimensions of the launch system with respect to height and the depth of the gas removal channels for the semiburied type of launch structure. The spacing and the angle are selected beginning with the admissible temperatures and escape velocity of the gas jet which can cause erosion of the deflector and also considering a decrease in the possibility of the formation of reflected waves (the so-called bottom effect phenomenon) which can destroy the tail section of the rocket.

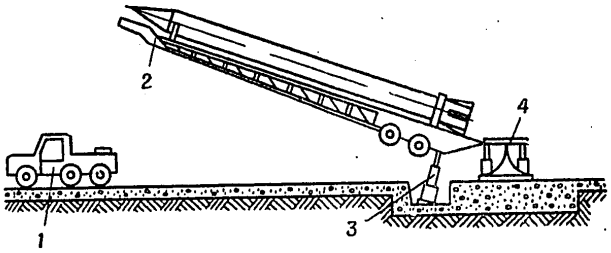

Figure 4.14. Semistationary erector with lifting frame of the transport unit:
1 -- tractor; 2 -- frame of the transport dolly; 3 -- hydraulic lift; 4 -- launching pad

With respect to structural design the gas deflectors are pure metal, wedge shaped and trough. The pyramidal deflectors usually have a number of faces equal to or a multiple of the number of combustion chambers of the rocket engines. In this case the gas jet either freely flows over the launch site or is removed along several gas removal channels. In the case of the wedge gas deflector the jet is split into two parts and is removed to the side; in the case of the trough deflector, it is removed in one direction.

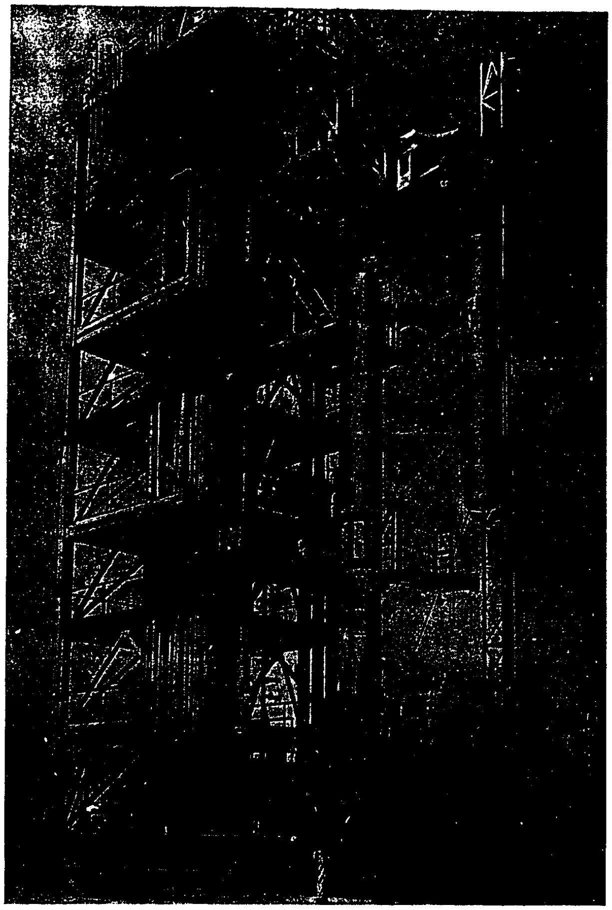

Figure 4.15. Assembly of the booster rocket stages using a service tower crane

The launching pads (Fig 4.16) for launching the light class rockets are made in the form of a frame installed on several supports (from 3 to 6) in which the lifts for moving the frame during acceptance and verticalization of the rocket are mounted. The lift mechanisms have hydraulic (hydraulic jacks) or mechanical (screw type jacks) drive. The gas deflector is located between the supports of the bench; sometimes the supports are protected by fairings.

On the upper section of the frame for erecting the rocket there are supporting elements, the number and structural design of which depend on the supporting elements of the rocket, wind and storm fastenings and also the attachments for fastening the electric plugs, the pneumatic blocks, the fill and drain connections. The rotating section is made in the form of a frame on a ball race and a rotary mechanism (toothing mounted on the rotating frame and reduction gear with drive).

The launching pad is fastened to the foundation of the launch site using anchor bolts or other elements. It can be dismantled and transferred to another launch site.

The stationary launching pad (Fig 4.17) is a quadratic reinforced concrete structure on supports with a hole in the upper plate and a wedge shaped gas deflector. The rocket is installed on the pad using its supporting elements.

The launch platform (the upper part of the launch system) for the "Saturn-V-Apollo" rocket system has a two-level structural design with a platform 7.6 meters high, 48.8 meters long and 41.1 meters wide with a hole in the center (13.7x13.7 meters) for the gases to pass through. A service cable tower is mounted on the platform (Fig 4.18) along with four grapples which hold the rocket system and three service cable masts. The platform is equipped with fastening mechanisms to the caterpillar carrier and to six supports and four telescopic columns of the launch stand.

In the compartments of the platform and on the upper plate electrical and mechanical plugs are installed which provide for connecting the booster rocket systems to the corresponding equipment in the vertical assembly building and on the launch stand and also the launch and testing electrical equipment, the equipment for testing the hydraulic systems, the fueling and pneumatic lines, the ventilators, air conditioners, and so on. The floor of the compartments is equipped with shock absorbers, and part of the equipment is mounted on springs. The compartments with electronic equipment have sound insulation, which reduces the noise level when the rocket engines are operating.

The launch system with removable trusses (Fig 4.19) is designed for the booster rockets that do not have supporting elements on the end and are auspended from the supporting assemblies on the central module at the point of fastening the side modules (for example, the "Soyuz" booster rocket). The launch system is in the form of four supporting trusses on which the booster rocket is hung and which are withdrawn under the effect of counterweights after thrust is developed; in the lower section the system has guides for the movement of the space rocket system in the initial part of liftoff.

The trusses and guides are fastened to the platform providing for verticalization of the rocket system using the hydraulic system located in the base of the supporting trusses. In the upper part of the platform there are service trusses, a service cable mast and cable mast for bringing the fueling and electrical lines to the rocket system.

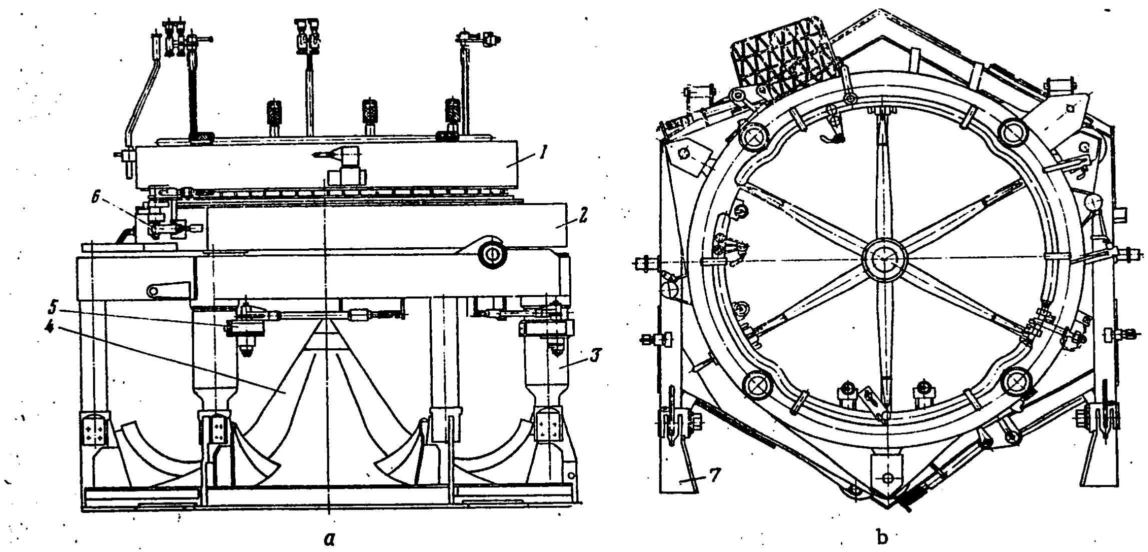

Figure 4.16. Launching pad (portable):
a -- side view; b -- top view; 1 -- rotary section; 2 -- lift section; 3 -- jack; 4 -- deflector; 5 -- lift mechanism; 6 -- rotating mechanism; 7 -- guides.

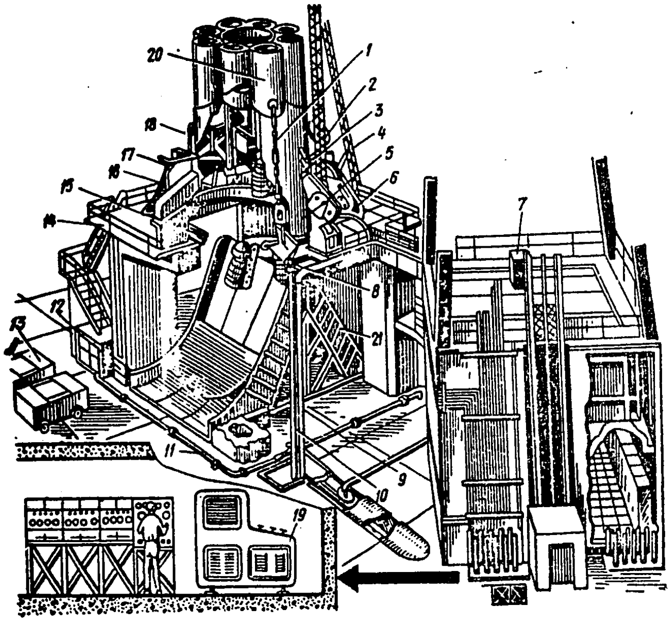

Figure 4.17. Launching pad (stationary):
1,18 -- service masts; 2,4 -- cable mast; 3,7 -- heaters; 5,16 -- supporting structures of the rocket; 6 -- valves; 8,9,10 -- fill lines; 11 -- water supply line; 12 -- hydraulic system control panel; 13 -- dollies with equipment for servicing the engine; 14 -- service platform; 15 -- electric cables; 17 -- shield with instruments for detecting leaks; 19 -- control panel of the engine service system; 20 -- tail section of the rocket; 21 -- gas deflector.

The launch system is mounted in the launch structure of semiburied type. The tail section of the booster rocket is below the "zero" level in this case.

A single-slope gas deflector and the trough type gas moving channel are used to remove the gases.

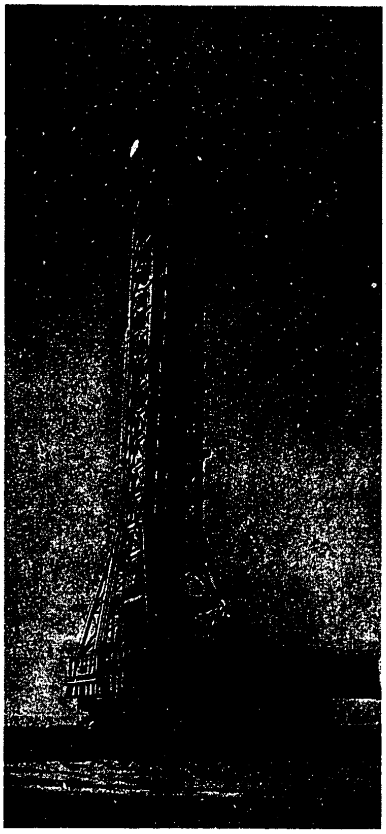

Figure 4.18. Launch platform (upper part of the launch system) for the "Saturn-V-Apollo" rocket system with service cable tower

4.5. Service Means

The service means include the tower trucks, trusses, towers and service cabs, the service cable towers (masts) and the cable masts.

The tower trucks (Fig 4.20 and 4.21) are used to service the light and medium class rockets; they are usually towers mounted on a truck chassis and have a drive to life the service platform with power takeoff from the truck engine or from an outside current source.

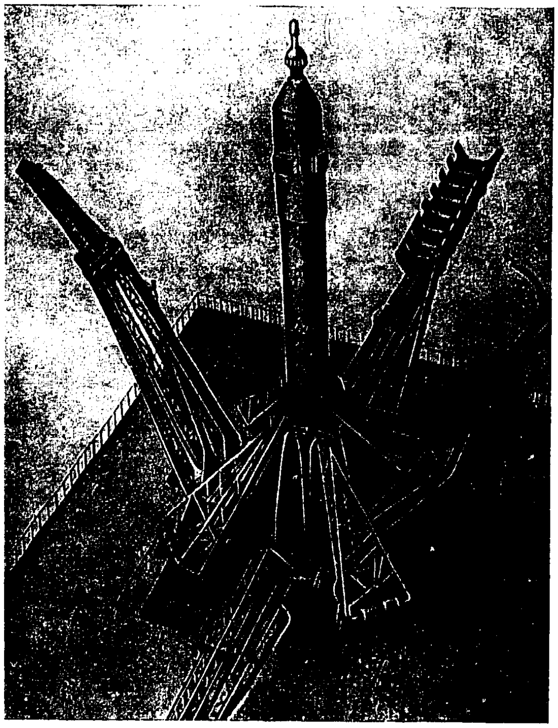

Figure 4.19. Launch system for the "Soyuz" booster rocket

The basic deficiencies of the tower trucks -- limited service height and low load capacity -- force them to be used primarily for auxiliary purposes.

The service trusses (Fig 4.22) are designed to service the heavy class rocket systems. They encompass the rocket systems on both sides, they have telescopic, folding and stationary platforms with enclosures and ladders.

Each service truss is made up of a bearing structure, the supporting assembly, the hydraulic system and control panel. The hoist runs through all of the service platforms along one of the trusses. There are hinged lever mechanisms for folding the service platforms on the bearing structure of the trusses when they are lowered to the horizontal position. The trusses can be mounted on the rotary of the launch system and rotated in the azimuthal plane together with the rocket system.

Before launching the rocket system the trusses are moved from vertical to horizontal position.

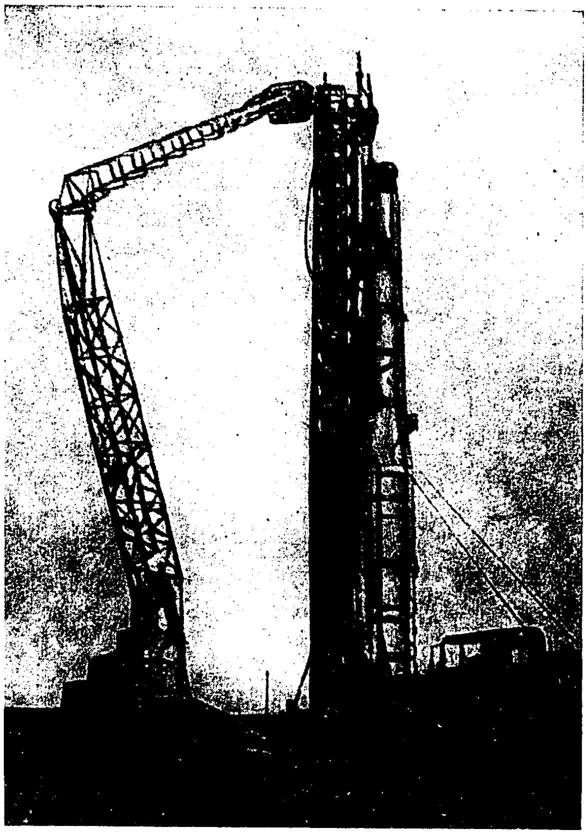

Figure 4.20. Arm type tower truck

The service towers are used for the same purposes as the service trusses, and they can be both movable and stationary.

The movable towers can be moved on railroads (up to 30 meters wide) a distance insuring their safety during launch or during an emergency with the rocket system.

The rotating towers (Fig 4.23) are used to service the rocket system in one plane. Before launch these towers are rotated along a ring rail around the central support at an angle insuring their safety.

The stationary service towers are autonomous units with an electric power plant, an air conditioning system, ventilation, lighting network, heating and communications. Their height reaches 100 meters, and they weigh up to 3,500 tons. Electrical, pneumatic, fill and drain lines with filling connections and also the thermostating system lines are laid on the service towers.

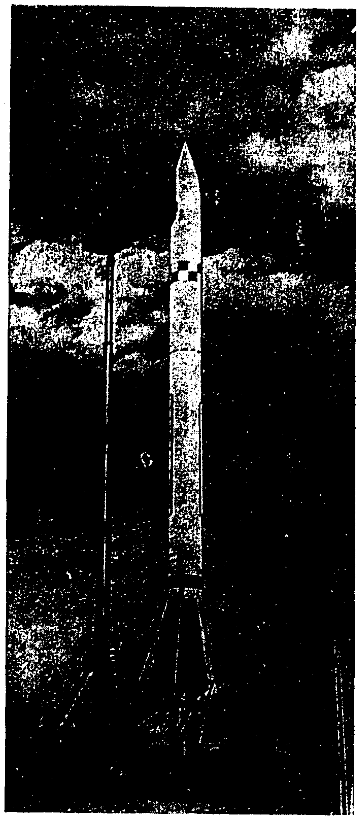

Figure 4.21. Telescopic type tower truck

The movable tower for the "Saturn-V-Apollo" space rocket system (the so-called mobile service tower) of the launch complex No 39 (Fig 4.24) is designed to service the compartments of the booster rocket and the "Apollo" spacecraft and install explosive hazardous equipment (the solid-propellant braking rocket engine, the engines of the emergency rescue system, pyrotechnical devices, and so on). The tower is a welded metal structure 122 meters high and it has a square base 41 meters on a side. A rotating 4-ton crane is installed on the upper platform of the tower. The tower has five trusses used as service platforms and supports for the pneumatic, hydraulic, electrical and other lines. The two lower platforms move freely along the vertical; the three upper platforms are rigidly attached, but the entire truss-platform unit can be installed at different levels depending on the service zones of the booster rocket and the space vehicle; the upper and the two lower platforms are open, the two middle platforms are covered on all sides, and they have an air conditioning system.

The tower is delivered to the launch stand by a caterpillar carrier; then it is lowered to the supports of the launch site prepared for it, and before long it is withdrawn to the parking area (approximately 2 km from the launch stand).

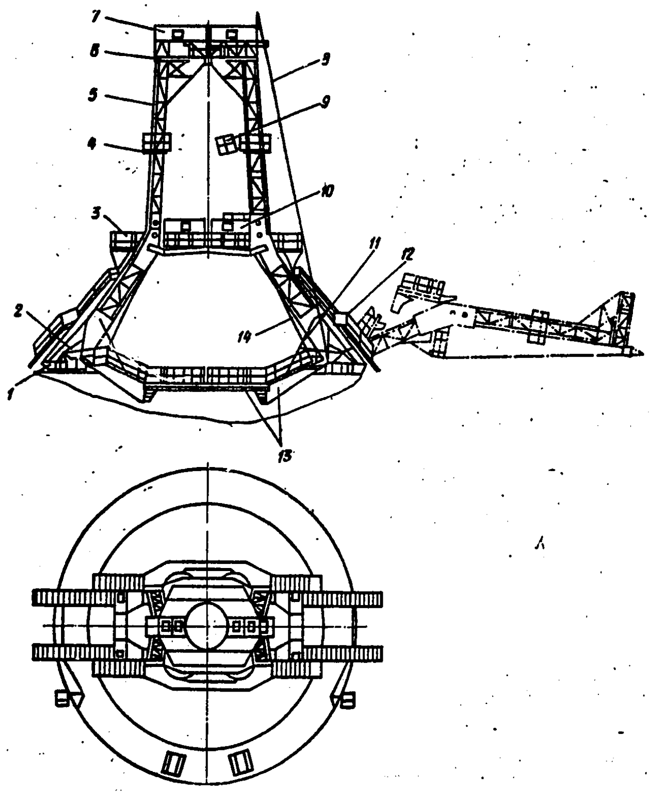

Figure 4.22. Service truss:
1 -- truss support; 2 -- hydraulic cylinder for raising the truss; 3 -- middle platform; 4 -- intermediate platform; 5 -- bearing structure of the truss; 6 -- upper platform; 7, 10 -- wind shield; 8 -- cable of the cargo hoist; 9 -- transfer platform; 11 -- hinged arm mechanism for folding the lower platform on the truss; 12 -- ladders and gangways; 13 -- lower platform; 14 -- pull rod of the hinged arm mechanism for folding the middle platform on the truss.

The service cabs (Fig 4.25) are designed to service the lower buried part of the rocket installed on the launch system and also the necks of the fill collector of the launch structure.

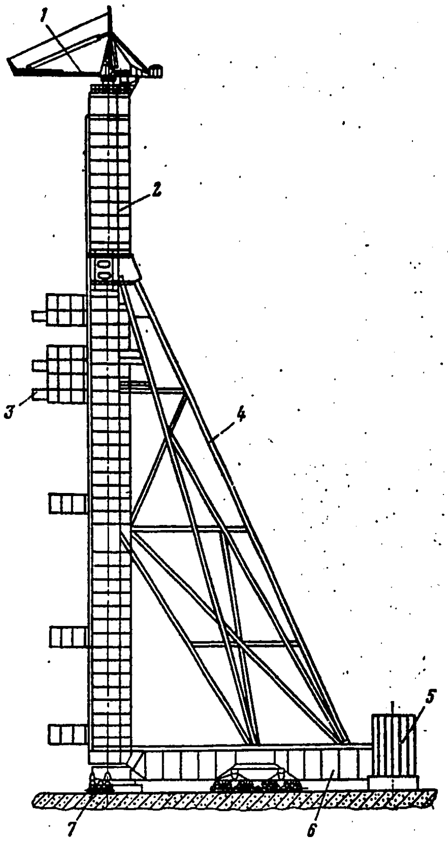

Figure 4.23. Rotary type tower:
1 -- crane; 2 -- tower trunk; 3 -- telescopic support; 4 -- braces; 5 -- central support; 6 -- supporting frame; 7 -- rollers.

Before launching the rocket system, the cab is brought to the bottom of the launch structure along the suspension rail and it is protected by a heat shield in the engine gas jet.

The service cable towers (masts) and cable masts are used to bring the electrical, fill, drainage and pneumatic lines to the rocket system. They have different dimensions (height to 100 meters and weight to several hundreds of tons), and they can be stationary or removable (withdrawable).

The stationary towers are mounted on the launch system or beside it; such towers have trusses (platforms) which are withdrawn to a safe distance before or at the time of launch.

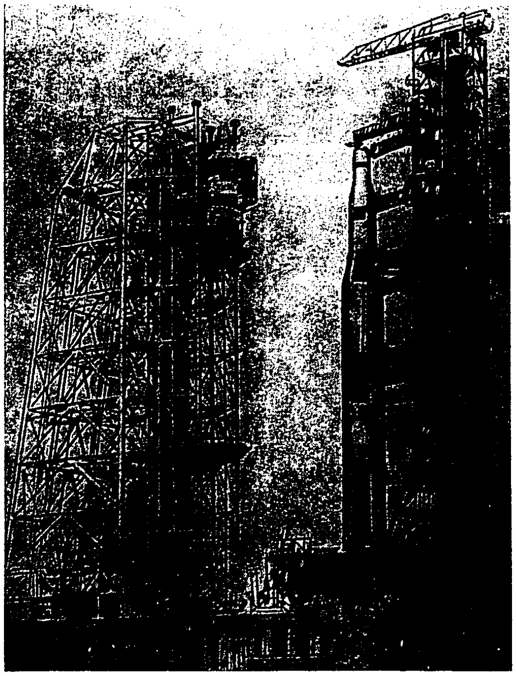

Figure 4.24. Service tower of the "Saturn-V-Apollo" space rocket system

The withdrawable service cable mast (Fig 4.26) or cable masts usually are installed on hinges on the launch system, and at launch time they are withdrawn to the required angle, using a counterweight or pneumatic (spring) drive; the kinetic energy during withdrawal is extinguished by a hydraulic shock absorber.

If the communications lines with the rocket are coupled to the installation and test facility (the vertical assembly building), the service cable towers or cable masts are transported to the launch position jointly with the rocket system.

The stationary cable mast (Fig 4.27) is a structure through which the cables are run to the upper stage of the rocket. At launch time, the plugs are unplugged, and their ground sections together with the cables are dropped from the rocket under their own weight.

The service tower cable for the "Saturn-V-Apollo" space rocket system (Fig 4.28) is mounted on the upper part of the launch platform and together with the rocket system is delivered to the launch complex by the caterpillar carrier.

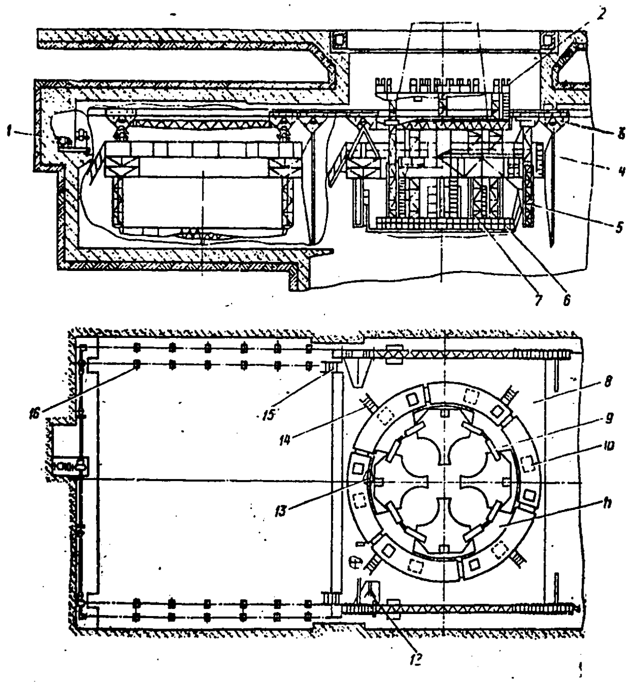

Figure 4.25. Service cab:
1 -- drive for the displacement mechanism; 2 -- central pads; 3 -- carriages of the displacement mechanism; 4 -- heat shield; 5 -- telescopic bisectional columns; 6 -- telescopic trisectional columns; 7 -- hydraulic cylinder; 8 -- platform; 9 -- telescopic bridge; 10 -- ring platform; 11 -- rotary disc; 12 -- control panel; 13 -- mechanism for turning the disc; 14 -- emergency ladder; 15 -- gangway; 16 -- chain drive

The tower is a steel truss 116 meters high through which the fuel and pneumatic lines, electrical and television cables, telephone lines, water lines and other lines are run. The tower has nine folding arms; eight fueling units are connected to five of them. A "clean chamber" with conditioned air is mounted on the upper arm. It is coupled to the hatch of the command compartment of the spacecraft and provides for entry and exit of the astronauts. The feed lines made up of rigid or flexible lines are joined through the crossovers to the lines laid in the tower, and they have plugs connected to the fueling units of the booster rocket. The service tower is equipped with 17 work platforms; all of the platforms are are connected by two high-speed lifts which were used for emergency exit from the spacecraft in case of an emergency and delivery of the crew to the fast-exit chute of the launch structure which begins at the launch platform.

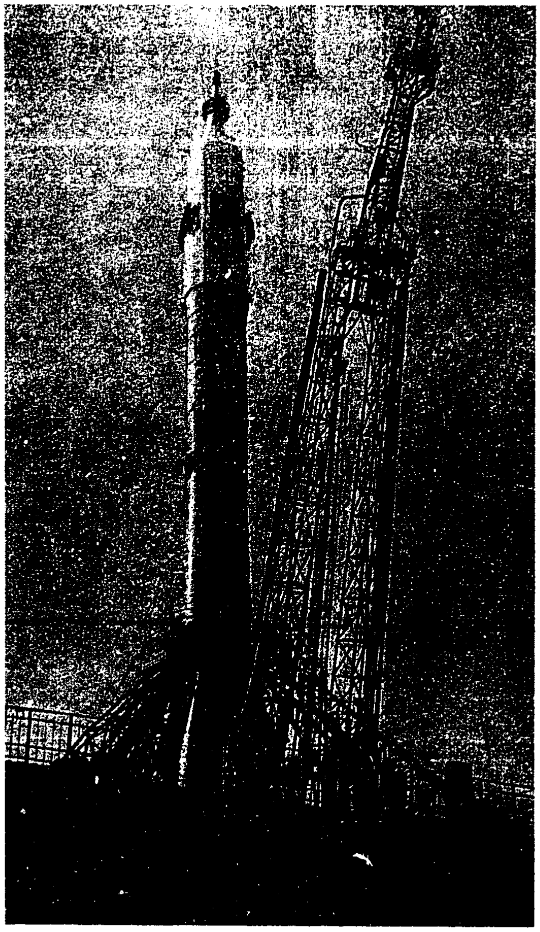

Figure 4.26. Service cable mast for the "Soyuz" space rocket system

A rotary arm drane with a capacity of 22.5 tons is installed on the tower. It can be controlled from any platform using a portable control panel.

4.6. Electrical Equipment

With respect to amount of intake electric power it is possible to compare the cosmodrome with a large modern plant equipped with complex highly automated systems and units. The electric power users at the cosmodrome are the electric drives of the trusses and service platforms, the electric motors of the elevators and hoists, the electric pumps of the servicing systems, the pneumatic pumps and ejectors, electric heating and air conditioning systems. All of them require 380/220 volt, 50-cycle 3-phase alternating current to power them. The sources of this electric power are called primary current sources. At the cosmodrome there are other electric power users which require special forms of current and voltage for their power supply. These include the technological operations control systems, the measurements and functional monitoring systems, the guidance system, and so on. The special forms of currents are required also by the on-board equipment which is powered from ground power supplies during preparation of the booster and spacecraft for launch. The power supply for the on-board equipment comes from special currents, and their sources are called secondary current sources. The secondary current sources are combined into the so-called special currents ground electrical supply system (SNEST) which generates alternating and direct current of different voltages and frequency. It must be noted that in the measurement and control systems, secondary electric power supplies can also be used as individual feed modules.

Figure 4.27. Cable mast at launch time

Since the launch time of the space rocket system usually is strictly regulated, interruptions in the electric power supply can lead to postponement of the launch to a given time and sometimes to more serious consequences, emergencies. This is why special attention is given to the problems of reliability and quality of the electric power supply.

The high reliability of supplying electric power is achieved by the following:

The application of highly reliable elements and assemblies of the systems;

Duplication of the primary and secondary electric power sources and cable couplings, the application of ring systems, and so on;

Clear organization of the work and high qualifications of the service personnel.

The sources of ground supply with electric power are divided into the primary ones which include the industrial power systems, diesel electric power plants and chemical current sources and the secondary ones, that is, the devices that convert the electric power of the primary 380/200 volt, 50 hertz current sources to currents and voltages necessary to power the ground and on-board automatic control and measurement systems.

The direct current converters (unstabilized and stabilized), the mechanical AC converters and static AC converters with increased frequency are used as secondary electric power sources.

The system for supplying the cosmodrome and the rocket system with electric power is presented in Fig 4.29.

The industrial power systems are the basic source of the electric power supply on which the requirements of increased reliability and maintenance of high voltage stability are imposed.

The electric power is fed to the launch complex through a step-transformer (see Fig 4.29), after which it goes through special entrance shields to the users and to the secondary power supply sources in the form of a three-phase, 380/200 volt, 50 hertz alternating current.

The diesel electric power plants (DES) are, as a rule, a reserve (redundant) source which provides electric power when the basic electric power transmission lines fail. A diesel generator is used as the source of electric power in the diesel electric power plants, the power of which also determines the power of the plant itself. The continuous operating time for the diesel electric power plants is not regulated, and it depends on the amount of fuel, that is, the capacity of the fuel tanks.

Usually automated diesel electric power plants are used which are automatically started when the power is shut down from the industrial sources and are capable of operating for a prolonged period of time without service personnel.

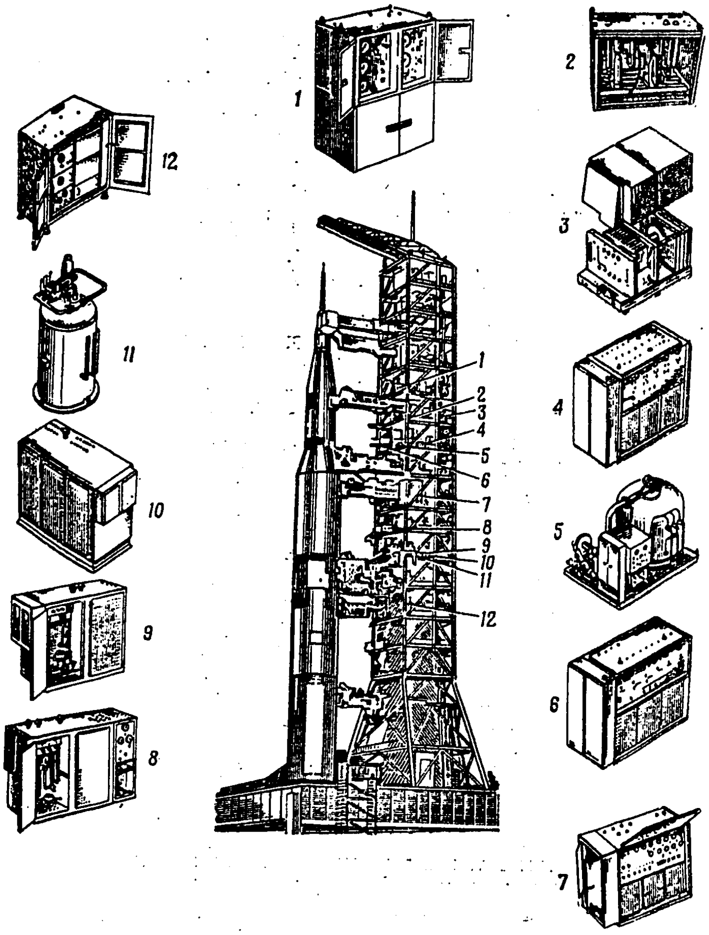

Figure 4.28. Cable service tower for the Saturn-V Apollo Rocket System

1--control module for the pneumatic system of the equipment module; 2--module switch; 3--cooling module for the equipment module; 4--control units for the pneumatic systems of the main engine of the third stage; 5--cooled gas (helium and hydrogen) feed module for blowing the third stage tanks, cooling the main engine jacket and filling the tank for whirling the turbine; 6--control module; 7--control module for the pneumatic systems of the auxiliary third stage engines; 8,9,10--control module for the pneumatic system of the second stage engine; 11--gas (hydrogen) feed module for blowing the second stage tank and cooling the engine jacket; 12--control module for the pneumatic system of the first stage engine.

The diesel electric plants are equipped with units to maintain the normal operating conditions, for protection, starting and stopping, emergency warning signals and also a system for automatic monitoring and control of the current frequency and voltage, the water and oil temperature and charging the storage batteries. In addition, manual remote control is provided which provides for starting and shutting down the diesel electric power plants, switching the generator on and off, reclosure after the response of the protection and elimination of the failure.

The diesel electric power plants can be portable, placed in the beds of trucks or on railroad cars and stationary, located in the cosmodrome structures.

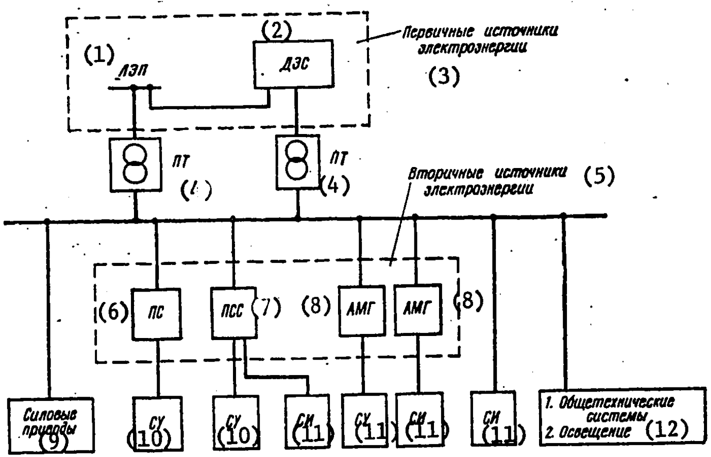

Figure 4.29. System for supplying the cosmodrome and the space rocket complex with electric power

Key:

1. electric power transmission lines
2. diesel electric power plant
3. primary sources of electric power
4. transformer substation
5. secondary electric power sources
6. unstabilized DC converter
7. stabilized DC converter
8. mechanical type AC converter
9. power drive
10. technological process operations control system
11. measurement system
12. 1. general engineering systems
    2. lighting

The chemical current sources provide direct current with a voltage of 30 and 6 volts to the measuring control systems and also the emergency lighting system, and they are used in the stationary automatic monitoring control units, in the portable lighting units and as a current source in "ready reserve"[1] for the case of failure of the basic source, for which the so-called "buffered" inclusion is practiced.

Inasmuch as the requirements of fire and explosion safety are imposed on the measurement and control systems in a number of cases, it is possible to use dry chemical current sources (dry cells) which have high internal resistance and low power. This permits insurance of operating safety of the systems, for in the case of the appearance of a failure, the magnitude of the current is limited by the internal resistance of the source. However, the small continuous operating time, the dependence of the parameters on the ambient temperature, the comparatively high cost complicate and limit the use of the chemical current sources. In recent times the DC rectifiers based on semiconductor elements have been most widely used.

The ground electric power supply system for special current (SNEST) includes the unstabilized DC converters (PS), stabilized DC converters (PSS), mechanical type AC converters (AMG), the current distribution unit (TRU), remote control panels (PDU), power distribution boxes (RSK) and a cable network.

The unstabilized static DC converters are designed to supply direct current to the systems and individual measurement and control instruments when highly stable voltage and increased reliability are not required. The voltage at the output of such a converter depends on the fluctuations and variations of the input AC voltage and the mode current.

The stabilized static DC converters will permit us to obtain a DC voltage at the output with deviations from the rated by no more than ±3%, and in the best cases, less than ±1%.

The mechanical type converters or electromechanical converters are electrical machines which convert one type of current to another, with different voltage, frequency, and so on. Depending on the purpose, they are divided into DC-AC converters (which convert alternating current to direct current or vice versa), DC converters (which convert the DC voltage), frequency converters, and so on.

The current distributing devices in the ground electric power supply systems to supply specialized currents play the role of the power commutators of

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[1] "Ready reserve" is the method of reserving or redundancy in which failure of the basic source of power does not lead to interruption of the power to the users, whereas in other reserve techniques time is required to connect the reserve power supply.

the output buses, static stabilized converters. These devices are made in the form of individual bays of usually unitized construction in which contactors and current protection elements are placed (automatic network protection systems, fuses), terminals and oil seal entries for cables used to couple the current distributing devices (TRU) to the output feeders of the static stabilized converters and load and also intermediate relays for remote control of the contactors and the current and voltage quality control instruments on the output buses.

The remote control panels are designed for remote inclusion of static stabilized converters or connection and disconnection of their output feeders in the current distributing devices directly from the point of connection of the instruments -- the power users.

The distributing power boxes in the ground electric power systems for special currents are used as terminal units designed to connect users remote from the static converters.

For the SNEST cable network, usually two types of cables are used: flexible and stationary. The flexible cables with plugs are used to connect the individual instruments (panels, bays, converters) entering into the functionally independent equipment complexes located inside one facility. The stationary cables which are soldered to the terminals inside the instruments have armor protection and are designed for operation in unheated facilities.

CHAPTER 5. FUELING SYSTEMS

5.1. General Information

The fueling systems are designed to fill the rocket systems with fuel components and compressed gases.

The fuels can be divided into high-boiling and low-boiling, two-component and single-component fuels in accordance with their basic physical-chemical properties.

The high-boiling fuels are liquids with a boiling point above 298°K at atmospheric or somewhat increased pressure under operating conditions which, being put in the rocket tanks or in the ground system storage facilities can be stored for a long time under the indicated conditions in practice without losses.

The low-boiling fuels are liquids with a boiling point below 298°K under operating conditions; they include liquefied gases (liquid oxygen, fluorine, nitrogen, hydrogen, and so on) having so-called "cryogenic" (below 120°K) the boiling point, from which they have received the name cryogenic. Under ordinary operating conditions the cryogenic fluids put in the tanks without thermal insulation are intensely evaporated at the expense of the influx of heat from the environment and require the application of effective thermal insulation to decrease losses from evaporation.

The two-component fuels are the fuels, the thermal energy of which is formed as a result of oxidation of one component (the combustible) by the other (the oxidizing agent) in the combustion process in the engine chamber. The two-component liquid fuels can be self-igniting (if combustion begins when they mix) and nonself-igniting (if additional means are needed for combustion of them).

The single-component fuels are complex compounds capable of decomposing under defined conditions into simpler and more stable materials with the release of thermal energy. The single-component fuels are used for auxiliary purposes: light thrust engines (orientation and stabilization) of the space vehicles and the upper stages of the booster rockets, for turning the pump turbines, and so on.

The efficiency index of rocket fuels is the specific thrust -- the ratio of the thrust created by the engine to the fuel consumption per second; the fuel having greater heat value and lower molecular mass of the combustion products has greater specific thrust.

Another important characteristic of fuel is its density: the greater the density, the smaller the volume and, consequently, the mass of the rocket tanks. An increase in density of the added liquid fuel components is achieved by cooling them or introducing a heavy inert admixture. This procedure was proposed for the first time by Academician V. P. Glushko in 1933. Among the assimilated fuels, the two-component fuels are more widespread than single-component fuels, which is explained by their higher specific thrust.

The fuels must have high specific thrust, high density, safety in handling, the possibility of long-term storage both under ground and space conditions, low cost, and so on.

None of the existing liquid fuels fully satisfies all of the enumerated requirements; therefore in each specific case certain of their advantages and disadvantages are taken into account, which is one of the causes of the great variety of them.

In world practice, among the high-boiling oxidizing agents the most widespread is nitric acid, nitrogen tetroxide and nitric acid solutions with nitrogen tetroxide; of the low-boiling ones, liquid oxygen. Studies are being made with respect to the use of liquid fluorine, ozone and mixtures of them with oxygen, for they have better oxidizing properties than oxygen.

Among the high-boiling fuels broad use is made of kerosene, hydrazine and its derivatives (monomethylhydrazine and asymmetric dimethylhydrazine -- NDMG); among the low-boiling ones, liquid hydrogen. Hydrazine is usually used in mixtures with other materials (thus, the fuel "aerozin-50" which is widespread in the United States is made up of 50% by mass hydrazine and 50% by mass dimethylhydrazine). At the present time studies are being made of the use of pentaborane.

The bicomponent fuels (combustible and oxidant) usually are characterized by the oxidizing agents, for they are the basic part of the fuel, and their number is comparatively small. Thus, the fuels used at the present time with the oxidizing agent -- liquid oxygen -- insure the greatest specific thrust; such fuels as kerosene, dimethylhydrazine and liquid hydrogen are used with them. The "oxygen-kerosene" fuel is best assimilated in rocket engineering, it is cheap to produce and convenient in operation. This explains its application in the first stages of the American "Thor-Delta" booster rockets, the "Thor-Agena," "Atlas-Centaur," "Saturn-I," "Saturn-IB," "Saturn-V" and also the Soviet booster rockets. The oxygen and asymmetric dimethylhydrazine fuel has the greatest specific thrust for liquid-propellant rocket engines of the oxygen class operating on high-boiling fuel; it is used on the second stage of the Soviet "Kosmos" booster rocket.

The "oxygen-hydrogen" fuel has a specific thrust that is 30 to 40% higher than the other assimilated rocket fuels and, in addition, is ideal from the point of view of environmental protection, for the products of its combustion are water vapor. This fuel has been used in the upper stages of such booster rockets as "Atlas-Centaur" (third stage) and "Saturn-V" (second and third stages). With further development of rocket engineering hydrogen can find application also in the first stages of the large space rocket systems.

The fuels based on nitric acid and nitrogen tetroxide are significantly inferior with respect to specific thrust to the fuels based on oxygen. They are capable of prolonged storage, the duration of which depends to a significant degree on their corrosive activity; but they are toxic. Such fuels as kerosene, asymmetric dimethylhydrazine, and hydrazine are used with nitric acid. The last two form self-igniting fuels, and with nitrogen tetroxide the fuels "aerozin-50," dimethylhydrazine and monomethylhydrazine are used (all self-igniting). The possibility of prolonged storage without losses, high density and self-ignitability explain the broad application of these fuels in the multiple-action engines and in low-thrust engines (for stabilization, orientation, braking, taken from other planets, and so on) and also in the booster rockets created on the basis of the combat rockets where the basic requirement is insurance of prolonged storage of the booster rocket in the filled stage. For example, in the engines of the "Apollo" spacecraft fuel based in nitrogen tetroxide is used: the "nitric" acid and asymmetric dimethylhydrazine fuel in the last stage of the "Atlas-Agena" booster and the "Thor-Agena" booster, and the nitrogen tetroxide and aerozine-50 fuel is used for the "Titan-III" booster rockets.

Hydrogen peroxide in various concentrations, hydrazine and asymmetric dimethylhydrazine are used as single-component fuels. Thus, in the "Vostok" booster rocket the products of decomposition of hydrogen peroxide were used as the working medium for the turbopumps, in the upper stage of the "Atlas-Centaur" rocket it was used to operate the auxiliary engine and turn the booster fuel pump drives.

In space rockets for individual systems, cryogenic fluids are used (oxygen, nitrogen, hydrogen and helium). Electrochemical processes between gasified oxygen and hydrogen in the fuel elements of the electric power supply system provide electric power for the on-board equipment of the space vehicle; oxygen and nitrogen in the life support systems of the spacecraft compensate for losses of oxygen during breathing and restore the atmosphere of the spacecraft when performing operations in space or docking with other vehicles; liquid nitrogen, hydrogen and helium, and in some cases, solid hydrogen and nitrogen find application in cooling the infrared radiation receivers, quantum amplifiers, and so on.

The application of cryogenic liquid fuel components with reduced temperature with respect to saturation temperature and atmospheric pressure (the so-called supercooled or underheated liquid) has great advantages. Such a reduction in temperature in practice is possible in a wide range, to the formation of a mixture of solid and liquid phases (the so-called slush).

Slight supercooling of the fueled liquid permits a significant decrease in the vapor formation in the booster rocket tanks during fueling process and makes it possible to have on-board drain valves of smaller size.

Filling the tanks with deeply supercooled liquid increases the time the fueled booster rocket is ready to launch without losses, for the supercooled liquid must first be heated to the boiling point and only then does it begin to evaporate. As a result of an increase in density, such a liquid permits a decrease in volume and mass of the rocket tanks and an increase in the drainless storage time under space conditions. Here the maximum effect is achieved by conversion of the cryogenic liquid to the solid state although the cryogenic components of the fuel in the solid state are in practice not used. For use in the engines, the deeply supercooled liquids (to the ternary point) and also slush in the form of finely disperse flowable mix are convenient.

In addition to the liquid fuel components, the space rocket systems are filled with compressed gases which have such properties as simplicity of accumulation and capacity of energy conservation for a prolonged time in the state of being compressed to high pressure, safety (the nitrogen and helium) for operation in various media as a result of the inertness. These properties make it possible to use compressed gases as a source of energy for on-board equipment with pneumatic drive or a solid state in the tank blowing systems, various types of purging, and so on.

In the space rocket systems nitrogen and helium have come to be widely used as a result of fire and explosion safety with respect to the working environment and absence of condensation at low temperatures. In this respect compressed helium is the most all-purpose gase, then nitrogen which has limitations with respect to condensation at low temperatures.

Compressed air usually is used in systems that are fire and explosion safe with respect to gaseous oxygen.

Compressed gases are put in the open bottles (banks of bottles) of the corresponding on-board pneumatic systems. Often one bank of bottles provides the operation of several pneumatic systems (blowing the tanks and purging various engine elements). After filling and before launching the rocket, a constant makeup of the bottles and supply of the gases for operation of the on-board pneumatic system takes place in the pre-launch period; the on-board pneumatic systems are converted to compressed gas feed from the on-board bottles only directly before launch.

In some cases, in order to increase the density of the compressed helium that is put in the bottles and in order to decrease the weight of the pneumatic systems, the banks of bottles are placed in a container filled with cryogenic liquid. Thus, on the "Atlas-Centaur" rocket, the helium for blowing the fuel tank and purging the engine in the first stage is in the bank of bottles placed in a jacket with liquid nitrogen which is poured into the ground system directly before launching the rocket, and in the first stage of the "Saturn-V" rocket the helium for blowing the fuel tank is in four bottles (volume 0.88 m^3 each) installed inside the oxygen tank.

Depending on the type of on-board pneumatic systems, the on-board bottles are filled both at the filling station and at the launch complex. Before filling with compressed helium and nitrogen used for operation in fire and explosion-hazardous environments with respect to air or in working environments with low temperature, the on-board bottles are purged with the gas they are being filled with in order to remove the air to the admissible concentrations.

The schematics of the ground filling systems depend significantly on the structural design of the pneumatic hydraulic system of the rocket. From the point of view of filling, both systems -- on board and ground -- are parts of a united system capable of functioning normally only under the condition of close interrelation of its component elements.

Basically the structure and the pneumohydraulic system of the tanks in the filling section are determined by the physical-chemical properties of the components with which they are filled, the amount (batch) and method of obtaining the given batch in the tank.

The structural design of the tanks is essentially influenced by the temperature at which the fuel components are put in them. Thus, tanks for cryogenic fuel components have thermal insulation to protect the liquid with which they are being filled from evaporation at the launch complex and in outer space and also to protect against aerodynamic heating when flying through the atmosphere.

The presence of thermal insulation on the tanks filled with liquid fuel components (supercooled oxygen, hydrogen and so on) with a temperature equal to or less than the condensation point of air prevents condensation of the air on the walls of the tank and significantly decreases the evaporability.

Thus, for hydrogen tanks of the American booster rocket "Saturn-I," "Saturn-V" and "Atlas-Centaur" plastic foam insulation is used which is blown with uncondensed gas (helium) to prevent condensation of the air on the cold walls of the tanks. This blowing increases the thermal conductivity of the insulation, but under space conditions the helium volatilizes, and the effectiveness of the insulation increases sharply. The sampling of the helium for analysis after blowing permits monitoring of the seal of the tank and the line and the adoption of necessary measures to prevent emergencies. Thus, for example, the seal of the hydrogen tanks of the "Saturn-V" is controlled while they are being filled.

The hydrogen and oxygen tanks of the life support systems and power supply systems of the "Apollo" spacecraft have insulation with several reflecting shields placed in the vacuum space between the inside and outside walls of the tank. This insulation called the vacuum shielding is most effective for prolonged storage of cryogenic liquids under ground and space conditions although it causes some increase in mass of the tank as a result of the outside wall.

In the space rocket systems a multilayer shielded insulation with outside soft thermal cover of insignificant mass is used. In order to protect the insulation from the condensation of air on the cold walls and crushing of the insulating shields (which are made of thin film) by the outside pressure, the thermal cover is blown with uncondensed gas during the filling process. After the vehicle (the stage of the rocket) goes into space the cavity of the thermal seal is connected by opening special valves and diaphragms to outer space, and the insulation begins to function as a multilayer vacuum shield.

The tanks of the booster rockets for cryogenic liquids with a temperature above the condensation point of air usually are not insulated, although individual sections of a tank have local insulation to prevent the effect of low temperatures on the instruments and elements of the engines. Losses from evaporation in the tank after filling are compensated for by additional filling (makeup) of the component. During makeup, such tanks are covered with a layer of frost formed as a result of freezing of the moisture from the surrounding air; the layer of frost to some degree lowers the heat influx, playing the role of a type of insulation.

The filling with supercooled cryogenic liquids has its characteristic features consisting primarily in a decrease in pressure of the saturated vapor of the cryogenic liquid as it cools and secondly, in the formation of a significant thermal layer of filled cryogenic liquid along the height of the tank as a result of the heat accumulated by the structural elements of the tank and filling through the filling valve which is usually located below the tank. Therefore, in order to avoid implosion of the tank as a result of the rarefaction created in it and to keep atmospheric air out which is capable of destroying the composition of the liquid with which the tanks are filled, the tanks are filled with the safety drain valves closed at constant excess pressure of blowing by uncondensed gas. The temperature stratification which is undesirable for operation of the engine is eliminated by mixing the liquid during the filling process or after it. The liquid is mixed by passing uncondensed compressed gas through it (so-called bubbling) or feeding the liquid with which the tanks are filled from the top through special manifolds.

During filling with cryogenic liquids and in the subsequent period before launching the rocket, the danger of heating up and boiling the liquid arises in the intake lines of the engine which is usually located appreciably below the tank as a result of inflow of heat from the environment. This danger can lead to rupture of the lines. In order to prevent this, a circulating loop is used (tank-intake line-circulating line-tank) which operates as a result of natural convection, for elimination of which gaseous helium is fed to the circulating line.

When filling with toxic and self-igniting fuel components, their vapor is removed through split drain connections to a special ground neutralizing system. For safety the exit areas of the drain lines in the tanks are selected, as a rule, at diametrically opposite locations. Before filling with liquids (liquid hydrogen) that is fire and explosion hazardous with respect to air, the air environment of the tank is replaced by a neutral environment, and during the filling process, these vapors are removed through the pre-ignition or diluting systems to a safe concentration.

The fuel tanks of the space rocket systems, depending on the supplied dose, have a volume from tenths to several hundredths and thousandths of cubic meters. The small volume tanks which are used for auxiliary engines and are designed for quite high inside pressure permit evacuation of their inside cavity, which permits application of the simplest filling system (the fill line and tank) called drainless. In this case the filling process consists in preliminary evacuation of the tank in order to remove air from it and subsequent filling of it with a given amount of liquid. This fill system usually is applicable for high-boiling components.

When adding low-boiling components by the drainless system it is necessary first to cool the structural elements of the tank to the temperature of the added component and to maintain this temperature during the time the rocket is on the launch system. This significantly complicates the structural design of the rocket and ground equipment; therefore the drainless system for filling with cryogenic components, as a rule, is not used.

In order to decrease the mass of the structure the large tanks (5 m^3 or more) are not designed for evacuation; they can only withstand small internal excess pressure basically determined by the operating requirements of the engine. These tanks are filled with discharge of pressure from their gas cushion through drainage safety valves in accordance with more complex filling system (the fill line-tank-drain line). During the process of filling and draining by this system the internal pressure of the gas volume (cushion) is constantly monitored by gauges or signal elements; with an increase in pressure above the admissible, an instruction is automatically put out to stop the filling process, which is reinitiated only after establishment of normal pressure.

In the majority of cases the fuel components are drained from the tanks with the drain-safety valve closed, which insures the required cleanness of the inside volume of the tanks and, in addition, accelerates the drainage process. In order to avoid implosion of the tank by atmospheric pressure under these conditions when the inside pressure drops to a defined amount the on-board blower is switched on, and in some cases the safety drain valve is opened.

The seal of the tanks of the booster rocket stages and the space vehicles designed for operating under space conditions is insured by using a fitting with small diameter of the passage cross sections and the application of fill systems with minimum number of fill-drain and discharge lines. In addition, the tanks of the space rocket systems are carefully checked for seal during the process of preparation at the engineering complex.

When filling the tanks, the precision with which they are filled to the given amount (batching) has great significance, for the excess mass on board the rocket, especially in the upper stages and on the space vehicle, leads to a decrease in useful load. The required accuracy is insured by selecting the filling conditions and the batching method.

The filled dosage is measured by the ground filling system means (the so-called external dosage), the devices installed in the rocket tank (the inside dosage) and a combination of measuring devices of the ground system and the rocket.

With external batching the required dosage is automatically measured by special ground units (mass or volumetric batching) entering into the filling system composition. The mass batcher measures the mass of the filled liquid directly, using high-precision devices of the balance type; the volumetric batcher measures the volume of the dosage or the volumetric flow rate using the measuring calibration tanks or the volumetric flow meters, as which liquid meters are used which determine the amount of liquid flowing by the number of displacements of the servoelement and various devices (turbine, choke, ultrasonic) which measure the speed of the liquid in the line. By monitoring the liquid temperature in the batcher and knowing its chemical composition it is possible to establish the density of the liquid at the time it is added and determine the mass dosage.

When batching comparatively small amounts (tens to several hundreds of kilograms), the mass batchers are used which insure greater accuracy than the volumetric ones and do not require the introduction of temperature corrections for taking into account the variation in density of the liquid or corrections which take into account saturation of it by its own vapor.

Increasing the filling batch leads to an increase in the size of the batchers which becomes commensurate with respect to volume with the ground storage and to complication of the filling system. The measurement of a large batch in partsis inexpedient, for the batching error increases.

Therefore for batching large amounts of liquid, the method of internal batching is used in which the functions of the batcher and the tank are matched. When determining the dosage in the tank, overflow cranes or a more complex monitoring system is used which in the presence of calibration of the tank are used to determine the volume of the batched liquid, recording it or several defined (discrete) positions of the level or continuously measuring it in the process of filling the tank. At the present time, capacitive, inductive, manometric and ultrasonic systems have become widespread for monitoring the level. In these systems the accuracy of measuring the volume of the added component depends on the accuracy of installing the sensitive elements and the filling flow rate on completion of batching selected in such a way that during the time of closure of the cutoff valve by the signal from the system which monitors the level, the error with respect to amount of batched component will not exceed the admissible error.

In some cases, combined batching is used, which consists in filling the tank to a defined level measured by the rocket means with subsequent drainage of a precisely measured excess batching to the mass batcher. This method makes it possible not to adjust the level monitoring system in the tanks for various flight programs.

5.2. Ground Fueling Systems

The space rocket systems are fueled with liquid components using the corresponding systems of the space center making up a significant part of the ground equipment and playing an important role in the process of pre-launch preparations. It is sufficient to state that the mass of fueled components is up to 90% of the launch mass of the modern booster rocket using liquid-propellant rocket engines. The filling systems to a high degree determine the structure of the space center and essentially influence the outcome of the space experiment itself. Two versions of servicing space rocket systems are possible:

Servicing the rocket systems with all fuel components at the launch complex after installation on the launch system;

Filling the tanks of the space vehicle with high-boiling component at the filling station of the engineering complex and the booster rocket tanks (also the space vehicle if cryogenic fluids are used) at the launch complex.

The first version insures greater operating safety with the space rocket system at the engineering complex, but it complicates the process of preparing it for launch and increases the number of pneumohydraulic "ground-on-board" connections. The second version permits the number of fueling systems and "ground-on-board" connections at the launch complex to be reduced and also the flow chart for the pre-launch preparations of the rocket to be reduced with respect to time, but it requires the performance of a number of measures aimed at insuring the required thermal conditions and safety when transporting the fueled vehicle and during prolonged stays at the launch position.

The classification of ground fueling systems is presented in Fig 5.1.

The number of fueling systems depends, as a rule, on the number of fuel components put in the space rocket, although for fueling essentially different on-board systems with identical components, various fueling means are used. Thus, the stages of the "Saturn-V" booster rockets and tanks of the power system for the "Apollo" spacecraft are filled with hydrogen from various ground systems.

The space center fueling systems are distinguished with respect to fueled components, the magnitudes of the batches, the number of fueled tanks, the method of supplying the fuel, the peculiarities of the schematic diagram and structure of the equipment. The basis for all the systems, in spite of the indicated differences, is the common schematic diagram: a storage with means of feeding the component -- pipelines with fitting -- user (the tanks of the booster rocket or space vehicle).

The storage is designed to store a component and is made up of one or several tanks. The tank usually has several outputs for connection to the lines from the portable transport means, discharge of the component to the fuel lines, drainage of gas from the tank cushion, supplying of gas to the tank blowing system, and so on. In order to simplify the structural design and layout, the number of outputs is decreased as much as possible, combining some of them. In order to maintain a defined composition (condition) of the stored fuel, storage under excess pressure, sealed connections and cutoff fittings, chemical analysis, periodic drainage of the liquid, cleaning of inside spaces, and so on are used. For each component, a special method of performing chemical analysis is developed in order to detect the micro-impurities, including determination of the sample-taking process.

High-boiling liquids are stored without losses; cryogenic liquids are stored with small losses as a result of the application of highly effective thermal insulation or without losses using the devices for return condensation of the vapor.

The storages are filled from the portable transport means delivering liquids from the fuel storage houses of the space center, or directly from the plants as they are produced. The volume of storage must be designed to meet all the requirements for the given component during the technological cycle of preparing the rocket system for launch, considering single or double repetition of the launch in case of postponement or early launch. When performing the calculations, the possible irrecoverable losses (drainage, evaporation, and so on), the unreachable remains in the storage tanks and the tanks of the booster rocket, the quantity of the component it takes to fill the service system lines and also the possible increase in the fueled batch for various versions of the booster rocket are taken into account.

In the service systems two methods of supplying the components are the most widespread: forced and pumped.

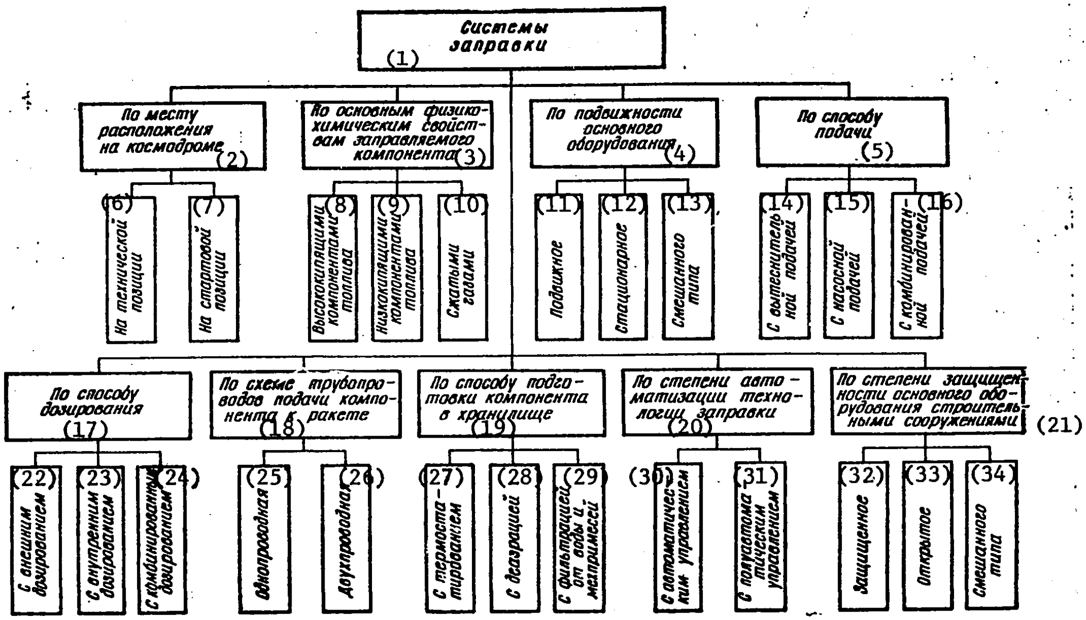


Figure 5.1. Classification of Ground Fuel Service Systems

Key: 1 -- Fueling systems; 2 -- with respect to location at the space center; 3 -- with respect to basic physical-chemical properties of the fueled component; 4 -- with respect to mobility of the basic equipment; 5 -- with respect to method of supplying the fuel; 6 -- at the engineering complex; 7 -- at the launch complex; 8 -- high-boiling fuel component; 9 -- low-boiling fuel component; 10 -- compressed gases; 11 -- mobile; 12 -- stationary; 13 -- mixed type; 14 -- with forced feed; 15 -- with pumped feed; 16 -- with combination feed; 17 -- by the batching method; 18 -- by the system of lines for feeding the component to the rocket; 19 -- by the method of preparing the component in storage; 20 -- by the degree of automation of the fueling process; 21 -- by the degree of protection of the basic equipment by structures; 22 -- with external batching; 23 -- with internal batching; 24 -- with combined batching; 25 -- single line; 26 -- dual-line; 27 -- with thermostating; 28 -- with deaeration; 29 -- with filtration to remove water and mechanical impurities; 30 -- with automatic control; 31 -- with semiautomatic control; 32 -- shielded; 33 -- open; 34 -- mixed type.

The first method insures the given pressures and flow rate by creating a blown pressure in the tank and the second, by the operation of a pump.

The application of the forced method of feed is limited by the admissible pressures in the tanks, for the achievement of the required strength characteristics (specially for the high-volume tanks) leads to a significant increase in mass and complication of the structure.

The pump method of feed in practice insures any pressures and flow rates, although it requires continuous flow of the liquid without bubbles for stable operation of the pump. The bubbles formed in the low-pressure zone (the so-called cavitation phenomenon) and filled with liquid vapor can lead to interruption of the operation of the pump. In order to avoid this, the total pressure at the input to the pump is increased by blowing the tank. In this case, the combination of forced and pump feed methods are obtained, that is, the combined method of feeding the fuel components.

The fuel flow rate determines the filling time. For modern space rocket systems, insurance of large flow rates does not cause any theoretical difficulties. Considering the property of high-boiling liquids to be stored in practice without losses, the tanks are filled with them in advance, several days before launch. Here the filling is done in a two-step operation: the basic flow (to 90-95% of the given batch) and the small flow (to the given batched amount). In contrast to the high-boiling liquids, in order to decrease the time of the low temperature effects on the rocket elements and the losses from evaporation, the fast-evaporating (cryogenic) liquids are put in the tanks several hours before launch. In this case in order to meet the requirements connected with the structural peculiarities of the rocket and for greater accuracy of batching, multistage filling conditions are used. Thus, the filling of the SI stage of the "Saturn-V" booster rocket with oxygen is accomplished in the following mode: 1135 liters/min to cool the tank; 5680 liters/minute (to 5% of the fueled mass) to exclude large loads on the structural elements of the rocket at the beginning of fueling; 37850 liters/minute (to 95% of the fueled mass) -- the basic high-speed fueling; 5680 liters/minute to the level gauges signal to stop batching. Then makeup takes place at 1890 liters/minute to compensate for losses to evaporation.

The simultaneous feeding of the oxidant and the fuel makes it possible to reduce the rocket fueling time. However, in practice, especially when using self-igniting and fire and explosion hazardous components, the rocket system is fueled in succession and in some cases, modularly.

The fuel component is fed from storage and goes into the rocket tanks through lines made up of pipes and fittings for the liquid and its vapor. The layout of the lines of the fueling system connecting the storage and the user is determined primarily by the pneumohydraulic layout of the rocket tank and the requirements with respect to insuring flow regimes. For liquid components it can be single or double line.

The single line layout provides for filling, drainage and for cryogenic components and topping off through one fuel line having branches in accordance with the number of fueled tanks. This layout has become the most widespread.

The double-line system provides for circulation of the fueled liquid in the tank in case of thermostating by the method of simultaneous feed and drainage. It includes the feed and drain lines connected to the corresponding tank and ground storage lines. The fueling line is made up of one or several pipelines if it is structurally disadvantageous to have one large-diameter line.

The fuel fittings are devices which insure a given flow of the component, adjustment of the flow and curtailment of feed. These fittings include valves, gate valves, regulators, chokes and so on. The valves insure seal (or with the given degree of seal) separation of two sections of the pipeline and they are divided with respect to functional contributes into the shutoff valve for stopping the feed and discrete regulation of the flow; drain valves for discharge of gas, liquid or a mixture of liquid and vapor from individual sections of the lines and tanks; safety valves for automatic discharge of excess pressure and check valves for automatic passing of liquid or gas in only one direction.

The shutoff and drain valves are controlled remotely using various drives (pneumatic, electric, electromechanical). The valves are designed for complete shutoff of the lines, and they are devices with manual drive. The chokes are used to regulate the degree of covering of the line and they are with manual or electromechanical drive controlled remotely.

In some cases, in order to insure complete separation of one volume for another in the tanks or lines, diaphragm assemblies are used in which the sealing diaphragm is cut off automatically with the given pressure gradient or forced using pneumatic drive.

The cutoff valves and drain valves, the gate valves and chokes can have signals of the extreme (open-shut) and intermediate positions providing for remote monitoring of their operation.

In the filling systems various types of automatic regulators are also used (for example, liquid, which insures variation of the liquid flow depending on the pressure variation in the gas cushion of the filled tank).

In order to prevent mechanical impurities from getting into the fuel tanks there are filters. The liquid or gas is purified to remove impurities both by passing it through porous or lattice materials of filter elements and by centrifugal effect. The purification method depends on the specific operating conditions of the fueling systems.

All of the operations performed using the fueling systems in the pre-launch preparation process can be divided into preparation, basic, final, post-launch and auxiliary.

The preparatory operations include checking out the equipment of the systems for operation, the bringing of the stored component to the required parameters (with respect to quantity, temperature, pressure); taking samples for chemical analysis; connection (coupling) of the fuel, discharge and drain lines to the corresponding valves or flanges of the on-board connections of the rocket with subsequent checking of the connections for seal; initializing all of the control system elements, and so on.

The basic operations include the preparation of the inside cavities of the rocket tank (for example, replacement of the air atmosphere by a neutral atmosphere for fire and explosion hazardous components with respect to air), filling the fill lines with the components, filling the tanks, makeup, thermostating the fuel, draining the components from the tanks in case of postponement of the launch.

The final operations include correction of the level (topping off to the given batch), relieving the on-board and ground fill lines of liquid and gas (draining the lines), disconnection (uncoupling) of the fuel and drain lines for the booster rocket, and so on.

The postlaunch operations include draining the remains of the fuel component from the fuel lines, replacement of the throwaway assemblies, conversion of the system to storage conditions.

The auxiliary operations include filling the storages from the transports, technical servicing of equipment, and so on.

The participation of the controlled fueling system elements in the performance of the operations is different (from 50 to 100% of the total number); therefore for large and complex fueling systems with respect to composition, automatic and semiautomatic technological operation control systems are used.

The automatic control systems provide for controlling the system elements and monitoring their operation in the automatic mode, and the semiautomatic control systems provide for only part of the technological operations in the automatic mode.

In addition, these systems insure the possibility of remote control of any element during performance of the operations.

The operation of the fueling systems and their elements is controlled by the lighting of lights and transparencies on the service control panels. When performing the technological operations, in addition to information about the order of response of the control system elements it is necessary to know and monitor the basic parameters of the fueling system (pressure, temperature, number of components in the storages and the rocket tanks, pressure, temperature and flow rate of the components in the lines and the feed units). The monitoring of these parameters is provided for by the corresponding measurement means with output of the readings to secondary instruments with visual scales. The information obtained makes it possible to estimate the state of the fueling system at any point in its operation.

The equipment of the fueling system basically is placed in the storage areas. It consists of tanks, feed and other types of equipment providing for storage and preparation of the components for fueling: the routes for laying the lines (fill-discharge and drain lines); at the service units, the service cable towers (mass), the service towers and trusses providing for bringing the ground lines to the rocket connection.

At the launch complex the fueling system equipment usually is protected from the destructive effects of the shock wave in case of a possible explosion of a rocket by reinforced concrete arched structures banked with dirt and service passageways capable of withstanding a defined load in case of explosion. The construction of such structures requires large means, especially for large spherical tanks.

The placement of the tanks designed in strength respects for a defined load from the shock wave in an open area essentially reduces the expenditures. Thus, at launch complex No 39 the large spherical tanks with liquid oxygen and hydrogen are left open at a distance of about 450 meters from the center of the launch structure; their structural design is for an excess pressure of 41 kPa, and the stability of the foundation with regard to shifting and tilting loads which can occur in case of an explosion of the "Saturn-V" booster rocket.

The equipment of the fueling system of the service units removed before launch to a safe distance does not require special shielding.

The fuel components storage facilities with feed means can be portable and stationary. The portable storages(tankers) are used to store a small amount of fuel; they do not require special structures except accesses and covered platforms and especially they are advantageous for modifying the launch complexes for vehicles with other fuel components. The stationary storages are used to store a large (several thousand cubic meters) quantity of fuel and for fueling the booster rocket tanks and space vehicles of the space rocket complex of the heavy or superheavy class.

The equipment of the service station is located in the main building (batchers, thermostating means, vacuum equipment), in the storage building removed from the main building (tanks with facilities for storing the component and preparing it for fueling) and in the main channels connecting the main building and the storage.

The fuel systems for fire and explosion hazardous components both at the filling station and at the launch complex are separated by a safe distance and are placed in isolated channels and structures.

5.3. Fueling Systems for Cryogenic Fuel Components

In modern rocket engineering cryogenic liquids are used as the fuel components for engines, the operating means for the fuel elements of power supply systems, the life support systems and the systems for blowing the space vehicles and rocket modules; coolants for supercooling other cryogenic liquids and compressed gases and also for so-called cryogenic purification of the compressed gases to remove admixtures in the ground gas supply systems; for special cryogenic systems installed in the space vehicles, and so on. The cryogenic liquids are also used in the ground gas supply systems of the space rocket complexes to obtain compressed gases by the gasification method.

Some of the data on the application of cryogenic liquids in the existing and prospective space rocket systems are presented in Table 5.1, and the basic physical constants of the liquid oxygen, nitrogen, fluorine, and hydrogen, in Table 5.2.

Table 5.1

Some Data on the Application of Cryogenic Liquids in Booster Rockets

Booster rocket (rocket stage)	Fuel	
	Oxidant	Combustible component
"Jupiter"	Liquid oxygen	Hydrocarbon (kerosene)
"Atlas"	The same	The same
"Titan-I"	The same	The same
"Centaur" (stage)	The same	Liquid hydrogen
"Saturn-S-I" (stage)	The same	Hydrocarbon (kerosene)
"Saturn S-II" (stage)	The same	Liquid hydrogen
"Saturn S-IVB" (stage)	The same	The same
"Kosmos" type rocket (upper stage)	The same	Asymmetric dimethylhydrazine
"Vostok" type rocket	The same	Hydrocarbon (kerosene)

Let us consider the physical-chemical properties of some of the cryogenic liquids that are most used at the present time.

Liquid oxygen O_2 is one of the most effective cryogenic oxidants (it is inferior only to fluorine and ozone), it is available and cheap, which is explained by its large reserves and nature and simplicity of procurement, it is nontoxic and in pure form is not explosion-hazardous; in the gaseous stage it is colorless and odorless.

Table 5.2

Basic Physical Constants of Cryogenic Liquids

	Криогенная жидкость (1)	(2) Химическая формула	(3) Атомная (молекулярная) масса	(4) Газовая постоянная, Дж/(кг·К)	(5) Плотность газа (при 273К и p = 760 мм рт. ст.), кг/м³	(6) Температура кипения (при p = 760 мм рт. ст.), К	(7) Температура „тройной точки“, К (в скобках — равновесное давление, кПа)	(8) Плотность жидкости, кг/м³ (в скобках — температура, К)	(9) Плотность равновесных паров, кг/м³ (в скобках — температура, К)	(10) Плотность твердой фазы, кг/м³ (в скобках — температура, К)	(11) Теплота испарения, кДж/кг	(12) Теплота плавления, кДж/кг	(13) Критические параметры			(17) Объем газа (при 273К и p = 760 мм рт. ст. при испарении 1 м³ криогенной жидкости), м³
													(14) температура, К	(15) абсолютное давление, МПа	(16) плотность, кг/м³	
(18)	Кислород	O_2	32	260	1,428	90,19	54,36 (0,146)	1142 (90,19)	4,9 (90,19)	—	213,5	13,9	154,56	5,12	435	800
(19)	Фтор	F_2	38	219	1,635	85	53,48 (0,259)	1500 (85)	—	—	173	13,4	144,31	5,56	574	840
(20)	Азот	N_2	28	297	1,25	77,36	63,15 (5,86)	804 (77,36)	4,98 (77,36)	947 (63,74)	197,5	25,7	126,25	3,48	310,96	643
(21)	Водород	H_2	2	4124	0,89	20,38	13,95 (6,86)	70,80 (20,38)	1,16 (19,92)	86,32 (13,95)	455	58,2	33,19	1,27	30	788

Key:

1. Cryogenic liquid
2. Chemical formula
3. Atomic (molecular) mass
4. Gas constant, joules/(kg-K)
5. Gas density (for 273°K and p=760 mm Hg), kg/m³
6. Boiling point (for p=760 mm Hg), K
7. Ternary point, K (in parentheses, equilibrium pressure, kPa)
8. Liquid density, kg/m³ (in parentheses, temperature, K)
9. Density of equilibrium vapor, kg/m³ (in parentheses, temperature, K)
10. Solid phase density, kg/m³ (in parentheses, temperature °K)
11. Heat of vaporization, kjoules/kg
12. Melting point, kjoules/kg
13. Critical parameters
14. Temperature, K
15. Absolute pressure, MPa
16. Density, kg/m³
17. Gas volume (for 273K and p=760 mm Hg on evaporation of 1 m³ of cryogenic liquid), m³
18. Oxygen
19. Fluorine
20. Nitrogen
21. Hydrogen

Considering that at low temperatures many materials (hydrocarbon steel, rubber, certain plastics and so on) become brittle and lose their ductile properties, construction materials in contact with liquid oxygen must be ductile, strong and resistant to combustion. Such materials include aluminum and its alloys, high-alloy stainless steels, copper and brass.

Oxygen supports combustion intensely and forms explosion-hazardous mixtures with liquid or gaseous hydrocarbons, and porous organic materials (sawdust, cotton wadding, rag, felt) impregnated with liquid or gaseous oxygen; they are explosion-hazardous under impact or on ignition. At ambient temperature the oxygen vapor is heavier than air, it spreads over the floor and can fill all of the low spots. When working with oxygen service personnel must protect clothing and hair from impregnation with gaseous oxygen (ignition of them on occurrence of a spark is possible), and after work it is mandatory to air out the clothing. In facilities where people work with oxygen it is categorically forbidden to smoke, light a fire or use uninsulated sources of current. All of the equipment used with liquid and gaseous oxygen must be carefully degreased, and any tools that are used must be copper plated to avoid sparks.

Liquid fluorine F_2 is the most effective of the modern cryogenic oxidizing agents, for the fuels formed by it have the greatest specific thrust and density which makes its application highly prospective. Fluorine has high chemical activity, it reacts with all organic and inorganic substances, on contact with it the majority of substances ignite. Metals can ignite from friction in case of high flow velocity and also in the presence of contamination in liquid fluorine. Some of the metals (iron, copper, nickel, aluminum and its alloys) are resistant to the effect of fluorine as a result of formation of a strong film of fluorides protecting against destruction on their surface. Liquid fluorine and its vapors are toxic and have a strong effect on the eyes, skin and respiratory tracts. Fluorine vapors, reacting in the damp atmosphere of air, form hydrofluoric acid. The products of combustion of fluorine-containing fuels are also toxic as a result of the formation of corrosion-active hydrogen fluoride in them. The equipment for liquid or gaseous fluorine must be carefully purified and passivated. For operating safety tanks and lines for liquid and gaseous fluorine are made with a nitrogen "jacket" which, as a result of the lower boiling point of liquid nitrogen filling it provides for storage of the fluorine in transport or filling tanks in the supercool state, which excludes losses to evaporation and condensation of its vapor formed during the filling of the tanks. The low excess helium pressure above the surface of liquid fluorine protects it from contact with atmospheric air.

Gaseous fluorine is neutralized by passing it over dry NaCl and $CaCl_2$ salts and liquid fluorine, by using sodium or a solution of calcinated soda.

The application of fluorine compounds with chlorine and oxygen is also possible as an oxidizing agent; they are safer to handle, they can be stored in tanks made of ordinary structural materials, and they are less toxic.

In the United States within the framework of the "Saturn-Apollo" program research work has been done to replace oxygen by a fluorine-oxygen mixture and for testing engines for the upper stage using liquid fluorine. At the present time the majority of problems connected with transporting liquid fluorine and the process of handling it have been solved, and its application as a rocket fuel component is possible after solving quite complex and tedious problems with respect to its operation as part of the rocket module.

Liquid hydrogen H_2 is one of the most effective cryogenic fuels. This is a transparent, colorless, low-boiling (it is inferior only to helium) and light liquid. It is not toxic or passive in terms of corrosion. Liquid hydrogen has a low boiling point (only 20 K above absolute zero), which determines the large losses to evaporation, the low density, which requires an increase in volume of the booster rocket tanks, energetic impulse for ignition 10 times less than for hydrocarbon fuels, high TNT equivalent (the explosion of 1 kg of liquid hydrogen mixed with the corresponding amount of oxygen creates energy equivalent to 10 kg of TNT), and its mixtures with air and oxygen are explosion-hazardous within broad concentration limits (4.1 to 74.2% of the volume for air and 4.6 to 93.9% for oxygen). Accordingly, the application of liquid hydrogen in rocket engineering has become possible only after the introduction of highly effective thermal insulation combined with various measures to prevent the occurrence of dangerous concentrations.

Liquid nitrogen N_2 is a cryogenic liquid, it is nontoxic, but improving the concentration of the gaseous nitrogen in an atmosphere of close facilities can lead to severe consequences; it is chemically inactive and imposes the same requirement on the materials as liquid oxygen. Liquid nitrogen is used as a source of gaseous nitrogen for blowing fuel tanks (the Soviet "Vostok" booster rocket) and for the ground type gas supply systems.

From the above-investigated physical-chemical properties of cryogenic liquids it follows that the low boiling point, low heat of vaporization, large amount of gas obtained during evaporation and the large difference in densities of the liquid and gas phases are common to them. These properties are taken into account during planning and design and operation of the cryogenic filling systems, the composition of which includes storage, means of supplying liquid from the storage to the tanks, means of supercooling the liquid, the controllable filling and cutoff equipment, means of removal and discharge (drainage) of liquid and its vapors to a safe distance and means of evacuation of the thermal insulation cavities.

The peculiarities of the structural design of the equipment of cryogenic filling systems arise from significant changes in the physical-mechanical properties of the metals and their alloys at low temperatures. With a decrease in temperature, as a rule, the strength characteristics (yield point and fatigue point, rupture strength) increase, and the plastic indexes are worse (impact toughness, relative constriction and elongation).

The reduction of impact toughness of carbon steels is so great that it leads to embrittlement of them and limits the application in assemblies and parts operating at low temperature. Therefore in cryogenic engineering hydrocarbon steels are only used to make jackets, supports, fasteners and other elements not in contact with the cryogenic liquid.

The metals that operate at low temperatures (inside vessels, pipelines and fittings) have such requirements imposed on them as satisfactory static and dynamic viscosity, vaccum density and even gas generation, stability of structure under long-term loads, low capacity for ignition in an oxygen environment (for oxygen equipment). These requirements are satisfied by alloyed steels of the austenitic class, aluminum alloys, nonferrous metals and their alloys, and among the nonmetallic materials, plastics having low thermal conductivity and high strength. In order to exclude the significant thermal deformations in the lines, various types of compensators, bellows or flexible metal sleeves are used.

The schematic diagram for filling tanks with cryogenic components is presented in Fig 5.2.

A storage facility for a cryogenic liquid consists of one or several tanks. The tank is a structural element made up of an outer jacket to which an inside vessel is attached through special slits or supports. The thermal deformation of the inside vessel is compensated for as a result of the corresponding fastening of the jacket (suspension or installation on supports). The evacuated space between the inside vessel and the outside jacket filled with thermal insulation forms a thermally insulated cavity. The suspensions and supports and also the pipelines joining the inside vessel and the outside jacket are additional elements (heat bridges) through which the heat is transferred from the environment to the liquid.

The total heat influx to the cryogenic liquid is

$$Q_{total} = Q_{rad}+Q_{gas}+Q_{heat}+Q_{heat\ bridge}=Q_{ins}+Q_{heat\ bridge},$$

where Q_{ins} is the total heat influx through the insulation;

Q_{rad} is the heat influx as a result of radiation;

Q_{gas} is the heat influx through the residual gases;

Q_{heat} is the heat influx as a result of thermal conductivity;

$Q_{heat\ bridge}$ is the heat influx through the thermal bridges.

The thermal influxes are calculated separately for each type of heat transfer, although in reality there is complex interaction of all of the components of the total heat influx.

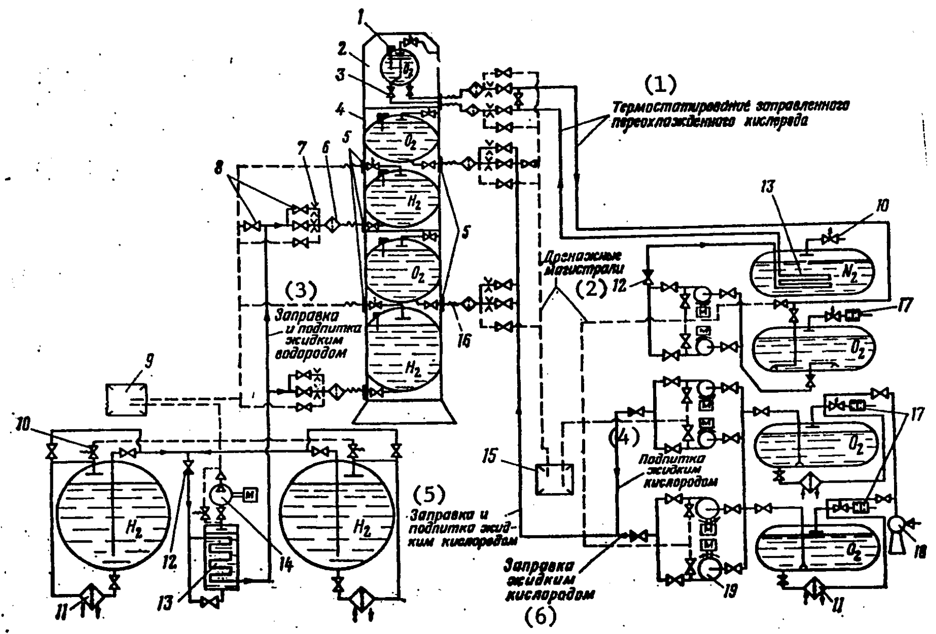


Figure 5.2. Schematic diagram for filling space rocket systems with cryogenic and fuel components:

1 -- level gauges; 2 -- spacing; 3, 8 -- cutoff valves (gate valves); 4 -- booster rocket; 5 -- booster rocket joint; 6 -- filters; 7 -- choke slides; 9 -- area for burning nitrogen; 10 -- drainage-safety valve; 11 -- heat exchange evaporators; 12 -- check valves; 13 -- heat exchange cooler; 14 -- vacuum pump; 15 -- area for draining oxygen; 16 -- flexible joint; 17 -- sealing diaphragm; 18 -- oxygen cooling ejector; 19 -- centrifugal pumps with electric drive

Key:

1. Thermostating the supercooled oxygen being put in the tank; 2. drain lines; 3. filling and makeup with liquid hydrogen; 4. makeup with liquid oxygen; 5. filling and makeup with liquid oxygen; 6. filling with liquid oxygen.

For a sufficiently deep vacuum in a thermally insulated cavity the heat transfer by the residual gases is very small. By increasing the length of the suspensions, supports, lines and applying materials with low thermal conductivity it is possible essentially to decrease the heat influxes through the bridges. The heat influxes as a result of radiation and thermal conductivity are decreased by the application of heat insulating materials with high reflectivity and low thermal conductivity.

In order to decrease the losses to evaporation in some cases the heat capacity of the departing liquid vapor is used, cooling special shields by the vapor in the thermal insulating cavity or different thermal bridges. The losses from evaporation also depend on the geometric shape of the container: they decrease with an increase in the ratio of the volume to the surface area. The most advantageous shape is a sphere, but the installation of spherical structures is connected with defined difficulties.

A cylindrical shape with a length of the cylinder equal to its diameter is more convenient; in this type of cylinder with electrical bottom and top the ratio of the volume to the surface area is insignificantly worse than for a sphere.

A stationary tank for prolonged storage of liquid oxygen (Fig 5.3) is a horizontal cylindrical vessel with electrical ends with a volume of up to 225 m^3. The inside vessel made of alloy steel with multilayered vacuum shielding insulation is installed on four mounts in the outer jacket of carbon steel, and it is fastened by three locators. After filling the tank with oxygen the vacuum reaches 0.01 Pa and is maintained for a prolonged period of time as a result of adsorption of the gas molecules by zeolite placed in special pockets with coils through which the hot gas is fed for regeneration of the zeolite. Between the inside vessel and the jacket in the feed and blowing assemblies located near the supports, bellows are welded out to provide for sealed exit through the vacuum cavity and compensation for displacements of the inside vessel with respect to the jacket during cooling. The outer jacket is a safety diaphragm through which the excess pressure is discharged in case of loss of seal in the inside vessel with the cryogenic liquid.

The stationary vessel for storing liquid nitrogen, oxygen and argon (Fig 5.4) is a vertical cylindrical vessel 66 m^3 in volume which is fixed in a jacket by two supports and is installed on four supports concentrically entering into the jacket support.

The portable storages are analogous to the stationary ones, but they are made of lighter metals and alloys and have a special attachment inside to extinguish longitudinal displacements of the liquid during transportation.

The cryogenic liquids in the tanks are stored under excess pressure and without it. Excess pressure created by their own vapor as a result of evaporation of the liquid in the tank (from thermal influxes from the environment) or in a special heat exchanger and evaporator, and in some

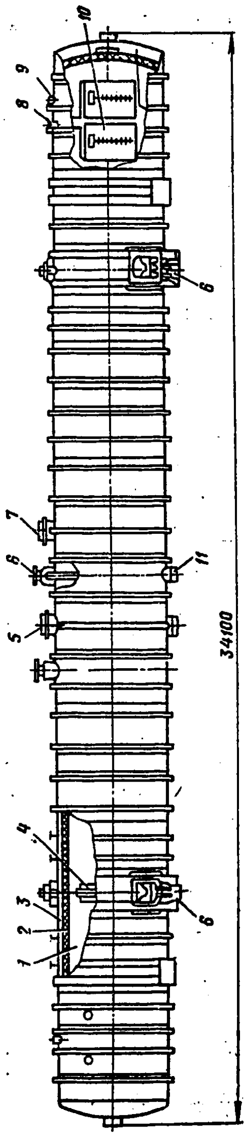


Figure 5.3. Stationary tank for storing liquid oxygen: 1 -- inside vessel; 2 -- multilayer vacuum shielded installation; 3 -- jacket; 4 -- suspension; 5 -- gas discharge and blowing lines; 6 -- locators; 7 -- upper liquid discharge line; 8 -- hot gas feed line to the pockets with adsorbent; 9 -- safety diaphragm; 10 -- pockets with adsorbent; 11 -- lower liquid discharge line.

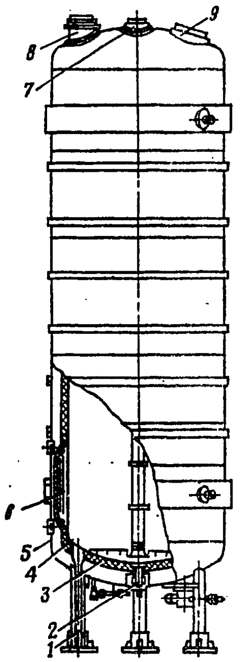


Figure 5.4. Stationary tank for storing cryogenic liquids: 1 -- support; 2 -- support; 3 -- multilayer vacuum shield insulation; 4 -- inside vessel; 5 -- jacket; 6 -- pockets with adsorbent; 7 -- liquid discharge line; 8 -- gas discharge and blowing line; 9 -- manhole.

cases also gaseous helium prevents atmospheric air from getting into the gas cushion of the tank and it prevents variation of the composition of the stored liquid. The required amount of excess pressure is insured by a closed drain valve (open periodically to discharge pressure) or a special choke disc installed in the drain line.

In the general case the required amount of cryogenic liquid in storage is

$$G_{storage}=K(G_{tank}+G_{pipe}+G_{makeup}+\Sigma G_{loss})+G_{np}+G_{ready}+G_{therm},$$

where K is the margin of safety taking into account possible versions of the rocket connected with increasing the filled volume;

G_{tank} is the amount of liquid put in the rocket tank in the given level;

G_{pipe} is the amount of liquid going to fill the pipelines connecting the storage and rocket tanks;

G_{makeup} is the amount of liquid going to make up the tank, that is, replace the losses from evaporation (this component is taken into account for the filling system with makeup);

ΣG_{loss} is the total irrecoverable losses of liquid to evaporation;

G_{np} is the amount of liquid remaining as a result of not being picked up (it is determined basically by the geometric characteristics of the tank and the layer of liquid having a temperature above admissible for feeding to the rocket tank as a result of heating from the blowing gas);

G_{ready} is the amount of liquid in storage insuring that the given readiness of the storage will be maintained after it is filled to fill the rocket without additional hauling;

G_{therm} is the amount of liquid required to insure the thermostating of the filled tank (this component appears only when thermostating with the application of the circulation method under the condition that the thermostating is realized by the reserves of previously supercooled liquid).

In the general case the irrecoverable losses are as follows:

$$\Sigma G_{loss}=G_{cool}+G_{blow}+G_{supercool},$$

where G_{cool} is the amount of liquid evaporated during cooling of the metal structural elements of the filling system and the rocket tank;

G_{blow} is the amount of liquid evaporated to create blowing of the storage tanks;

$G_{supercool}$ is the amount of liquid evaporated during cooling of the filled liquid by the evacuation method (this component is taken into account only when cooling the liquid by evacuation).

The amount of liquid required to insure thermostating of the filled tanks:

$$G_{therm}=G'_{therm}\cdot T\cdot n,$$

where G'_{therm} is the consumption of the liquid during thermostating;

T is the operating time of the thermostating system during one cycle to obtain the given temperature in the tank;

n is the number of thermostating cycles.

When using the gas cooling units or special cooling fluid insuring supercooling of the filled cryogenic liquid without losses, the value of G_{therm} can be taken equal to 1 to 3 hour flow rates of thermostating as the cold storage unit for the initial thermostating cycles. When using a cooling cryogenic liquid in the ground filling system it is necessary to have equipment for storing it and feeding it to the heat exchanger.

The reserves of the cryogenic liquid in storages for large booster rockets usually exceed the filled doses by 1.5 to 3 times. Thus, the ratio of the amount of liquid in the storages providing for launching of the "Atlas-Centaur," "Saturn-IB," "Saturn-V" booster rockets to its amount in the tanks is approximately equal to 2, 1.4 and 1.8 for oxygen, and 2.8, 2 and 2.3 for hydrogen respectively.

Feed Equipment

In the cryogenic fuel component fueling systems, forced and pump methods of supplying the fuel components and also combination methods are used.

In the forced method the blowing is created by a gas which comes from the receiver or is obtained during the filling process in the heat exchange equipment (a gasifier) as a result of evaporation of some part of the component with the help of a heat-exchange agent (for example, hot water from the heating network) or from an electric heater, and in some cases under the effect of ambient heat. The cryogenic liquid is fed to the heat exchanger by a pump (in the pumped feed system) or by gravity feed. In this case the required hydraulic kit for arrival of the liquid is insured by the location of the evaporator.

From the storages the cryogenic components are fed to the booster rocket tanks through lines usually made of individual sections, the length of which is determined by the manufacturing and transporting possibilities. The section of line (Fig 5.5) consists of inside and outside (of the jacket) tubes. The inside tube is oriented with respect to the outside tube and is rigidly connected to it using supports made of material with low coefficient of thermal conductivity (fiberglass).

The inside tube is made of alloyed austenitic steel, and the outside (jacket) from ordinary carbon or stainless steel. The space between the tubes (the thermal insulation cavity) is filled with powdered or multilayered insulation with subsequent evacuation through an evacuation line with a valve. In order to maintain and improve the vacuum, on the outside of the inside line zeolite (for oxygen lines) or activated charcoal (for hydrogen lines) is placed in pockets. These materials have good adsorption properties at low temperatures and reduced pressures. A rupturable safety diaphragm is installed in the housing in case of increased pressure in the thermal insulating cavity of the line (if the inside tube breaks its seal).

A flexible metal hose with multilayered vacuum shielding insulation (5.6) is made up of inside and outside sealed hoses. The inside hose is oriented with respect to the outer supports of material with low thermal conductivity and together with the sleeve, tube and pocket with the adsorbent is insulated by an aluminum-covered film. The outer hose is made of a sealed hose, an adapter and a tube, on one of which a bellows-type vacuum valve and rupturable safety diaphragm are installed.

The sections of lines are connected by means of split bolt or unsplit welded connections. In order to prevent accumulation of static electricity in the lines with split connections, special jumpers are installed to insure reliable electrical contact between the individual sections.

In the pipeline, depending on the specific conditions, thermal insulation of different effectiveness is used. Thus, the lines for liquid hydrogen and helium and also the lines for long-term transportation of small flow rates and great extent usually have powdered or multilayered vacuum insulation, and the lines for brief transportation of large flow rates and short extent, insulation made of foam plastic, fiberglass foam and in some cases (for liquid nitrogen and oxygen) do not have it at all.

The component feed (flow rate) is regulated using the valve module having hydraulic characteristic of the line.

For a large difference in the filling and makeup flow rate the feed systems have separate filling makeup pumps and separate ground fill and topping off lines. In order to obtain an exact level in the tank before finishing up topping off, the drain valve of the tank is closed, which sharply decreases the boiling of the added liquid and permits exact topping off of the tank to the required amount.

When feeding the cryogenic liquid through the fill lines, the transitional nonstationary initial filling regime is the most responsible and complex during which the line is cooled to the temperature of the liquid. The first lots of liquid on evaporation form a large quantity of vapor and

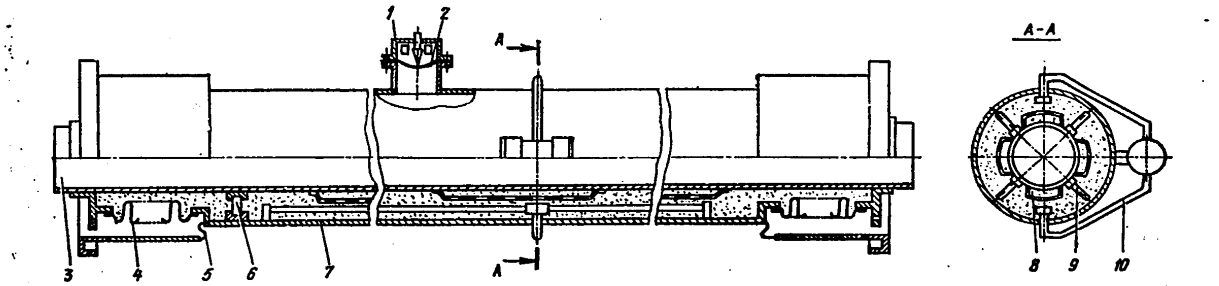


Figure 5.5. Section of the pipeline:
1 -- safety dome; 2 -- rupturable diaphragm; 3 -- inside line; 4 -- bellows heat bridge; 5 -- flexible element; 6 -- support; 7 -- jacket; 8 -- pocket with adsorbent; 9 -- supporting pin; 10 -- vacuum line.

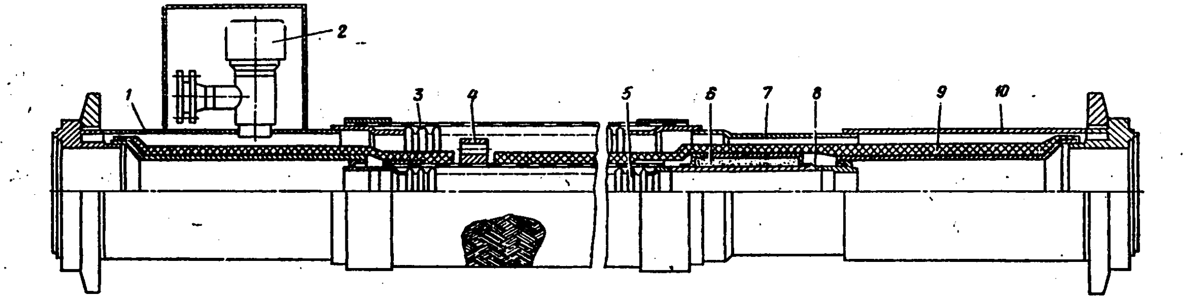


Figure 5.6. Metal hose with vacuum shielded insulation:
1 -- tube; 2 -- vacuum valve; 3 -- powder metal hose with braiding; 4 -- support; 5 -- inner metal hose with braiding; 6 -- pocket with adsorbent; 7 -- adapter; 8, 10 -- tube; 9 -- sleeve

fill the entire pipeline with it. The formed vapor is heated almost to the initial temperature of the line and is discharged through a drain valve located at the end of the line. As cooling takes place, the initial section of the pipeline is filled with liquid; in subsequent sections, a vapor liquid mixture is formed, and the vapor continues to escape through the drain valve.

The cooling of the walls of the pipelines with the vapor makes it possible to decrease the irrecoverable losses of the cryogenic liquid to cooling the lines. During the cooling process fluctuations of the pressure are possible which exceed the feed pressure (which can lead to forcing of the liquid and vapor into the tank) and pulsations with respect to the flow rate respectively. Taking this into account, the longer pipelines are cooled with low flow rate, and only after cooling and filling them with liquid are they converted to increased flow rates. In order to prevent the transfer of the pressure pulsations to the tank or the pump at the beginning of the line, a check valve is installed, on closing of which provision is made for transfer of part of the flow after the pump to the tank in order to avoid disruption of the operation of the pump.

In order to decrease the cooling time and fill the long lines, the vapor formed is discharged through additional drain valves or special gas discharge units (for example, the flow type gas-liquid separators) installed at a defined distance from each other. Considering the great difference in densities of the vapor and liquid phases, the feed line is located with some rise in the direction of movement of the liquid, and gas discharge devices are installed on the upper part of the line. For this system the vapor is intensely discharged from the line, the liquid fills the pipeline faster, but in this case the losses to evaporation increase, for the cooling takes place in the given case basically at the expense of evaporation of the liquid. When filling the separator with liquid the flow, rising, closes the gas discharge.

During the movement of the cryogenic fluid even through an insulated tube, heating of it as a result of the thermal influx from the environment, the heat released in overcoming the hydraulic drag, the heat generation during operation of the pump, and so on is unavoidable. This causes evaporation of part of the liquid, it leads to the formation of a two-phase, gas-liquid flow and it decreases the carrying capacity of the lines. Therefore, during the servicing process, an effort is made to obtain a single-phase liquid flow which is possible during movement of the liquid in the state of not being heated to the equilibrium temperature. The magnitude of the underheating is selected so that during the heat release the formation of the vapor phase is excluded, which makes it possible to stabilize the hydraulic drag of the feed line, exactly to calculate and maintain the flow parameters of the input to the tank. This regime is insured when supplying liquid with increased pressure. In certain systems where obtaining the single phase flow is impossible, in order to remove the vapor formed on the lines, gas separators are installed. In addition, the filling of the tank with a liquid which is cooled in the fueling system (below the boiling point at atmospheric pressure) makes it possible to reduce the amount of gas in the tank as a result of heating of the liquid in the fill line to a minimum.

Supercooling Means

In order to cool cryogenic liquids, various refrigerating processes are used which can be unconditionally divided into external cooling and evacuation cycles.

In the external cooling cycles, the heat from the cooled liquid is selected using the gas refrigerators or heat exchangers with colder cryogenic liquid (coolant) by direct contact with the cooled liquid with the colder surfaces of the indicated devices.

The operating cycle of the gas refrigerators is based on the compression, heat exchange and expansion processes of the working medium circulating through a closed loop (for example, gaseous helium), which on coming to the refrigeration chamber is heated and takes up the thermal load from the cooled liquid.

In the evacuation cycles, the heat from the cooled liquid is removed at the expense of evaporation at reduced pressure which is created by special vacuum units.

Combinations of the cycles are possible.

In order to store a cryogenic liquid without losses and cool it in the storage facilities, the "evaporator-condenser" system is used with the application of gas refrigerators. The liquid vapor in the cushion of the tank is condensed by this system in the refrigeration chamber, creating a pressure gradient as a a result of which the liquid begins to evaporate, and the condensed liquid flows back to the tank.

The cryogenic liquid is supercooled in the filling systems by various methods (Figures 5.7 and 5.8). The most complicated method is the method providing for cooling of the liquid without losses to evaporation and requiring the application of refrigeration units of complex design; the simpler procedure is the procedure in which the cooling takes place as a result of evaporation of the basic cryogenic liquid or special coolant. If direct contact of the basic liquid and the coolant is undesirable for safety reasons, an intermediate inert heat transfer agent is used. The use of one supercooling method or another is determined in the final analysis by its effectiveness, reliability and economy.

The most widespread is supercooling based on the use of systems with the application of coolant, evacuation and combination of them which, in spite of the deficiencies (losses to evaporation) have relatively simple equivalent. As a coolant in some systems either the basic cryogenic liquid cooled by evacuation or another cryogenic liquid with lower temperature (for example, liquid nitrogen or supercooling of oxygen) or mixtures of cryogenic liquids supercooled by evacuation are used (for example, a mixture of liquid nitrogen and oxygen with a composition of 77% O_2 and 23% N_2 with hardening point of 50 K).

The evacuation method is based on the properties of phase transition of liquid to vapor with heat absorption. If the system is adiabatic, the evaporation process will take place only as a result of the decrease of its internal energy which is accompanied by a lowering of the temperature. The equilibrium state of the two-phase "liquid-vapor" system is characterized by a relation defined for each liquid of the saturated vapor pressure as a function of temperature. If in the two-phase "liquid-vapor" system in the equilibrium state the saturated vapor pressure is reduced by Δp, that is, conversion is made to the nonequilibrium state, the liquid turns out to be superheated with respect to the pressure obtained, which leads to the initial evaporation process. If the pressure above the liquid is kept constant, then with an adiabatic system the evaporation process is accompanied by a decrease in temperature, and it will continue until the "liquid-vapor" system reaches a new equilibrium state.

The use of hydrogen slush as the fuel component differing from boiling hydrogen by its high density and longer storage time without losses is of great interest.

In the United States studies were made within the framework of the "Saturn-Apollo" program with respect to the problems of developing methods of obtaining, storing, transporting and fueling with hydrogen slush and also an estimate of the effectiveness of its application. The studies demonstrated that hydrogen slush with 50% solid phase content has high absorbing heat capacity. The losses to evaporation can be expected only with a total heat influx exceeding 112 kjoules/kg.

At the present time the simplest and most economical method of obtaining this slush is vacuum pumping of the liquid hydrogen vapor with alternate processes of freezing-thawing, insuring periodic breaking of the solid crust on the surface of the liquid hydrogen.

A characteristic feature of hydrogen slush obtained in this way is the process of "aging" it. Initially the loose particles of undefined shape that were obtained become spheroidal with time, forming a dense mass in the precipitated slush. On storage of the slush, in order to eliminate thermal stratification and local compacting it is necessary to mix it. In order to maintain a uniform homogeneous mixture in the tank, the concentration of the solid phase must not exceed 60%. In order to free the slush it is possible to use both pumping and forced means of feed.

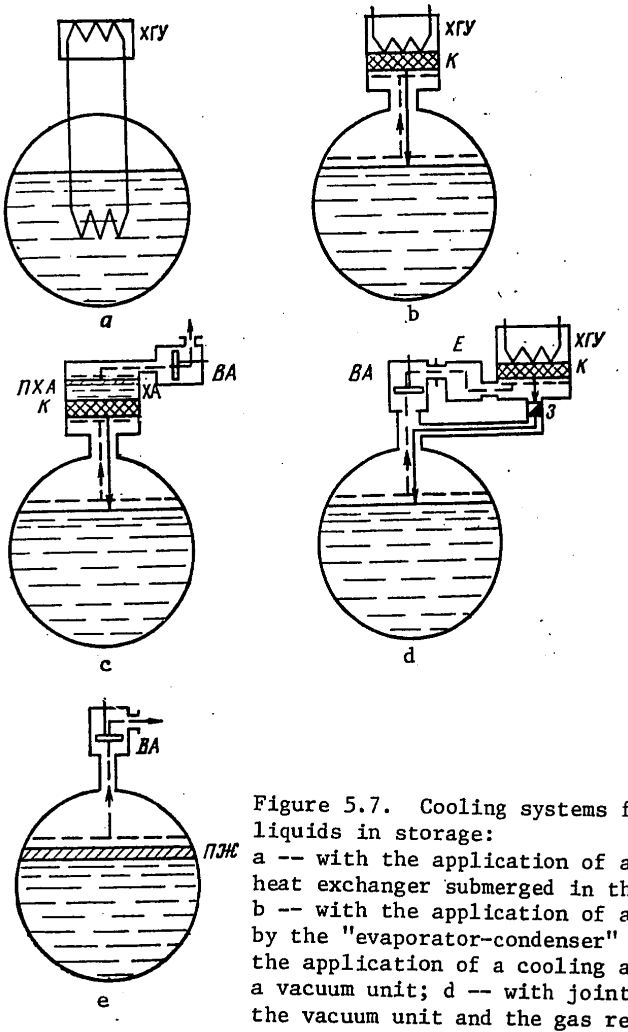
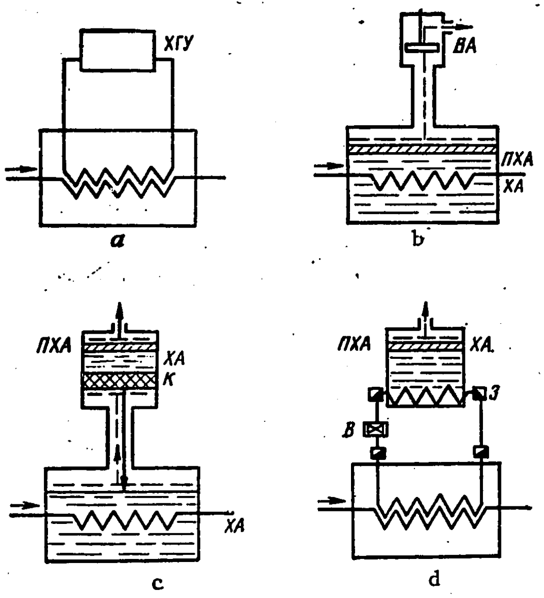


Figure 5.7. Cooling systems for cryogenic liquids in storage:
a -- with the application of a gas cooler with heat exchanger submerged in the cooled liquid; b -- with the application of a gas refrigerator by the "evaporator-condenser" system; c -- with the application of a cooling agent cooled using a vacuum unit; d -- with joint application of the vacuum unit and the gas refrigeration unit which condenses the vapor after the vacuum unit; e -- with the application of a vacuum unit with loss of cryogenic liquid as a result of discharge of the vapor to the atmosphere; ХГУ -- gas refrigeration unit; ХА -- coolant; ВА -- vacuum unit; Е -- vapor gathering tank; 3 -- gate valve; пж -- liquid losses; ПХА -- coolant losses; К -- condenser.



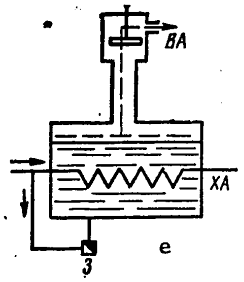


Figure 5.8. Cooling diagrams of cryogenic liquids when they are flowing in a pipeline: a -- the heat exchanger of the gas refrigeration unit; b -- heat exchanger with coolant cooled by evacuation; c -- heat exchanger with the application of coolant and condensation of its vapors using another coolant with lower temperature; d -- heat exchanger with the application of inert gas as the intermediate heat-transfer agent cooled by the coolant; e -- heat exchanger with coolant (liquid picked up from the basic flow) cooled by evacuation; ХГУ -- gas refrigeration unit; К -- condenser; ХА -- coolant; ВА -- vacuum unit; В -- ventilator fan; З -- gate valve; ПХА -- coolant losses.

The simplest system of supplying the hydrogen slush to the rocket tank is the circulation loop through which the hydrogen slush goes from the ground storage to the tank to a defined level; then the feed is continued with simultaneous discharge of the cooled hydrogen to the ground filling system through a drain hole having a special device for protection from the solid particles. Thus, in the tank it is possible to obtain the required concentration of the solid phase.

The control fill-cutoff fittings (gate valves, valves) are designed to control, regulate and stop the feed of cryogenic liquid during the technological process operations of storing and filling the tanks in the space rocket systems, and, as a rule, it has manual, or pneumatic drives and signals of the required positions of the shutoff (plates). Two separate cavities of the pneumatic drive provide for fixed extreme positions of the valve plate as a result of feeding compressed gas to one of the cavities and the absence of it in the other. In addition, the structural design of the individual valves provides for one of two extreme positions of the plate without the presence of compressed gas as a result of the effect of a spring. On storage between losses, the seal of the inside cavities of the system is insured by the manual seal valves. In some cases the pneumatic drive of the valve can have a manual, worm transmission by means of which it is sealed without feeding compressed gas.

Before the beginning of filling, compressed gas is fed to the valve, and the necessary manual valves are open, as a result of which the hydraulic fitting of the system is initialized in which the inside cavities of the lines are protected from the incidence of atmospheric air, and the pressure in them is increased from evaporation.

The pneumatic valves through which the high liquid flow rate takes place have special devices providing for slow variation of the flow rate (from the maximum value to total cutoff) to avoid hydraulic hammer.

For this purpose the cutoff fitting of the fill and drain lines of the system is placed in such a way that in the basic flow line there were no large blind taps in which the vapor phase can form during movement of the cryogenic liquid through the main line. The presence of such taps can lead to unexpected hammer phenomena in the response of the fittings installed in the blind taps and in the main line. For example, when opening the valve of a blind tap (Fig 5.9, a) the vapor accumulated in the blind tap flows out quickly, and the liquid from the basic line, accelerating and approaching the still incompletely open valve, is braked sharply, as a result of which hydraulic hammer takes place. This type of hydraulic hammer (Fig 5.9, b) can be formed in a blind tap and when the valve is closed on the main line. In this case, in the basic line when braking the flow in front of the valve, the pressure rises, the liquid begins to fill the blind tap, as a result of which the vapor phase in it can be condensed and the flow speeded up.

In order to avoid this phenomenon in the blind taps small drain holes are used to exclude the accumulation of vapor, and a careful analysis in calculation of the response sequence of the valves is carried out during the technological operations connected with the feed or discharge of the cryogenic liquid. Underestimation of this situation can lead to serious consequences. Thus, during the process of test filling of a mockup of the "Saturn-V" booster rocket during blowing of the tank from the gasifier, unexpected closure (2 minutes after opening) of the valve occurred on the section line of the fill pumps, as a result of which hydraulic hammer occurred, the magnitude of which (26 MPa) exceeded the margin of strength of the corrugated pipeline, which led to its rupture and the loss of 2765 m^3 of liquid oxygen.

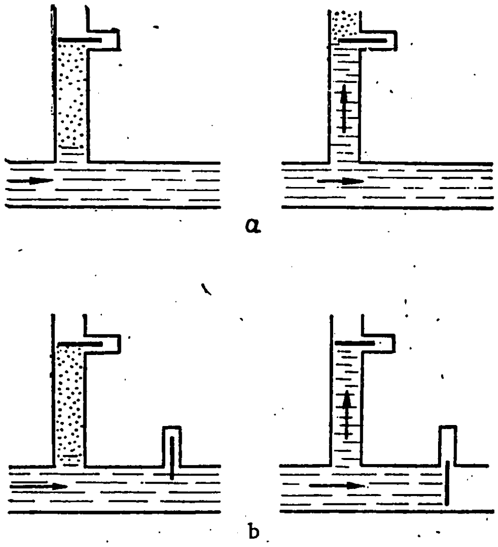


Figure 5.9. Schematic of sections of cryogenic pipelines with blind taps:
a -- when the valve of the blind tap is open; b -- when the valve on the main line is closed.

The fittings for cryogenic liquids usually are made according to the following scheme: a housing connected with the line using split or unsplit couplings -- the shutoff with drive (spindle group) having a split connection with the housing, which makes it possible to replace it in case of using up the reserves or failure without dismantling of the line. In order to decrease the heat influx to the cryogenic liquid the housing has thermal insulation in the form of the outer powdering with the thermal insulating material or double walls, the cavity between which is filled with powder or multilayer insulation and is connected to the vacuum cavity pipelines. In order to reduce the thermal influxes from the direction of the spindle group, the cutoff unit is connected to the push rod of the drive through a heat insulating bridge, which makes it possible to place the drive in the "warm" zone and essentially simplifies its structure and servicing.

High requirements with respect to seal are imposed on the fittings of the cryogenic fill system. They are insured by creating the required specific pressure on the seal of the "seat-slide" lock in the application of sealants of the type of polyfluoroethylene-steel, steel-steel, and so on.

The means of removal and discharge (drainage) of the cryogenic liquid and its vapors in the cryogenic fill system consists of drain lines designed to remove the liquid vapors from the cushions of the tanks and the booster rocket tanks and for removal of the liquid and its vapors from the drainage valves and the valves on the fill lines and also from the fill columns of the storage.

The ends of the drain lines are taken out to one location insofar as possible, located at a safe distance from the launch complex systems. The vapor is discharged to the atmosphere here, and the liquid is drained into special tanks or trenches.

The drainage of liquid and gaseous nitrogen is the simplest and does not require that special measures be taken. The drainage of the oxygen vapors as a result of explosion and fire hazard of the mixtures with organic materials is realized through special fittings which decrease the gaseous oxygen content to safe concentrations in the boundaries of the drainage area. Liquid oxygen is collected in a special drain tank.

The drainge of the liquid and gaseous hydrogen is most complicated, for the existing safety engineering rules do not permit the creation of fire-hazardous concentrations on ground level near the exits from the drainage systems. For low flow rate hydrogen is discharged without retardation by an inert gas or after burning; with large flow rates, with retardation or with afterburning using a special ignition plane.

Hydrogen is afterburned by the method of combustion through a hydroseal, the drain line of which is protected by water from air getting into it or directly through the drain line and the afterburner. Devices are installed on all of the drain lines which exclude advancement of the flame front to the drain line. Usually before the beginning and after discharge of gaseous hydrogen, the drain line is purged with 10-15-fold volume of gaseous hydrogen or helium.

When transporting liquid hydrogen, the drainage regime is selected considering the minimum speed in the drainage line fitting in which turbulent mixing of gaseous hydrogens with the surrounding air takes place and obtaining the flow rate of the gaseous hydrogen at the exit which does not require afterburning or retardation.

The hydrogen vapor is ejected through a special, so-called safe drainage device designed to obtain hydrogen-air mixture with the hydrogen content excluding inflammation.

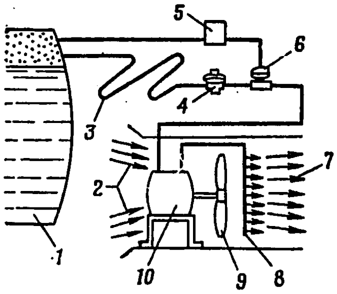


Figure 5.10. Drainage system of a railroad tanker:
1 -- liquid hydrogen tank; 2 -- surrounding air moved by a fan; 3 -- coil heater; 4 -- flow rate regulator; 5 -- regulator; 6 -- regulating valve; 7 -- incombustible hydrogen-air mixture; 8 -- connecting line for discharge of the gaseous hydrogen; 9 -- fan; 10 -- gas turbine.

The diagram of a drainage system (Fig 5.10) developed in the United States for a railroad tanker that carries liquid hydrogen provides for an automatic mode of maintaining excess pressure in the gas cushion of the tank. On achievement of a defined pressure in the cushion, the valve automatically opens and the gas goes through the coil heater and pressure regulator to the gas turbine which turns the air fan. On leaving the turbine the hydrogen is dispersed in front of the fan, mixing with the air, which leads to a hydrogen-air mixture in which the hydrogen content is appreciably below the inflammation limit.

The evacuation means are used to create and maintain a vacuum within the required limits in order to insure efficient operation of the thermal insulation in the tanks and lines during operation.

Before putting the cryogenic liquid in the tank, provision is made for evacuation of its thermal insulating cavity to a residual pressure of 1.3 Pa through the vacuum lock with the pipeline to the evacuation column. The residual pressure during preliminary evacuation is controlled by the thermocouple tubes with exit to secondary instruments and through the electrocontact vacuum meters. After putting the cryogenic liquid in the tank, the vacuum in the thermal insulating cavities is brought to the required value, and it is maintained during the operating process by adsorption pumps.

Adsorbents are materials capable of adsorbing residual gases by their surface. The adsorption process is exothermal; therefore the amount of absorbed gas increases with a reduction in the adsorbent temperature. In the adsorption pumps the adsorbent is in the zone with lowest temperature, which provides for maintenance of the given vacuum with admissible leakage of gases into the thermal insulating cavity over a long period of time.

For example, some industrial tanks with activated charcoal are capable of maintaining the required vacuum for several years. With a decrease in the absorption capacity as a result of saturation with gases the adsorbent is heated to high temperatures (the absorption capacity is restored).

In modern tanks, a multilayer vacuum shield and vacuum powder insulation are used as thermal insulation.

The multilayer vacuum shield insulation is a set of series-arranged deflecting shields with minimum degree of blackness thermally insulated from each other by separating inserts. The reflecting shields limit a large part of the heat influx as a result of radiation, and the separating inserts decrease the thermal conductivity between adjacent shields. The effectiveness of this insulation is determined primarily by the material of the reflecting shield, the inserts, the amount of pressure in the thermal insulation space, the process used to manufacture it and install it in the tank. The shields usually are made of aluminum foil several microns thick or from aluminized (on one or both sides) polymer film, and the inserts are made of various fiberglass materials (glass paper, glass wall, glass voile, and so on). The multilayer vacuum shield insulation requires a deep vacuum (to 0.01 Pa), for with a decrease in it, the coefficient of thermal conductivity increases sharply (by 200 to 300 times with an increase in pressure to 133.3 Pa).

The powder vacuum insulation is an evacuated (to 13.3-1.3 Pa) space filled with powdered material (aerogel, perlite, and so on) with low coefficient of thermal conductivity. A further increase in the vacuum has no significant effect on the magnitude of the thermal influx which is determined not by the thermal conductivity of the residual gases but by the thermal radiation and thermal conductivity of the powder material. The thermal emission through the vacuum powder insulation decreases also with addition of metal and nonmetal powder to it playing the role of shields. However, such additives (bronze, aluminum), along with a decrease in thermal radiation, cause growth of the thermal conductivity; therefore the concentration of the added powder must insure minimum coefficient of thermal conductivity.

The multilayer vacuum-shield insulation is more effective than the powder vacuum insulation. It has a coefficient of provisional thermal conductivity (including all the components of the influx through the insulation) approximately 10 times lower than in the powder-vacuum insulation, and it is basically used in transport tanks for liquid hydrogen and helium and also in tanks in which the application of the powder vacuum insulation does not insure the given requirements with respect to evaporability.

In addition, this insulation makes it possible to have a thickness of the vacuum space much less than for the powder vacuum insulation, for a large number of shields can be put in the limited space.

In practical developments, the combination of these two types of insulation find application (insulation shields placed in the vacuum space filled with powdered insulating material).

Safety Measures

It must be remembered that spills of cryogenic liquid are dangerous from the biological point of view. This is explained by low temperature, easy evaporability and large concentrations of the vapor formed in the facility.

Entrance into the facility and the structures and remaining in them are permitted only with an admissible vapor concentration.

It is necessary to work with cryogenic liquids only in protective clothing and glasses, avoiding incidence of them on exposed parts of the body, for this can lead to burns and tissue death.

Oxygen is fire-hazardous; therefore a small spark occurring as a result of the accumulation of static electricity or on impact can cause ignition of the gaseous oxygen-saturated clothing and other materials.

When designing and installing the ventilation units at the sensors of the gas analysis system it is taken into account that the gaseous oxygen is heavier than air, as a result of which it can fill low places in the facilities and structures.

Hydrogen is the lightest element; its vapors are appreciably ligher than air, and the energy impulse required for ignition is low. This increases the possibility of its ignition even for a relatively short time of dangerous concentration in an open area. A spark or flame in an open space causes ignition of a hydrogen-air mixture. The high rate of combustion of hydrogen and the short length of the flame extinguishing section complicate fighting such a fire. During the combustion of hydrogen in a closed facility the increase in pressure can lead to an explosion although usually almost ideal mixing of the gases and the presence of an explosion shock wave are required for an explosion. In addition, the presence of various impurities, especially oxygen in liquid hydrogen is dangerous. The low boiling point of liquid hydrogen and the extremely low solubility of oxygen in it can lead to the accumulation of oxygen particles and air in the storage tank, the mixture of which with hydrogen explodes. With an insignificant oxygen content the mixture is not explosive.

For operating safety with liquid hydrogen, various measures are taken which exclude the probability of ignition and the formation of fire-hazardous and explosive mixtures: the grounding of the tanks and lines, preventing accumulation of static electricity, protection against atmospheric electricity, the application of electric power equipment in the explosion and fire safe execution or transfer of it to the safe zone;

measures with respect to fire and explosion prevention consisting in constant remote gas analysis by low-inertia sensors and the taking of the required measures with respect to the analysis results (curtailment of filling, the feed of an inert medium, and so on) using high-speed remotely controlled equipment.

The formation of dangerous concentrations of hydrogen in the atmosphere prevent ventilation of possible leaks, spills of liquid hydrogen are prevented by the application of welds, and the formation of fire-hazardous mixtures, by maintaining excess pressure inside the system excluding the incidence of air; by cleaning out the lines and tanks to remove oxygen, air and other impurities to the admissible amounts before filling them with liquid hydrogen and installing fine-purification filters on the fill lines of the tanks; periodic cleaning of the tanks to remove accumulated impurities by draining and heating the tanks with analysis of the residual gases to determine the accumulated impurities.

Filling the "Saturn-V" Booster Rocket with Cryogenic Fuel Components

For example, let us consider the procedure for filling the "Saturn-V" booster rocket. The rocket tanks are filled first with liquid oxygen, then liquid hydrogen. The total fill time is 4.5 hours in this case.

In order to fill the tanks of the S-I, S-II and S-IV stages with liquid oxygen, a fill system is used which includes the following:

A spherical tank with perlite insulation with a volume of about 3400 m^3 calculated for inside pressure to 82 kPa consisting of an inside vessel of alloyed steel of the austenitic class 21 meters in diameter, an outside vessel of ordinary, unalloyed steel 22.8 meters in diameter; suspension of the inside vessel executed using vertical and horizontal rods; pipelines exiting from the inside vessel and located in the thermal insulating space of the tank along the length in such a way as to insure minimum thermal influxes and to protect the cutoff fittings from low temperatures during storage;

The heat exchanger for gasification of the liquid oxygen insuring a pressure in the tank cushion required for normal operation of the centrifugal pumps;

A pumping station for feeding oxygen to the tank with two centrifugal pumps (one reserve) with high output capacity (38 m^3/min with a pumping pressure of 3.72 mPa); the pump drives, through an electromagnetic coupling which during the filling process insures adjustment of the flow rate from 9.5 to 38 m^3/min for high output pumps and from 0.57 to 3.8 m^3/min for low-output pumps;

The fill lines under the distribution modules of the valves for each tank (the fill lines for large flow rates of 0.35 m in diameter has no insulation; the fill line for small flow rates of 0.152 meters in diameter has vacuum insulation);

The drain line for removal of oxygen to the drainage area.

The filling process consists in filling the tank first with a low flow rate (approximately to 5 to 7% volume), then on the large flow rate (to 90-96%) with subsequent transition to small flow rate, and on completion of batching, to the makeup rate. The tanks of the S-I, S-II, S-IV stages are filled to 1300 m^3, 320 m^3 and 80 m^3 of liquid oxygen respectively.

To fill the tanks of the S-II and S-IV stages with liquid hydrogen, a filling system which includes the following is used:

A spherical tank with powder vacuum (perlite) insulation about 3230 m^3 in volume designed for an internal pressure to 0.61 mPa consisting of the inside tank made of high-alloy steel 18.5 meters in diameter and the outside tank made of ordinary unalloyed steel 21 meters in diameter;

The heat exchanger located near the tank, for gasification of liquid hydrogen to create the blowing pressure with the forced method of feeding hydrogen to the tank; gasification takes place as a result of heating of the surrounding air;

The fill lines with vacuum thermal insulation and the distribution blocks of valves for each tank;

Drainage lines for removal of hydrogen to the combustion area;

A high-pressure tank receiver for gaseous hydrogen with portable gasification unit (the gaseous hydrogen is required to burn the hydrogen coming from the drain lines of the system).

Before filling, all the inside volumes for gaseous and liquid hydrogen are purged successively by nitrogen and helium to remove oxygen.

The process used to fill the tank consists in cooling the tank with a small quantity of hydrogen, filling the tank with low rate (to 5% of the volume), then at high rates (to 95%) with subsequent transition to low rate and on completion of batching, to makeup rate. The tanks of the S-II and S-IV stages are filled with 1000 m^3 and 280 m^3 of liquid hydrogen respectively.

All the filling operations are performed automatically using special control systems which insure the required sequence of operations both for normal operating conditions and for various deviations and failures. This control is duplicated by the remote and automatic control panels for each control element. During the filling process, television viewing and monitoring of the responsible assemblies and units are constantly carried out.

5.4. Systems for Filling with High-Boiling Fuel Components

The high-boiling fuel components are used in rocket engineering for the basic and auxiliary engines of the booster rockets and space vehicles. Some of the data on the application of high-boiling components are presented in Table 5.3, and their physical-chemical properties, in Table 5.4.

Table 5.3

Some Data on the Application of High-Boiling Fuel Components in Space Rocket Systems

Rocket (stage)	Fuel Oxidant	Combustible component
"Kosmos" (first stage)	Nitric acid	Kerosene
"Kosmos" (second stage)	Liquid oxygen	Asymmetric dimethylhydrazine
"Titan-II", "Titan-III"	Nitrogen tetroxide	Aerozin-50
"Agena" (stage)	Nitric acid	Asymmetric dimethylhydrazine
"Apollo" spacecraft:		
Takeoff and landing engines;	Nitrogen tetroxide	Aerozin-50
Orientation engine	The same	Monomethylhydrazine
"Surveyor" spacecraft (the steering engine)	The same	Aerozin-50
"Centaur" (stage); auxiliary engine	Hydrogen peroxide	

Nitric acid HNO_3 is a high-boiling oxidant with high density. It is explosion-safe. 100% nitric acid is a colorless liquid with sharp odor, it is hygroscopic, unstable and toxic. It decomposes easily into water, free oxygen and nitrogen oxides (the latter color it from yellow to brown). Additives of nitrogen tetroxide or water are used as stabilizers. The nitric acid vapors are harmful to the health (if they get on the skin they cause diseased, slow-healing ulcers).

Nitric acid and its vapor have high corrosion activity with respect to the majority of materials, for the reduction of which, the so-called inhibitors are introduced into the nitric acid. For storage, stainless chrome and chrome-nickel high-alloy steel, the majority of aluminum alloys and non-metallic materials (polyfluoroethylene, asbestos) are used for storage.

The effectiveness of nitric acid, as an oxidant, increases significantly on solution of nitrogen oxides.

Nitrogen tetroxide, N_2O_4, is a high boiling oxidant. It is more effective than nitric acid. Nitrogen tetroxide is explosion-safe, stable and less aggressive than nitric acid, and it is toxic. Insuring greater specific thrust (by 5%) than nitric acid, it has a narrower range of maintenance

Table 5.4

Basic Physical-Chemical Properties of Some High-Boiling Fuel Components

Fuel	Chemical formula	Density, kg/m^3	Boiling point T_k, °C	Melting point T_{melt}, °C
Nitric acid	HNO_3	1510	86	-44
Nitrogen tetroxide	N_2O_4	1450	21	-11
Kerosene	$C_{10}H_{20}$ (provisional)	800	200–250	-49
Hydrazine	N_2H_4	1010	113	+ 1.5
Asymmetric dimethyl-hydrazine	$H_2N\text{-}N(CH_3)_2$	790	63	-57
Monomethylhydrazine	$H_2N\text{-}NH(CH_3)$	875	87.6	-52.4
Aerozin-50	Mixture of 50% asymmetric dimethyl-hydrazine and 50% hydrazine	900	70	- 7.3
Hydrogen peroxide (100%)	H_2O_2	1450	150	- 1

of liquid state, which is increased by dissolving other nitrogen oxides in it. For example, the introduction of nitrogen monoxide lowers the freezing point by approximately 28°.

Kerosene $C_{10}H_{20}$ is a high-boiling fuel, colorless or yellow liquid. It is a mixture of hydrocarbons obtained for distillation of petroleum within defined temperature or cracking limits; out of all of the fuels it is the most dangerous, simplest and most convenient in operation. It is chemically stable even at high temperatures, it has low corrosion activity with respect to metal and has low toxicity. Kerosene is cheap and available. It is widespread in engineering, and its production has a broad raw material base. Kerosene has inconstancy of chemical composition, depending on the origin of the petroleum. This deficiency is eliminated by creating artificial hydrocarbons which have the same characteristics as kerosene but have defined chemical composition and constant chemical properties. Kerosene is inert with respect to construction metals, but admixtures with water, sulfur compounds and organic acids increase its corrosiveness.

Hydrazine N_2H_4 is a high-boiling combustible and a single-component fuel for liquid-propellant rocket engines. It has the highest density among the fuels used, and is colorless, it smokes in the air, it is capable of thermal or catalytic decomposition with the formation of a hot gaseous mixture of hydrogen, nitrogen and ammonia; it is hygroscopic, it easily picks up atmospheric moisture; it is toxic, it has an irritating effect on the mucous membrane of the eyes; on superheating in a closed space or under the effect of a powerful pulse it is subject to explosive decomposition; it has high hardening point which complicates use of it. With respect to metals it has low corrosion activity, but in the presence of oxygen it acts on copper and its alloys. The copper ions catalyze the decomposition. In rocket engineering, it is used as a fuel component with asymmetric dimethylhydrazine (aerozine-50), ammonia, and so on.

The asymmetric dimethylhydrazine (ADMH) $H_2N\text{-}N(CH_3)_2$ is a high-boiling fuel, a derivative of hydrazine obtained by replacement of the hydrogen atoms by hydrocarbon groups; a colorless liquid with ammonia odor, it is hygroscopic and toxic; as a fuel it is less effective than hydrazine (in its molecule in addition to hydrogen atoms it contains less effective carbons), it is more convenient in operation, for it retains its liquid state in a large temperature range; in the presence of water it is corrosion active with respect to aluminum and its alloys; it is easily oxidized by oxygen of the air.

Asymmetric dimethylhydrazine is thermally stable, but with an increase in temperature it decomposes with the release of heat and the formation of hot gaseous products; it is less explosive than hydrazine, but on superheating in a closed space it explodes. It is superior to nitric acid with respect to toxicity.

In missile engineering it is used as a basic fuel, a component part of the combustible (aerozin-50) and as a single-component fuel for the turning of the pump turbines of the engines.

Monomethylhdrazine $H_2N\text{-}NH(CH_3)$ is a high-boiling fuel, a derivative of hydrazine, colorless liquid which fumes in the air with ammonia odor, and it is toxic; with respect to its properties, including corrosiveness it is similar to asymmetric dimethylhydrazine. With respect to effectiveness and stability it occupies an intermediate position between hydrazine and asymmetric dimethylhydrazine.

Hydrogen peroxide H_2O_2 is a high-boiling oxidizing agent and a single-component fuel, a colorless liquid, it is toxic, explosion and fire hazardous (organic materials are easily burned on contact with it), when it gets on human skin it causes serious burns and is unstable. Metals (copper, nickel, silver, the products of iron corrosion, and so on) and chemical manganese compounds are catalysts, on contact with which hydrogen peroxide decomposes stormily into water and atomic oxygen with the release of a large quantity of heat. Water evaporates, and the mixture obtained (vaporizing gas) is heated to 520°C with 80% concentration and to 1000°C with 99% concentration. The equipment for the hydrogen peroxide is carefully cleaned (degreased, flushed with distilled water, and so on), and it is passivated.

Such properties of the components as high corrosiveness, toxicity, inclination to decomposition, fire and explosion hazard, self-ignition of some of the fuel vapor, high requirements with respect to batching accuracy when filling require the corresponding schematic and structural solutions when designing the filling systems. Therefore, the schematic diagram of the filling systems using high-boiling components has such specific equipment as the batchers for insuring high accuracy of filling (for filling the space vehicles), means of neutralizing the toxic components and their vapors, thermostating systems to provide for filling the tanks with components of a defined temperature.

The high-boiling components stored usually are made up of several tanks (for especially aggressive liquids a reserve tank is provided) and troughs for removal of the spilled liquid to a neutralization system.

The reserve of the stored component is selected beginnig with the quantity consumed for one or several fillings, to fill the lines connecting the storage and the rocket, for guaranteed remains in the tank and so on.

The tank for high-boiling components is a cylindrical reservoir with semi-elliptic ends and single walls, the composition of which includes safety valves operating both on excess pressure and on rarefaction; the devices for taking samples; the means of monitoring and measuring levels, temperature and pressure both with direct and with remote monitoring; the fill lines, drain lines and blowing lines and devices for removing air (deaeration) from the components.

In some cases (when thermostating the liquid) the tanks have thermal insulation on the outside made of incombustible insulation material (asbestos, slag cotton, glass cotton, and so on) protected by a housing or hood.

When storing the components having high corrosiveness and hygroscopicity, measures are used to purify them of possible mechanical impurities and water.

The liquids oxidized in the air are stored at excess pressure of the natural vapor or inert gas (nitrogen, helium, and so on).

A mandatory condition of the stable storage of hydrogen peroxide is the presence of defined thermal conditions and finish of the inside surfaces of the vessels for which the equipment is passivated.

Before filling and during the storage process many of the fuel components are thermostated (cooled or heated), which arises from the calculated density of the component in the tanks or the condition of its stable storage. As a rule, the fuel components are cooled in the summer and heated up in the winter.

The required storage temperature is maintained by thermostating the system having means of remote monitoring and control. In the launch complex the source of cold (heat) is the only refrigeration center; at the filling station it is a special thermostating system including freon refrigerators and water heating elements. The heat transfer agents are nonfreezing solutions of salts or antifreezes. The fuel components are thermostated by circulation using a pump in the "tank-heat exchanger" loop.

Before filling, in order to insure reliable starting of the engine, some of the fuel components are subjected to deaeration (removal of air) by evacuation of the space above the liquid surface or bubbling (passing an inert gas — nitrogen or helium — through the liquid).

The means of supplying the high-boiling fuel to the tanks of the booster rockets and space vehicles use both forced and pump methods of feed. The main lines are laid usually with some slope to insure complete drainage of the components on completion of the filling into special drainage tanks from which after taking the analysis the liquid goes back to the storage tanks or into the neutralization system. For seal, the joints of the sections of the aggressive liquid lines are made welded or with a minimum number of flange connections. All of the fittings have seals.

In order to fill the booster rocket tanks with toxic components, two systems are used. With respect to one system the vapor formed during filling is run through the drain line into special units (afterburners) in which they are burned, and the combustion products go to the atmosphere; in accordance with another scheme the vapor formed goes through the drain line from the booster rocket to the gas cushion of the storage tank (the so-called connection). For toxic, aggressive, fire-safe liquids, field pumps are used (Fig 5.11) without shafts that go to the outside in the explosion-protected execution.

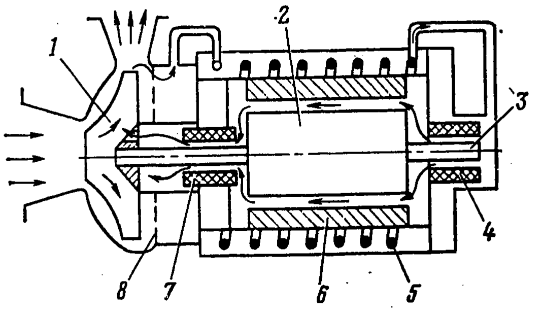


Figure 5.11. Sealed electric pumps for toxic, aggressive and fire-hazardous liquids:
1 -- impeller; 2 -- rotor; 3 — shaft; 4 -- rear bearing; 5 -- coil; 6 -- stator; 7 — front bearings; 8 -- screen

The tanks of the space rocket system are filled with high-boiling fuel components both at the filling station and the engineering complex (the tanks of the space vehicle) and in the launch position (the tanks of the booster rocket and the space vehicle).

Each component has its own filling system at the filling station (Fig 5.12), which includes the basic storage, batcher, filling columns and liquid, gas and vacuum pipelines which connect them into a united pneumohydraulic system. The pipelines are connected to the fill necks of the tanks using filling connections serving also to drain the component, evacuate the lines in the tanks, for spilling of the component before filling, drainage and purging of the fill lines before disconnecting, supplying the required reagents to decontaminate the toxic components. For safety, the fill connections for the fuel and the oxidizing agent are located on opposite sides, alongside the fill columns.

The filling process consists of coupling the lines of the fill systems to the fill connections of the space vehicle and checking the joint for seal, thermostating of the component in the given temperature and deaeration (these operations usually are performed in advance), filling of the batcher, evacuation of the fill lines from the batcher to the fill connections and tanks (when filling by the drainless system), filling the fill lines to the tanks (in order to increase the accuracy of the batching), filling the tanks from the batcher to the given amount, drainage and purging of the fill lines to the drain tank with relieving of the batcher of the component, disconnecting the fill connections, sealing the fill necks of the tanks and neutralization of the remains of the components and its vapor.

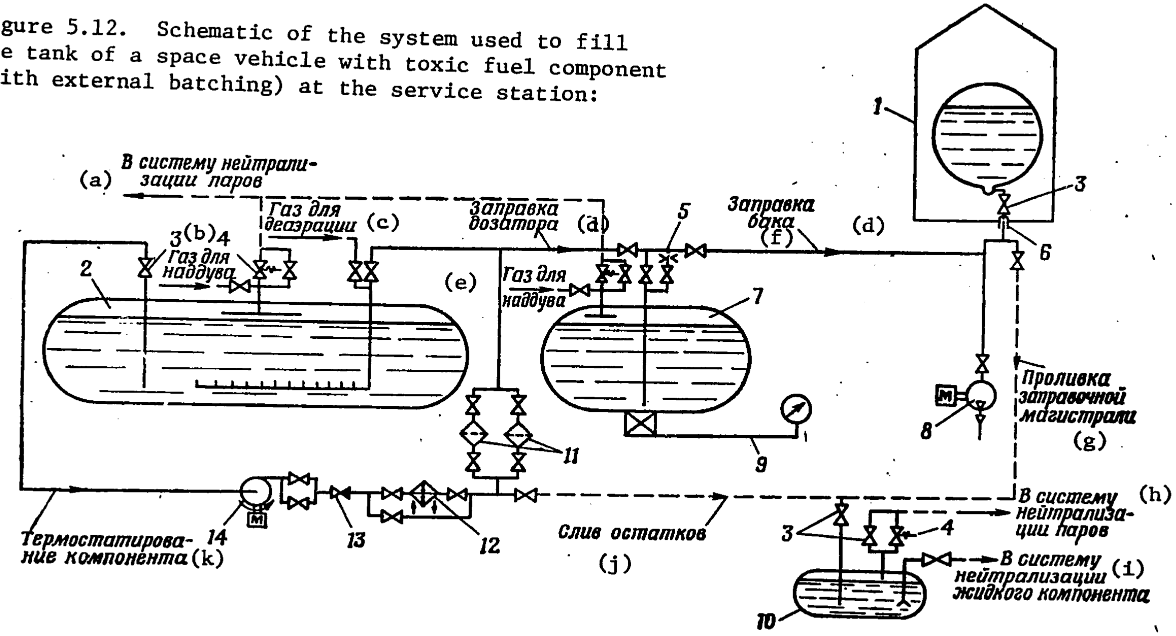
In the case of internal batching (Fig 5.13) the fill system does not have a batcher, which determines its theoretical peculiarity and the filling process.

The neutralization means provide for decontamination of the toxic and aggressive liquids and their vapor.

The most widespread are two neutralization methods: physical -- flushing and purging the lines based on good solubility of certain liquids and water or in organic solvents and chemical — neutralization of the oxidizing agents by solutions of alkali, and the combustible fuel components by strong oxidizing agents (chlorine-containing reagents). When selecting one method or another the structure of the equipment subject to neutralization is taken into account (the tank configuration, the presence of places that are difficult of access, and so on) and also the corrosion resistance of the materials with respect to neutralizing materials and neutralization products.

The neutralization of toxic and aggressive liquids and vapor is possible also by burning them in the neutralization chamber (Fig 5.14) with subsequent discharge of the combustion products into the atmosphere. Such chambers are made both stationary and portable. The neutralization of the components and the vapor by accumulation of them and subsequent effect on them by the corresponding chemical reagents is possible (Fig 5.15). These chemical reagents decompose the components and vapor to harmless compounds. The aqueous solutions of the final reaction products are pumped by pumps into the evaporation areas. In order to absorb the vapors of toxic components, adsorbents are used.

Figure 5.12. Schematic of the system used to fill the tank of a space vehicle with toxic fuel component (with external batching) at the service station:



1 -- space vehicle; 2 -- storage tank for the toxic component; 3 -- cutoff valves; 4 -- safety drain valves; 5 -- choke disc; 6 -- filling connections; 7 -- mass batcher; 8 -- vacuum pump; 9 -- device for measuring the mass of the component in the batcher; 10 -- drain tank; 11 -- filters; 12 -- heat exchanger of the thermostating system; 13 -- check valves; 14 -- centrifugal seal pump.

Key: a -- to the vapor neutralization system; b -- gas for blowing; c -- gas for deaeration; d -- filling the batcher; e -- gas for blowing; f -- filling the tank; g -- fill line spill; h -- to the vapor neutralization system; i -- to the liquid component neutralization system; j -- drainage of remains; k -- thermostating of the component.

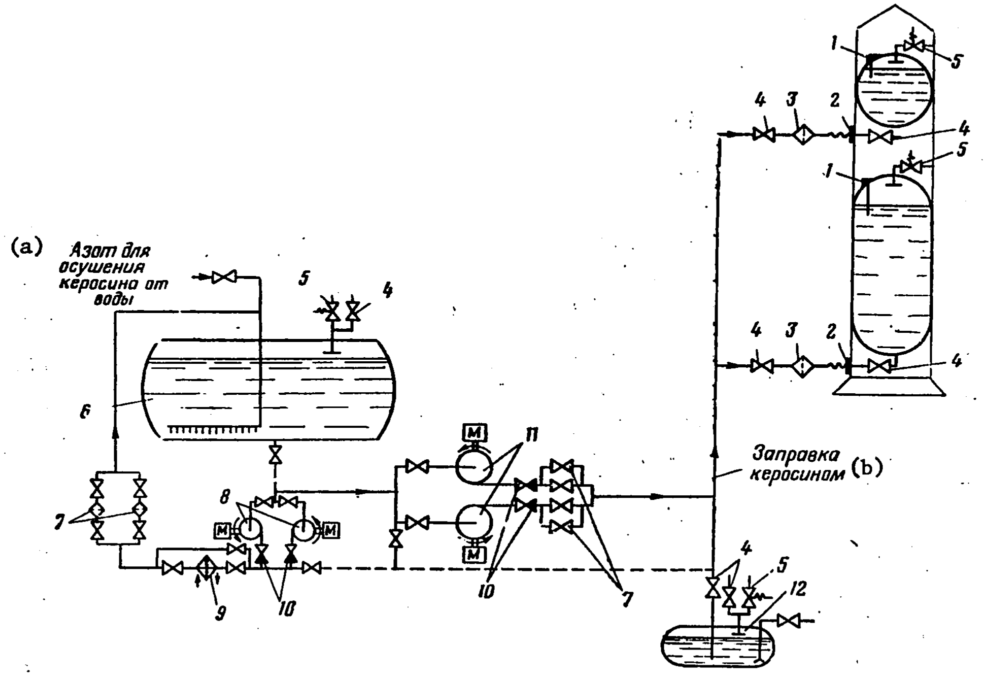


Figure 5.13. Schematic of the system used to fill rocket tanks with kerosene (with internal batching) at the launch complex:
1 -- level gauges; 2 -- split connections of the rocket; 3 -- filters; 4 -- cutoff valve; 5 -- safety drain valve; 6 -- kerosene storage tank; 7 -- filters of the thermostating system; 8 -- pumps of the kerosene thermostating system; 9 -- heat exchanger of the thermostating system; 10 -- check valve; 11 -- filling pump; 12 -- drain tank

Key:
a -- nitrogen for drying kerosene of water; b -- filling with kerosene

Hydrogen peroxide is neutralized by multiple dilution with water; the use of water jet pumps simultaneously pumping out and diluting the hydrogen peroxide is especially effective.

During operation of the fill systems, safety measures are carefully observed. The incidence on the skin of aggressive liquids causes strong slow-healing burns and ulcers; therefore all operations are performed in special protective clothing. Before entering into the facility with the fill equipment usually the gas content of the air is monitored by the gas analysis system, and if necessary, gas masks are used.

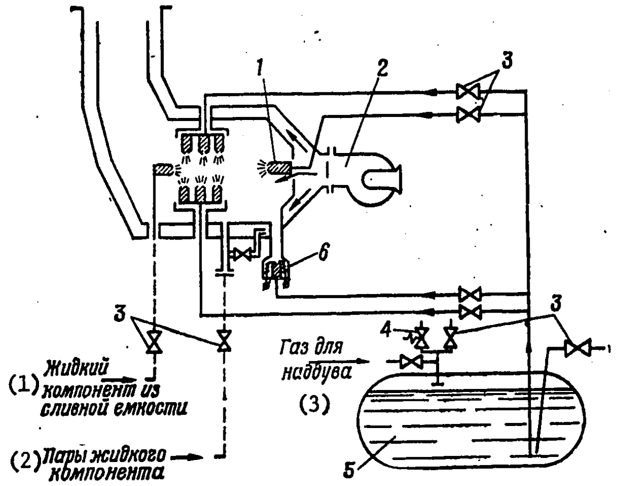


Figure 5.14. Neutralization system for the toxic component by combustion:
1 -- combustion chamber with injector; 2 -- air fan; 3 -- cutoff valve; 4 -- drainage safety valve; 5 -- fuel tank; 6 -- forechamber with sparkplug

Key:

1. Liquid component from the drain tank
2. Vapor of liquid component
3. Gas for blowing

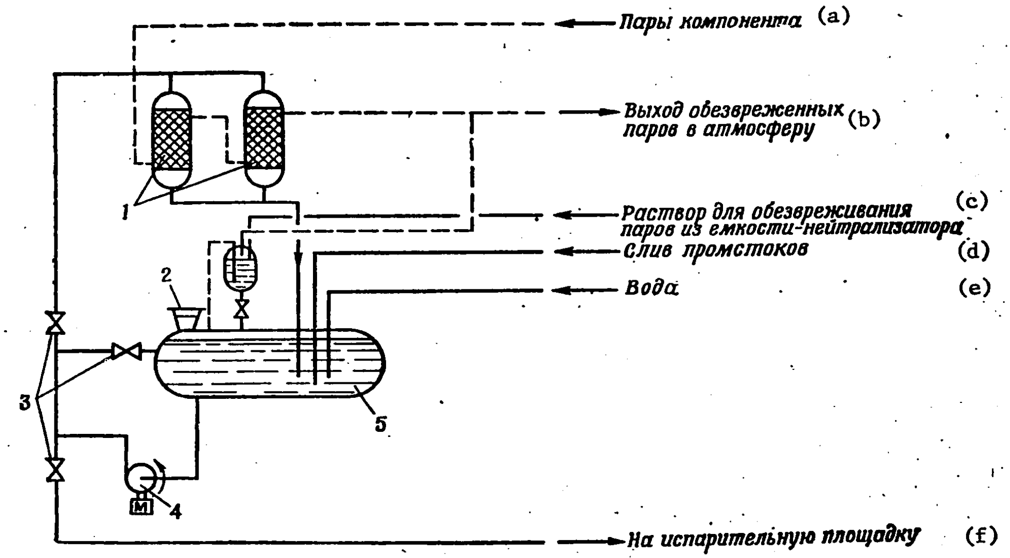


Figure 5.15. Neutralization system for the toxic component using the chemical method: 1 -- adsorber; 2 -- charging neck for the reagent; 3 -- cutoff valve; 4 -- pump; 5-- neutralization tank

Key:

a -- component vapor; b -- exit of contaminated vapor to the atmosphere; c -- solution for decontamination of the vapor from the neutralizer tank; d -- drainage of industrial waste; e -- water; f--to the evaporation area

Filling the Space Rocket System with High-Boiling Fuel Components

As an example, let us consider the filling of some of the space rocket systems.

The "Apollo" spacecraft is filled on the launch complex from the service tower. During the first day of preparation, a tank truck is brought to the tower with nitrogen tetroxide; then the tanks of the service module (9.5 m^3), the jet control system of the command module (0.23 m^3), the takeoff and landing stages of the lunar module for the basic and auxiliary devices (3.8 m^3) are filled successively.

On the next day a tank truck with aerozin-50 is brought to the service tower and the tanks of the service module (8 m^3), the tanks of the takeoff and landing stages (4.5 m3) are filled successively, and the tanks of the jet command module system (0.38 m^3 of monomethylhydrazine) are filled from a separate reservoir.

The system for filling the first stage of the "Saturn-IB" booster rocket with fuel at the launch complex includes storage, a pump, ground lines connecting the storage and the booster rocket. The lines to the tank are connected through the cable mast which is moved to the side before launch. The storage is made up of a tank, the filtration and pumping system, the monitoring and measuring system. The tank which holds 215 m3 has safety valves, lines and fittings. The filtration system is used for removal of water and other impurities from the hot water during the storage process and feed of the components. The measuring and monitoring system provides for monitoring the temperature and pressure.

After filling the tank from the portable transport means to prevent accumulation of mechanical impurities and water in it the fuel is filtered by circulation through a separator filter. The analysis samples are taken through the quick-removable cover of the tank.

The booster rocket is filled in several operations. Two days before launch a somewhat greater amount of fuel than required is put in the tank. Initially the tank is filled to 15% of its volume, after which its seal is checked. Then the tank is filled to 98% volume at high flow rate (7500 ℓ/min), and to the full volume at low flow rate (750 ℓ/min). On the last day, 35 minutes before launch (after filling the booster rocket with the oxidants -- oxygen), the amount of fuel is finally batched by the drainage from the tank. The amount of drained fuel is determined by a computer.

5.5. Gas Supply Systems

Compressed gases -- helium, nitrogen and air --are widely used in rocket engineering.

The compressed gases are used to control the hydraulic equipment of the filling systems and individual mechanisms of the launch devices; the filling of the on-board booster rocket tanks; purging of various parts of the line to create a protective atmosphere in the purged cavities; bubbling (mixing) of the fuel components both in the rocket tank and in the storage tanks; blowing of the tanks before launch and during the drainage process; provision for the air conditioning systems, fire extinguishing systems, forced feed means; the working medium for various ground and on-board refrigeration units; the creation of the required atmosphere in the rocket tanks and in the ground storage tanks before filling them and after drainage with the application of fire and explosion-hazardous (with respect to air) liquids and vapors and also during pneumatic testing of the equipment of the booster rockets and ground systems (checking the points of connection of the ground and on-board lines for seal, checking the adjustment of the reduction gears, and so on).

Such widespread application of compressed gases is explained by the advantages such as the possibility of supplying from one energy source (the receiver tanks) of a large number of users, simplicity of the storage of the energy by compression to high pressures and convenience of application of the electropneumatic devices combining the capacity for creating the required force and the speed of the electrical systems.

The demand for compressed gases is met by the pneumatic systems of the space center, the specific characteristics of which are as follows by comparison with other filling systems:

Large number and variety of the performed operations combined with a greater number of users;

Significant operating time of the gas supply system (in all stages of preparation of the space rocket system);

Provision of compressed gases for the concluding, responsible pre-launch operations (blowing of the tanks, introduction of various ground and on-board devices, and so on) and the operations performed at the beginning of movement of the space rocket systems (uncoupling of the split connections at the beginning of liftoff, the removal of the platforms with uncoupled fill, drain and other lines);

A wide range of parameters (to pressure and flow rate) of the gases supplied to the user.

The compressed gases used in space rocket complexes have high requirements imposed on them with respect to their purity with regard to mechanical admixtures, moisture and oil. The presence of mechanical particles, the precipitation of ice crystals and oil during choking from wet compressed air lead to spoiling of the elements of the pneumatic system, loss of seal of the pneumatic fittings and failure of them.

The gas supply systems provide compressed gases to the engineering and launch complexes and are constructed in accordance with the following scheme: "Compressed gas force-pipelines with distribution, cutoff, regulating and safety fittings-user" (Fig 5.16).

The application of high pressure gases permits us to have feed lines with relatively small cross section and low metal consumption.

The force of the compressed gases is the central compressor made up of autonomous units for each gas and receiver and also the liquid nitrogen storage located alongside.

From the compressor the high pressure gases go through pipeiines to the receivers of the engineering and launch complexes which also can serve as portable compressor stations. The gas reserve in the receiver must provide for the technological process cycle of operations after which the receiver is refilled.

The compressor station is made up of mobile or stationary multistage piston type compressors with three-phase asynchronous motors in the stationary compressor stations and diesel engines in the portable stations. Frequently the compressor and the diesel engine are combined in a single unit (the diesel compressor), and their pistons are directly joined to each other. The diesel compressor has comparatively high efficiency, exceeding by 1.5-2 times the efficiency of the analogous compressor with traditional drive from a diesel engine.

The sources of gases for the compressors are atmospheric air, nitrogen coming from the nitrogen extracting unit or from a special liquid nitrogen storage and helium delivered from the manufacturing plant by special transport units in high pressure tanks.

Atmospheric air and other gases compressed in the compressors contain mechanical impurities and dust and also water and oil vapor, for removal of which the drying and cleaning unit is used. The gas moisture is determined by the "dewpoint" -- the temperature for which the water vapor contained in the gas becomes saturated, and with a further reduction in temperature supersaturated; in this case the excess moisture falls out in the form of dew, the time of fallout of which is fixed by a moisture indicator.

The moisture is removed from the gas by three methods: cooling of the gas below the required "dewpoint" by the inertial method in the moisture and oil separators (removal of the drop moisture) and absorption of the moisture by the adsorbents.

In the first method the gas is strongly cooled in the heat exchanger, as a result of which the maximum amount of moisture which is contained in the gas before its saturation decreases, and the excess moisture falls out in the form of snow or frost on the walls.

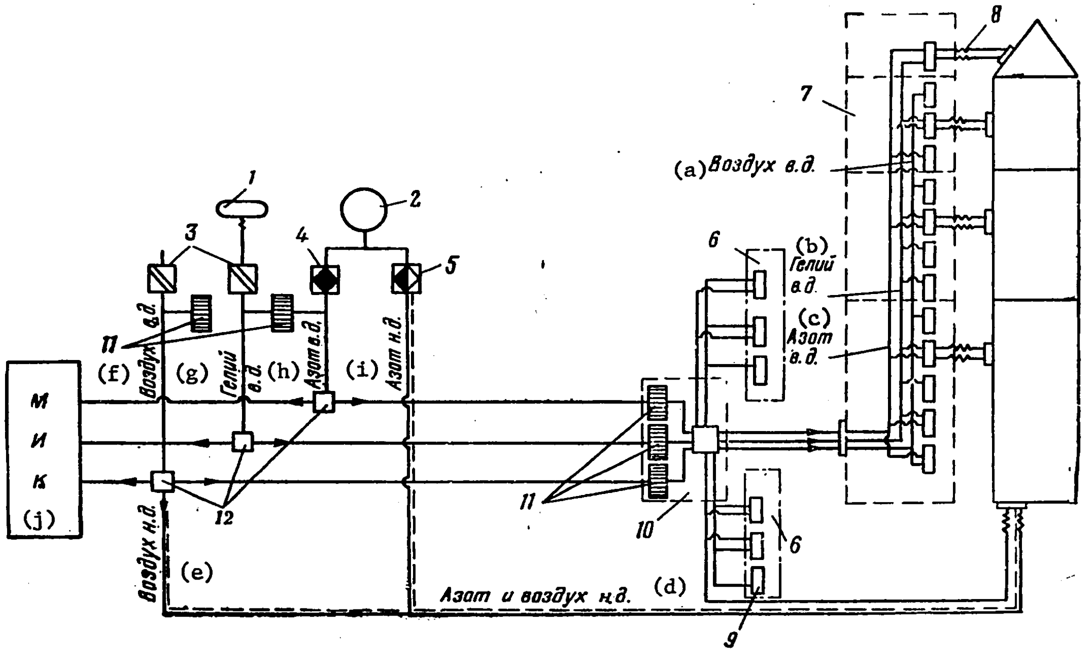


Figure 5.16. Gas supply system:
1 -- transport tank with gaseous helium; 2 -- liquid nitrogen storage; 3 -- high pressure compressor; 4 -- high pressure gasification unit; 5 -- low pressure gasification unit; 6 -- ground launch systems; 7 -- service unit; 8 -- flexible lines (hoses); 9 -- pneumatic boards for feeding compressed gases to the user; 10 -- launch system for providing compressed gases; 11 -- compressed gas receiver; 12 -- distributing board

Key:
a -- high pressure air; b -- high pressure helium; c -- high pressure nitrogen;
d -- low pressure nitrogen and air; e -- low pressure air; f -- high pressure air;
g -- high pressure helium; h -- high pressure nitrogen; i -- low pressure nitrogen;
j -- installation and test facility

With the second procedure, the principle of a sharp change in direction of movement on the gas and loss of speed by it is used, as a result of which the drops of water under the effect of inertial or centrifugal forces are discharged to the side surface, they flow off into a special low settling tank, from which they are removed through the drain line from the moisture and oil separator.

The most widespread is the third procedure -- absorption of moisture by the adsorbents (alumogel, silicagel, synthetic zeolites). In this case the drying modules have two adsorbers: one operates, and the other recovers its absorbing properties on purging with hot air. The gas is purified of mechanical particles by ceramic filters. The purified and dried gas from the compressor is released to the users or it is accumulated in the receiver tanks.

For large flow rates for gaseous nitrogen and hydrogen, two methods of obtaining compressed gases are used: with the help of low pressure stationary gasification units with subsequent release to the user or compression in compressors and with the help of stationary or portable high pressure gasification units in which the processes of compression and gasification are combined.

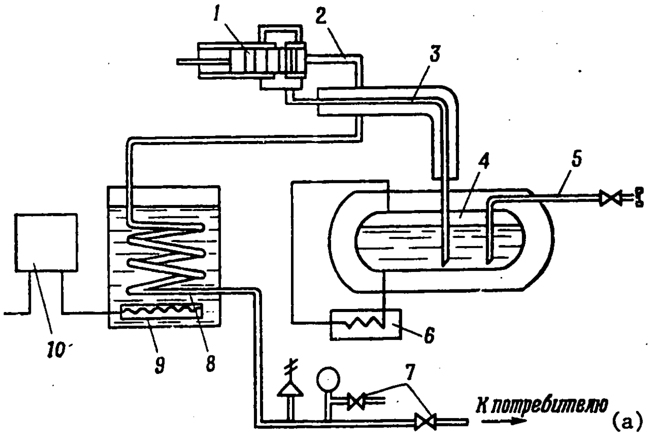


Figure 5.17. Schematic of the gasification unit:
1 -- liquefied gas pump; 2 -- liquid feed line from the pump to the evaporator; 3 -- liquid feed line from the tank to the pump; 4 -- liquefied gas reservoir; 5 -- reservoir filling line; 6 -- evaporator for blowing the reservoir; 7 -- check valve; 8 -- evaporator; 9 -- heater; 10 -- electric bay

Key:
a. to the user

The high pressure gasification units are constructed in accordance with one schematic diagram (Fig 5.17) which includes the tank for storing the liquefied gas with the evaporator, creating the required pressure at the input to the pump serving for compression of the liquefied gas and feeding it to the evaporator; the evaporator represents a multipass coil put in heated water. The gas formed in the device heated to 283-303K goes through the check valve to the receiver tanks, passing through the cleaning and drying units.

The helium goes to the receiver from the compressor units having good sealing surfaces to prevent its loss (the helium is a very fluid and easily penetrated gas).

The receiver (compressed gas storage) is equipped with means of receiving, storing and feeding gas to the users. In order to decrease the dimensions of the receiver, the compressed gases are stored in tanks at a pressure to 41.2 MPa. Each tank usually has two outlets to common manifolds with cutoff and safety fittings.

The input and output lines of the tanks joined in the sections are led out to the pneumatic boards with controlled cutoff, regulatable and safety fittings, filters and monitoring and measuring instruments. In order to determine moisture of the gases and to take samples, the receiver has a special board. The control of the receiver fittings and the pressure monitoring are possible both manually and remotely.

For convenience of operation the fittings and the monitoring and measuring instruments of the individual sections are grouped on individual pneumatic boards. The elements of the fittings, the instruments and the tanks are connected by lines to the lens type connecting devices providing for seal of the joints even with some misalignment of the pipelines.

The compressed gas is fed from the receiver through the distribution boards with reducers to the users. For remote control of the output of the gases from the sections of the receiver and feed of the gases to the specific users, electropneumatic valves mounted in the pneumatic boards are used.

The primary fittings of the pneumatic systems are the gas reducers, the safety valves, the electropneumatic valves and the gate valves.

Gas reducers are automatic regulators which step down the pressure to a given magnitude as a result of choking of the gas in the cross section formed by the valve and its seat. The reducer maintains a given pressure at the output on variation of the flow through it and the pressure at the input. The structural designs of the reducers are varied and depend on the requirements imposed on their accuracy, output capacity, dimensions and weight. The reducers can be spring and unit type, and in turn, the latter are divided into simple, with control pressure, with hydraulic booster and with pneumatic booster. Depending on the direction of the effect of

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the incoming gas on the regulating element (valve), the spring reducers can have direct action valves (the valve is lifted from the seat under the effect of the incoming gas) and check-action valves (the valve is held against the seat by the incoming gas).

A spring type reducer with check valve (Fig 5.18) operates as follows. Under the effect of the incoming gas fed to the cavity, to the unbalanced area of the valve and the spring, the valve, pressed against the seat, does not pass the gas to the low pressure cavity. When adjusting (loading) the reducer for a defined regime by turning the regulating screw the spring is compressed, and the valve is opened by the pusher. The gas goes to the cavity V_H, where its pressure on the diaphragm equalizes the force of the spring. In the absence of flow beyond the reducer the gas with a defined adjustment pressure again clamps the valve against the seat. On flow of the gas beyond the reducer the output pressure in the cavity V_H and the pressure of the diaphragm are diminished, as a result of which the valve opens, choking the gas passing through the slit between the seat and the valve. The pressure in the cavity again rises, and with a defined magnitude of adjustment between the forces acting on the moving system of the reducer, dynamic equilibrium is established which corresponds to a defined gas flow rate. With variation in the gas flow rate, a new equilibrium is established for a different magnitude of the choking slit.

The reducer with the direct-action valve operates analogously.

In order to reduce the large gas flow rates, unit reducers are applied which are made up of two parts; the power and actuating (adjusting) reducers; adjustment is realized by loading the actuating reducer. After the actuating reducer (the ordinary spring reducer) the gas goes to the controlling cavity of the power reducer and opens the valve of the latter. The pressure at the output of the power reducer compensates for the force from the gas pressure in the controlling cavity, and dynamic equilibrium is established for a defined flow rate. With a variation in the gas flow rate the dynamic equilibrium is established for a different magnitude of the clearance between the seat and the valve in the power reducer. A simple unit reducer operates by the same principle.

The unit reducers with hydraulic and pneumatic boosters also operate analogously, but with greater accuracy.

The safety valves are used to prevent the inside cavities of the tanks and lines from a possible increase in pressure; with an increase in pressure the valve moves away from the seat, and the gas is released through the exit opening to the atmosphere or the drain line; the valve closes with a reduction in pressure.

The various structural elements of the safety valves classified by the nature of opening of the valve are divided into proportional, nonproportional, pulsed and mixed type. In addition, the proportional and

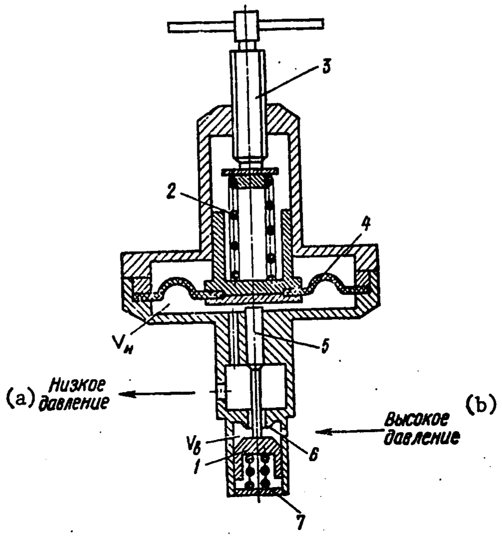

Figure 5.18. Spring-type reducer with check valve:
1 -- valve; 2 -- operating spring; 3 -- adjustment screw;
4 -- sensitive element; 5 -- push rod; 6 -- seat; 7 -- valve spring

Key:
- a. low pressure
- b. high pressure

nonproportional valves can be direct and check action. In the direct action safety valves the operating pressure opens the valve, breaking its seal, and in the safety check valves it pushes the valve against the seat, tightening (sealing) this connection. The flaps in the proportional safety valves open for a flow rate proportional to the rise in pressure; in the nonproportional safety valves, discontinuously as a result of the creation of additional forces.

The widest use is made of nonproportional check valves which, by comparison with the remaining ones, are better sealed. The nonproportional safety check valve (Fig 5.19) operates as follows. In the absence of pressure, the valve receives only a small force from the spring, which only fixes the valve in a defined extreme position. The operating pressure of the safety cavity clamps the valve tightly against the seat and moves them in this position upward, clamping the operating spring. With an increase in pressure, the sealing force of connection of the valve and the seat increases until the pressure of the safety cavity is compared with the adjustment pressure. At the adjustment pressure, the valve, reaching the stop, halts, and the seat under the effect of the increasing pressure will continue its movement. As a result, the seal of the valve-seat connection is disturbed, and the gas goes to the cavity A under the additional area f. The seat moves upward without additional rise in pressure, opening the output opening of the cavity A. The pressure in the cavity A is stabilized, and the seat halts. With a reduction in pressure in the safety cavity under the effect of the operating spring the seat clamps the valve, removing it from contact with the stop. The pressure in the cavity A drops, and the seal of the valve-seat connections is restored.

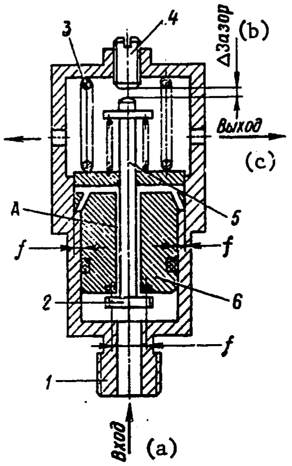

Figure 5.19. Nonproportional safety check valve:
1 -- housing; 2 -- valve; 3 -- operating spring; 4 -- adjustment screw; 5 -- valve spring; 6 -- seat

Key:
a. Input
b. Clearance
c. Output

The pulse safety valves are made up of two valves: the small cross section control valve and the basic valve for passing the entire flow. The feedback control valve which responds automatically operates on the basic valve, opening and closing it. This system insures high accuracy of the response for large values of the flow rates and pressures.

The mixed type safety valves in the initial opening step operate in accordance with the nonproportional check valve scheme, and on complete opening, by the proportional check valve scheme.

Gate valves and pneumatic valves (shutoff fittings) are designed for reliable closure of the pneumatic lines, and when they are open they provide the required flow rates of the gas with minimum pressure losses. Pneumatic valves with control pressure and electropneumatic valves (pneumatic valves with control from an electromagnet) are distinguished.

The gate valves can have both manual and remote drives (electric engine). The force on the cutoff of the valve is transmitted through the self-braking screw couple, and the shutoff of the valve retains the established position after removal of the control input. The valves are set so that in the closed position the seal of the push rod will not be under the effect of the working medium.

Electropneumatic valves provide for remotely controlled feed of the gases to the various users. The characteristic of the electropneumatic valve is given in the deenergized state. Depending on the position of a cutoff, the electropneumatic valve can be closed (deenergized-closed) and open (deenergized-open) and also they can be made with and without drainage. The electromagnetic valve without drainage simply stops feeding gas to the user when it is closed, and the electromagnetic valve with drainage not only stops feeding the gas, but discharges the gas remaining between the user and the electropneumatic valve to the atmosphere. The electropneumatic valve with drainage is used primarily to control the pneumatic valves, electropneumatic valves without drainage -- for various types of purging, blowing and opening of pneumatic locks.

When developing the layout of the pneumatic system and its operating conditions, usually electropneumatic valves are selected, the electromagnets of which will be deenergized for the maximum amount of time. However, in practice, cases of prolonged (to several days) staying of the electromagnet of an electromagnetic valve under current are possible.

The direct-action electropneumatic valve and with pneumatic booster are distinguished. In the direct-action electropneumatic valve, the electromagnet shifts the push rod of the basic valve directly covering the gas cavities; in the electropneumatic valve with pneumatic booster, the push rod of the servovalve (the unloading valve) having smaller working areas than the basic valve. The displacement of the servovalve causes redistribution of the forces acting on the sensitive elements of the electropneumatic valve which leads to a displacement of the basic valve, the electropneumatic valve with pneumatic booster is used for large cross sections of the pipelines. The double-action electropneumatic valvesused to control double-action pneumatic valves have one input and two puts for the gas. Gas is always used in one of the output cavities. The displacement of the electromagnet causes gas feed to the other output cavity and drainage of the gas from the filled cavity. The application of one double-action electromagnetic valve replaces the use of two electromagnetic valves with drainage. This decreases the number of fittings in the system and increases its reliability.

The electropneumatic valves usually are made up of an electromagnet, a housing with seats for the shutoff assemblies and connections for joining to the pipelines, a shutoff containing a push rod with a valve or system of valves and special devices -- the mechanism for manual inclusion (if it occurs), signalling the position of the valve, the fixing device (if it exists), and so on.

The pneumatic valves with controlling pressure are used for remote closure of the lines with high compressed gas flow rate usually paired with the electromagnetic valves, which makes it possible to operate by the following scheme: "an electric signal from the control panel -- electromagnetic valve -- feeding of the control air from the electromagnetic valve -- response of the pneumatic valve (closing or opening the line)."

With respect to structural designs of the pneumatic drive the pneumatic valves are divided into simple and double action valves. The simple action pneumatic valves have one controlling pressure cavity, after discharge of which the valve shutoff is shifted to the other position by the pressure of the medium and an elastic element (spring). These pneumatic valves have one fixed position without feeding a controlling pressure. The position where the controlling pressure is not fed to the valve is considered to be normal. The double-action pneumatic valves have two controlling pressure cavities. The position of the shutoff of the pneumatic valve is determined by the fact that a controlling gas is fed to each cavity. Without the controlling pressure and without the clamping springs the double action valve does not have a fixed position. The position is considered normal when the controlling pressure is fed, and the electropneumatic valves are deenergized. These pneumatic valves are controlled either by two electropneumatic valves (one deenergized -- open, the other deenergized -- closed) or by one double-action electropneumatic valve. It must be noted that the speed of the pneumatic valves can be altered in the required direction by using replaceable injectors installed on the controlling pressure line at the input to the pneumatic drive.

Gas Supply System of the "Saturn-V" Booster Rocket

The gas supply system provides for the production, storage and distribution of the compressed gases -- nitrogen and helium. The low pressure compressed air is used in the conditioning systems.

The high pressure gaseous nitrogen and helium are obtained using converter-compressor equipment which includes the liquid nitrogen storage (a spherical tank with perlite nonvacuum insulation); the high and low pressure liquid nitrogen pumps and gasifier; the filtering and drying unit; the helium high-pressure compressors and distribution boards.

The gaseous nitrogen is obtained by gasification of liquid nitrogen which is passed through the deep cleaning filters to the high and low pressure pumps; then it goes to the gasifiers and after them to the filtering and drying units where already in the gaseous form it is purified of vapor and hydrocarbons and on passing through the fine cleaning filters, it is fed to the distribution boards under a pressure of 41.2 and 0.98 MPa.

The gaseous helium arrives in the transport units under a pressure of 15.2 MPa. The helium is fed through the fine purifying filters at significantly lower pressure into the compressor units having oil and water traps, after which at a pressure of 41.2 MPa it is fed through the cleaner to the distribution unit.

From the distribution devices the high pressure gaseous helium and nitrogen are fed to the compressed gas storage of the vertical assembly building and to the launch complex storage. The storages include the receivers from nitrogen and helium made up of several tens of tanks. The collectors and the tanks of the receiver are equipped with safety valves and rupturable diaphragms for the case of an emergency rise in pressure.

The amount of compressed (to a pressure of 24.5 MPa) nitrogen and helium is insured by performanc of all of the operations of assembly and testing of the "Saturn-V" booster rocket in the vertical assembly building and also the demand of all of the users of the launch complex and the booster rocket itself.

In addition, the gaseous nitrogen and helium are used during the operations:

The nitrogen for control of the valves of the filling system for the fuel components and the valves of the rocket during the pre-launch preparation; the purging of the different equipment of the booster rocket and the ground systems in order to insure explosion safety; the operations of the pneumatic cylinders of the mechanisms for turning the moving platforms on the service cable mast and blowing the tanks of the S-I fuel stage;

Helium for pre-launch blowing of the oxygen in hydrogen tanks; charging of the on-board tanks; purging of the different equipment of the booster rocket and the ground systems; bubbling of the oxygen in the rocket tanks and control of the individual mechanisms.

CHAPTER 6. THERMOSTATING SYSTEMS

6.1. Purpose, Structure and Composition

Thermostating is insurance of the given thermal conditions of the space rocket system or its elements during the process of their ground preparation in order to create conditions for normal functioning of the on-board equipment and systems. The given regime is insured at the engineering complex, when transporting the space rocket system within the boundaries of the space center and at the launch complex.

As a rule, it is not the space rocket system as a whole that needs maintenance of thermal conditions, but only individual components of it.[1]

The space rocket systems include equipment requiring defined temperature conditions for operation, variation of which lowers its characteristics and disturbs the normal functioning. The temperature also determines the characteristics of the on-board electric power supply sources, the operating reliability of the engine assemblies, the thrust of the solid fuel boosters in the rockets and the engines of the emergency rescue system for the space vehicles.

The thermostating of the fuel components insures the given temperatures of the oxidant and the combustible component going into the engine and the required density, and the thermostating of the cryogenic components, reduction of their losses from evaporation. The space vehicles are thermostated in order to maintain the required air temperature in the compartments with the equipment, the structural elements and individual assemblies and and units (the instruments, power supplies, the serviced tanks and so on) and also, what is extremely important, in order to provide life support for the cosmonauts during the pre-launch preparation time.

The optimal temperature range depends on the composition of the booster rocket and space vehicle systems, the type of installed equipment, the fuel

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[1] Hereafter all these elements will be called "the thermostating targets."

components used, the structural design of the solid fuel engines, and so on. Usually for the instrument compartments and the engines of booster rockets the optimal range is from +5 to +25°C, and for solid fuel booster rockets and the emergency recovery engines of the space vehicle, from 0 to +40°C or a positive temperature range without restriction of the upper limit. For some booster rockets the temperature range is not limited, and such rockets can be prepared and launched without the application of special thermostating means at any surrounding air temperature.

For space vehicles with ground preparations the range from +15 to +25°C is considered optimal although deviations from these values are possible. Thus, the air temperature in the operating zones of the installers and testers in the spacecraft or space station is permitted from +10 to +30°C. The preferable temperature for the containers with food installed in the space vehicle (ship or station) is considered to be the temperature from 0 to +15°C. The admissible temperature range of the space vehicle after filling its fuel tank at the filling station is significantly limited.

The thermostating problems include both supplying heat to the elements of the space rocket systems and removal of it. The heat is usually supplied when the rocket system is outside the facility at low surrounding air temperature (when transporting, in the launch position, and so on), and it is removed to the engineering complex; when transporting the space rocket system (the top module) within the boundaries of the space center and in the launch complex. In the engineering complex usually excess fuel is removed from the inside volumes of the space vehicles during electrical testing and also from the compartments where the installation men and test people are operating. When transporting and at the launch complex the rocket system (top module) is protected in the summer from high surrounding air temperatures and solar radiation.

The given thermal conditions of the space vehicles sometimes are insured by joint operation of the ground thermostating means with the on-board thermal regulation system. The on-board thermal regulation system of the space vehicle usually is made up of two hydraulic loops -- cooling and heating. The excess heat is removed from the internal volumes of the vehicle by the cooling loop which, by means of the intermediate liquid-liquid thermostating heat exchanger is connected to the outer loop -- the ground liquid system for supporting the thermal conditions.

In the hydraulic main of the inner loop, a temperature is maintained which is required for operation of the assemblies of the vehicle realizing heat removal from the atmosphere of the compartments. The temperature in the loop is regulated either by temperature variation and the amount of cooled heat exchange agent in the outer line or by the regulating elements in the loop itself. The heating loop is also connected to the outer loop using the intermediate liquid-liquid thermostating heat exchanger (ZhZhTT); in this case, the heated heat exchange agent is fed to the outer loop.

In order to thermostat the elements of the space rocket system, air systems are also used to maintain the thermal conditions (VSOTR) which both supply and remove heat. The thermostating air is fed to the instrument compartments and the engines of the booster rocket, under the nose cone or the space vehicle elements are blown by it.

Maintenance of the thermal conditions during the period after completion of the operation of the ground thermostating means is insured as a result of preliminary bringing of the temperatures of the structural elements and air in the compartments of the rocket system to the given levels during thermostating process, determined by the outside temperature conditions and the degree of thermal installation of the elements of the rocket system and also as a result of selecting the time for disconnecting the thermostating means.

During the thermostating process, the temperature is monitored at the most important (from the point of view of the thermal conditions) points of the vehicle by using special temperature gauges connected with the ground panels. The readings of the gauges are used to control the thermostating conditions.

6.2. Classification of the Systems

The ground thermostating systems are classified by the method of thermostating, the heat-exchange agent used, and mobility.

With respect to the method of thermostating the systems are divided into active and passive thermostating systems and combined systems.

The active thermostating systems provide for supplying heat to (removing from) the vehicle and have sources of heat or cold and equipment for supplying the heat-exchange agent in their composition. These include the air (VSOTR) and liquid (ZhSOTR) thermal conditioning systems.

The passive thermostating systems insure the given thermal conditions as a result of insulating the vehicle from the environment. They include the thermal insulating hoods for the top modules, the space vehicles and the engines of the emergency rescue systems which decrease the heat exchange between the vehicle and the environment and also various coatings with different coefficients of reflection and absorption.

The systems of combined means use methods of both active and passive thermostating. These are the electrothermal hoods in which the limitation of the heat exchange with the environment is realized as a result of thermal insulation, and the heating, as a result of the electric heaters.

With respect to the heat-exchange agent used the thermostating systems are divided into air and liquid systems; in the air system the heat exchange agent is air; in the liquid systems, it is different liquids (brines, freons, antifreezes).

With respect to mobility the thermostating systems are divided into portable and stationary. The choice of one version or another depends on the cold and heat requirement of the thermostating object, the required flow rate of the heat transfer agent, the conditions of applying the system and also the composition and structure of the ground complex.

The systems with low cold and heat output capacity are usually portable. They have a source of electric power (they can also be fed from an outside source), and they are used both at the engineering and launch complexes. They are universal and mobile, which makes it possible with a limited number of units of equipment to provide for thermostating in the different stages of the technological process cycle for preparation of the space rocket system. Such systems are used, as a rule, for light class rockets. The portable units are used also to insure the thermal conditions of the space rocket system for its elements during transportation within the boundaries of the space center. Thus, using the portable units, the space vehicle or the top module is thermostated on delivery to the filling station and also when being hauled from the engineering complex to the launch complex as part of the completely assembled rocket system if the transport time exceeds the admissible for which the normal conditions of the vehicle or the top module will remain within the given limits.

For rockets of medium, heavy and superheavy classes, the equipment of which is basically stationary, the thermostating systems are also stationary. The support of the thermal conditions of such rockets will require high cold and heat output capacity which it is impossible to achieve by using mobile units. The stationary systems are placed in special structures and part of their equipment, in other ground units and systems (for example, on the service tower of the launch complex, and so on). The portable thermostating units are used in these cases only to transport the space rocket systems or elements of them.

6.3. Sources of Cold and Heat

In the thermostating systems the sources of cold are compression type refrigeration units, turbocompressors and turborefrigeration units, systems which use choking of gas and devices with the application of the vortex effect, and the sources of heat are electric and water heaters, and so on.

In the thermostating systems, in order to cool the heat-transfer agents, the piston refrigeration units have received the greatest application. In these units, the heat is picked up as a result of boiling the cooling agent (usually freon) in an evaporator with subsequent compression of its vapor in the piston compressor; in this case the picked up heat is transferred to the water or air. The piston compression refrigeration units, in spite of their complexity, have been quite reliably developed at the present time, and they do not cause any special difficulties in operation or maintenance.

In the turbocompressor the compression of the coolant vapor takes place as a result of the creation of a centrifugal force on rotation of the impeller; directing the vapor successively through a number of impellers, it is possible to obtain the required degree of compression.

The turborefrigeration units are a combination of a turbocompressor with regenerative heat exchangers, and they operate by the thermodynamic cycle called the "Russian cycle." The turborefrigeration unit which produces 1 kg of cold air persecond with a temperature from -80 to =135°C and a cold output capacity to 30 kwt is made up of a turbine (the turbine expansion engine) and compressor on a single shaft, regenerator, the refrigeration chamber, valves, air bypass units, a booster and switching mechanism. The advantages of the turborefrigeration units are the low mass, small size and the possibility of using atmospheric air instead of expensive refrigeration agents,and the deficiencies low air pressure at the output which complicates their application in the thermostating system.

The systems using choking of gas are based on the principle of a reduction in gas pressure on passage of it through a constricted opening with simultaneous reduction of the temperature. These systems include the pneumatic panels with reducers (valves, diaphragms), which step down the pressure and hoses with sprayers; the air which comes out of the sprayers cools the thermostating object. The advantages of these systems are simplicity of structural design, high reliability and ease of servicing, and the deficiencies include the low efficiency of the cycle, the nonregulatability of the air temperature and the possibility that moisture will get into the object, which is condemned in the structural elements of the various assemblies, hoses and sprayers during the air cooling process.

The devices using the vortex effect (the Rank-Khilsh effect) are used to obtain a flow of air cooled to -(10 to 60)° and heated to +(50 to 100)°C. The main part of these units is an eddy tube (the vortex refrigeration unit) into which the air that has been compressed in the compressor in advance goes. In the tube the air acquires an eddy motion, as a result of which the inner layers are cooled, and the outer ones are heated.

The eddy tube (Fig 6.1) is a smooth cylindrical tube equipped with a unit with tangential nozzles, a diaphragm with axial opening and a choke. On escape of air through the nozzle, an intensive circular flow is created, the axial layers of which are cooled, and they leave in the form of a cold flow through the opening in the diaphragm, the hose, a muffler and a fitting; the peripheral layers are also heated in the form of a hot flow and they exit through the tube, the hose and the muffler. As the choke is covered, the cold flow through the opening of the diaphragm increases with a corresponding increase in the flow rate of the hot flow.

The devices usually have several tubes, at the exit from which air is obtained with different temperature. The devices also include the air preparation unit which includes filters, oil separator and water heat exchanger for preliminary cooling of the air after the compressor.

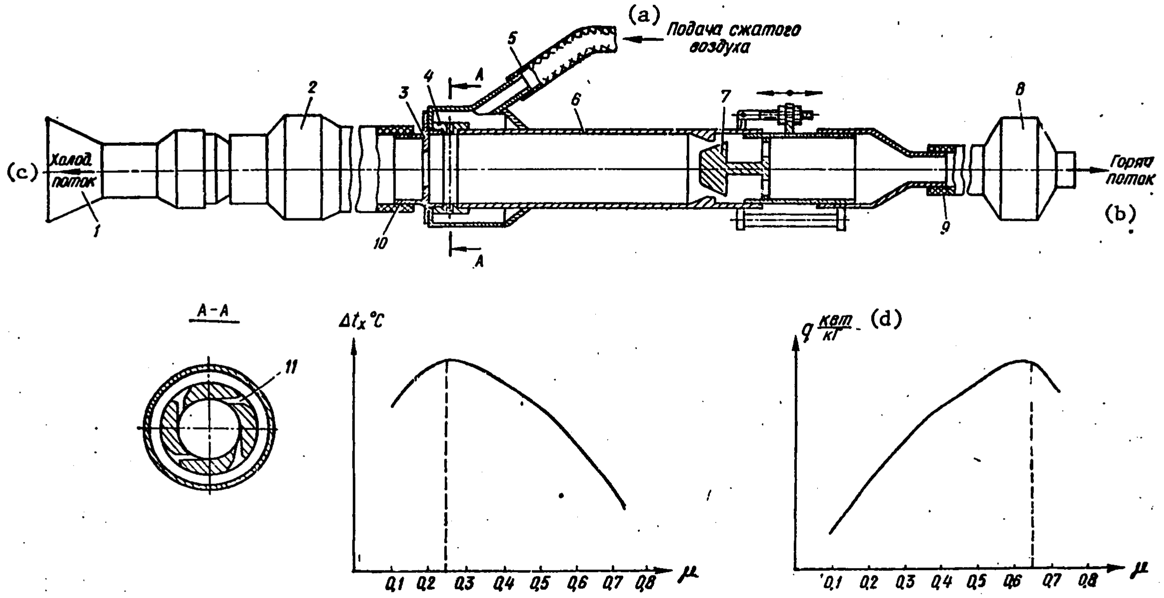

Figure 6.1. Eddy tube:
1 -- fitting on the cold end; 2 -- muffler on the cold end; 3 -- diaphragm; 4 -- nozzle;
5 -- compressed air feed hose; 6 -- tube; 7 -- choke; 8 -- hot end muffler;
9 -- hot end hose; 10 -- cold end hose; 11 -- tangential nozzle.

Key:
a -- compressed air feed; b -- hot flow; c -- cold flow; d -- kwt/kg.

The advantages of the devices with the application of an eddy effect are simplicity of structural design, operating reliability and possibility of fast temperature regulation, and the deficiencies include a low efficiency cycle and powerful noise occurring during operations; the noise is reduced by the application of mufflers on the fittings of the "cold" and "hot" ends and also sound insulation of the tube casing.

Electric heaters with different power serving both to heat the air (gas) and the liquid heat-exchange agents are used as the sources of heat in thermostating systems. In order to regulate the temperature, the heaters are usually made of several sections included in various combinations.

The water heaters use hot water from the boiler room of the space center or from other systems where it is a byproduct. In systems with the application of the eddy effect for heating, air emitting from the "hot" end of the eddy current is used.

6.4. Structure of the Thermostating Systems

The air thermostating systems, independently of the structural design, have sources of cold and heat, tanks with coolant, a system of lines with regulating fittings, pipelines for supplying air, a mechanism for removal of the on-board split connection and a control system.

The largest VSOTR systems used for thermostating space rocket systems at the launch complex have a significant influence on the composition and placement of the structures and other systems.

In addition to the VSOTR and the ZhSOTR systems, the cold users can also be the thermostating systems for the fuel components, the air conditioning system for the facilities, and so on.

In the stationary thermostating systems all of the refrigeration equipment is placed in a single refrigeration center, which insures the demand for cold and heat. This composition of the equipment makes it possible to use it more efficiently, increase the efficiency, and the neutralizer servicing and operation.

The cold center can be placed both in an individual structure and in the launch facilities under the pad. The special structure for the refrigeration center is usually of an arch type, semiburied with the necessary protection in case of explosion of the rocket on launch.

For more efficient use, the refrigeration equipment is placed as close as possible to the user (rocket), since with an increase in distance the heat losses increase significantly. The equipment must be compact, fire and explosion safe and automated to the maximum. The large refrigeration equipment (the refrigeration unit, the heat exchange units, the tanks with a system of lines and the regulating fittings for intermediate heat-exchange agent, the pumps, water supply systems) and also the control panels with the monitoring and measuring instruments requiring the presence of service personnel usually are placed in an individual structure, and the channels for supplying air, in the facilities under the pad and on the service tower.

The air feed channels include fans, filters, air coolers, electric heaters and air ducts. The fans (air blowers) are designed to create the required air pressure and feed; the filters are designed to remove dust and mechanical impurities from them, the air coolers are made to cool the equipment to the required temperature and settle out moisture contained in it; the electric heaters are used for heating. The air ducts are placed on the service tower and lead to the rocket at the corresponding levels.

The VSOTR systems operate both by the open and closed cycles. In the first case the air fed to the rocket is discharged to the atmosphere through one of the hatches; in the second case, it returns to the system.

In order to remove the on-board connections with the air ducts on the service tower platforms disconnect mechanisms are provided. These mechanisms remove the on-board connections with the air ducts to a safe distance, excluding the possibility of collision of them with the rocket under the effect of wind loads. At some launch complexes (basically for light and medium class rockets) the disconnection and removal of the on-board split connections are accomplished manually.

The air systems for supporting the thermal operating conditions are operating both in the manual and in automatic modes. In the manual mode the air temperature is selected by the operator and maintained by variation of the temperature of the heat-transfer agent, its consumption in the air cooler, disconnection (connection) of one of the air coolers or inclusion of the required number of sections of the electric heaters. In the automatic mode the air temperature is maintained by a special device which on disconnection of it from the given one sends a signal to the servomechanism regulating the consumption of the heat transfer agent through the air coolers or it changes the number of connected (disconnected sections of the electric heaters.

The means of supporting the thermal regime of the engineering complex usually have separate air and liquid thermostating systems (although the possibility of combining them into a united refrigeration center is not excluded), and with respect to construction principle they are analogous to the systems of the launch complex. However, as a result of the fact that the cold and heat requirements at the engineering complex are less, and the remote and automatic control frequently is not required, they are simpler with respect to structural design. The system equipment is placed in the installation and test facilities for the booster rockets and the facility for installation and testing of the space vehicles, in additions on the buildings or in special buildings.

Let us consider the structure and the operating principle of the stationary air thermostating system of the top module at the launch complex with air flow rate of 4 m^3/sec and temperature from -10 to +40°C (Fig 6.2). The system operates by the open cycle, that is, with discharge of the air to the outside, and it is fed from the cooling center, in which the refrigration units, brine tanks for the heat-exchange agent, the pump group, the system of brine and water lines with adjustable gate fittings, control panels and other equipment are located. The fans for supplying air, the filter, the air cooler, the electric heater, the air duct and the mechanism for removal of the on-board connections are placed on the service tower.

The air is cooled in two steps: in the first step the atmospheric air forced by the fan and passing through the filter is cooled in the air cooler to a temperature of 2-5°C as a result of heat exchange with the heat-exchange agent (27-29% calcium chloride solution) coming from the cooling center; simultaneously the moisture precipitates out (to 95%) which is contained in the collected air. It runs off to the bottom of air cooler and is removed. In the second step the air in the air cooler is cooled to a temperature below 0°C with precipitation of moisture on the surface of the air cooler in the form of "frost." As the cross section of the air cooler is decreased as a result of the formation of the "frost" the air feed from one air cooler is switched to the other, and in order to defrost the first air cooler, a special fan and electric heater are switched on; this air is not used for thermostating and is discharged through the connection to the atmosphere.

During operation of the system and the heating mode, the air fed to the top module is heated in an electric heater. In order to obtain the air with given "dewpoint" it is first cooled in the air coolers where precipitation of the moisture takes place.

The system operates both in the manual and in automatic modes. In the manual mode the given air temperature at the input to the top module is selected and maintained by the operator by varying the flow rate of the heat-exchange agent fed to the air cooler. A defined temperature of the heat-exchange agent is maintained in the brine tanks. In the automatic mode the given air temperature is maintained by instruments in accordance with the readings of the temperature gauges installed at the input to the top module. In this case, the operator of the control system adjusts the thermostat to the required temperature (variation in the temperature automatically changes the flow rate of the heat-exchange agent), and the given temperature of the heat-exchange agent is maintained in the brine baths by varying the amount of coolant going to the evaporators. The air flow rate is adjusted remotely by opening (closing) the air valves or increasing (decreasing) the number of fans put into operation.

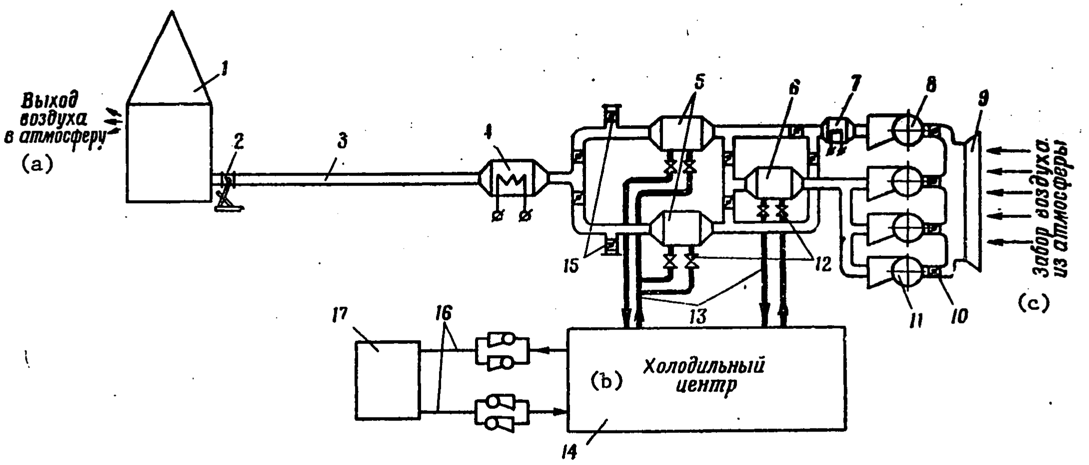

Figure 6.2. Diagram of the stationary air thermostating system:
1 -- thermostating object; 2 -- mechanism for removal of on-board connection; 3 -- air duct; 4 -- electric heater; 5 -- second stage air cooler; 6 -- first stage air cooler; 7 -- defrosting electric heater; 8 -- defrosting fan; 9 -- air filter; 10 -- air valve; 11 -- air fan; 12 -- stop valve; 13 -- heat-exchange agent lines; 14 -- refrigeration center; 15 -- connection for discharge of air during defrosting; 16 -- cooled air feed line; 17 -- cooling tower.

Key:

a -- exit of air to the atmosphere; b -- refrigeration center; c -- collection of air from the atmosphere.

The portable air thermostating units are mounted in the body of a railroad car or truck. Such units are fed both from the outside network and from the inside source of electric power, which permits them to operate during movement (when transporting the rocket or the top module within the limits of the space center). The portable air units usually operate by closed cycle without application of the intermediate feed-transfer agent, with cooling of the air in the evaporator of the refrigerator; connection and disconnection of the lines, as a rule, is manual.

Let us consider one of the units designed for thermostating the top module of the rocket when transporting it from the installation and test facility to the filling station and also within the composition of the fully assembled space rocket system during transportation from the engineering complex to the launch complex.

All of the equipment of the unit (Fig 6.3) is placed in the railroad car divided into several compartments. The source of cold is freon refrigerators with air cooling condensers. A diesel generator is installed in the unit; for connection to the outside current source there is a coil with a cable; the unit operates by a closed cycle. The cooled or heated air is fed to the top module located on the railroad carrier (in the fully assembled space rocket system, on the transport-erection unit), using an electric fan by the system of stationary and flexible air ducts and adapters, and then it again goes to the air cooler of the unit. The control panel is used to control the operation of the cooling and heating unit in the manual and automatic regimes. In the automatic regime the given air temperature is maintained by the instruments in accordance with the gauge readings.

Liquid Thermostating Systems. In the stationary ZhSOTR systems the heat-exchange agent is cooled both from the cooling center (in common with the VSOTR system) and from the autonomous source of cold. The feed lines of the heat-transfer agent are placed in facilities under the pad on the service tower. For protection of the ZhZhTT [liquid-liquid thermostating heat exchanger] of the space vehicle from excess pressure in the ZhSOTR systems, a pressure relay is provided. In the portable units all of the equipment is placed in the body of the truck, and the heat transfer agent is cooled by heat exchange with the coolant of the refrigerator.

The liquid systems operate only by a closed cycle. On completion of operation of the system, before disconnection and removal of the hydraulic block from the rocket, the heat transfer agent is drained off, and the lines are blown out with compressed nitrogen in order to protect the on-board lines from corrosion and exclude incidence of the heat transfer agent on board the rocket or space vehicle.

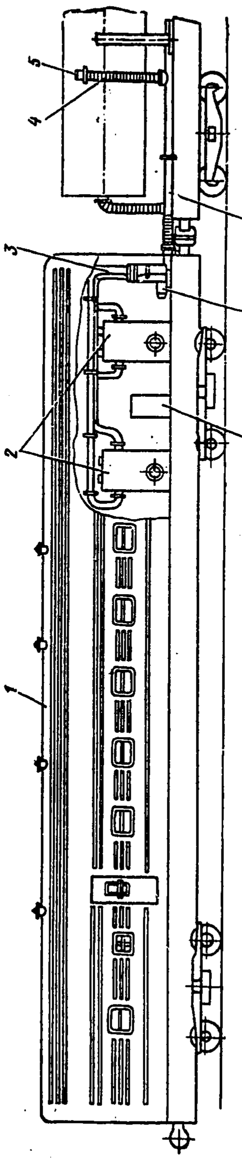

Figure 6.3. Portable air thermostating unit:
1 -- body of the railroad car; 2 -- air cooler; 3 -- heater; 4 -- flexible air duct; 5 -- adapter; 6 -- stationary air duct; 7 -- electric fan; 8 -- control panel

The operation of the ZhSOTR in the manual and automatic modes is analogous to the operation of the VSOTR.

As an example let us consider a portable liquid thermostating unit. The unit (Fig 6.4 and 6.5) is used to feed the heat-exchange agent (antifreeze) with a temperature from -5 to +50°C to the ZhZhTT of the space vehicle with a flow rate of $0.27 \cdot 10^{-3}$ m^3/sec, and it is mounted on the body installed on the automobile chassis. The unit can serve as both the launch complex and the engineering complex. When working on the launch complex, in order to feed the heat-transfer agent, pipelines are used which are laid on the service tower (truss); in the engineering complex there are special pipelines for the installation and test complex.

During operation of the unit in the cooling mode, the heat-transfer agent is moved by an electric pump from one division of the mixing tank to the other; it passes through the evaporator where it is cooled by a coolant (freon) which boils at low pressure and temperature. the cooled heat transfer agent is moved by an electric pump through a flexible hose, through the pipeline on the service truss, through the distributor and the pressure delivery hose to the tube space of the liquid-liquid heat-exchanger of the target. It picks up heat only from the space vehicle and is again drained into the mixing tank of the unit. At the input to the ZhZhTT heat exchanger there is a pressure relay which shuts off the pump with a rise in pressure above admissible.

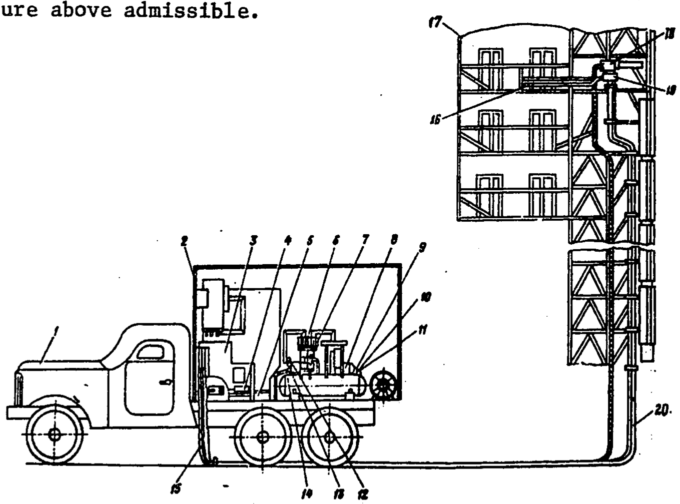

Figure 6.4. Portable liquid thermostating unit:
1 -- truck chassis; 2 -- body; 3 -- mixing tank; 4,5 -- electric pumps; 6 -- compressor; 7 -- filter-drier; 8 -- electric heater; 9 -- evaporator; 10 -- heat exchanger; 11 -- receiver; 12 -- heat regulating valve; 13 -- solenoid valve; 14 -- manual regulating valve; 15 -- flexible hose; 16 -- pressure hose; 17 -- service truss; 18 -- resistance thermometer; 19 -- distributor; 20 -- pipeline on the service truss

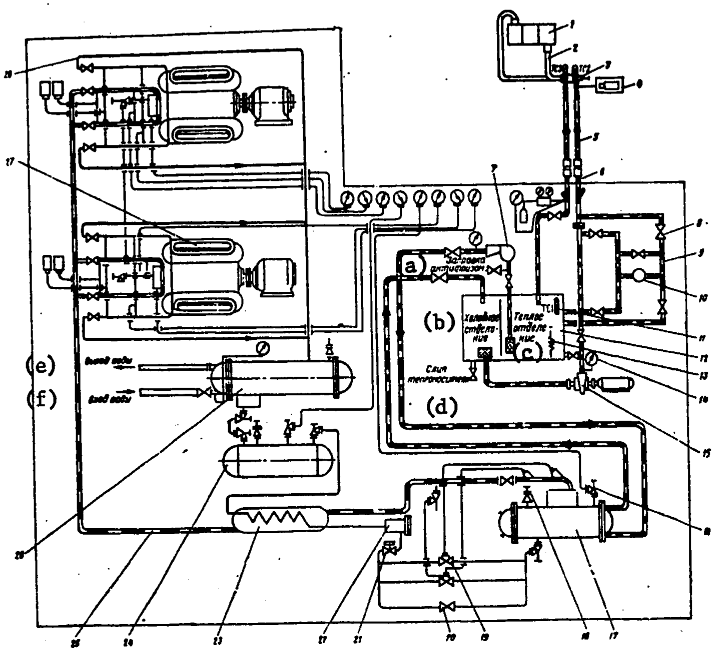

Figure 6.5. Schematic of the portable liquid thermostating unit: 1 -- ZhZhTT; 2 -- pressure hose; 3 -- distributor; 4 -- pressure relay; 5 -- pipeline on the service truss; 6 -- flexible hose; 7 -- electric pump; 8 -- shutoff valve (coupling); 9 -- antifreeze line; 10 -- flow rate relay; 11 -- resistance thermometer; 12 -- mixing tank; 13 -- electric heater; 14 -- manometer; 15 -- electric pump; 16 -- shutoff valve (angular); 17 -- evaporator; 18 -- safety valve; 19 -- heat regulating valve; 20 -- manual regulating valve; 21 -- solenoid valve; 22 -- filter-drier; 23 -- heat exchanger; 24 -- receiver; 25 -- freon section line; 26 -- condenser; 27 -- compressor; 28 -- freon delivery line

Key:

a -- filling with antifreeze; b -- cold division; c -- warm division; d -- heat exchange agent drain; e -- water output; f -- water input.

The coolant vapor formed during boiling in the evaporator is removed by the compressors through the intermediate space of the heat exchanger in which they were superheated as a result of the counterflow of freon from the receiver. The compressor compresses the freon vapor and pumps it into the condenser where it is cooled by water and condensed.

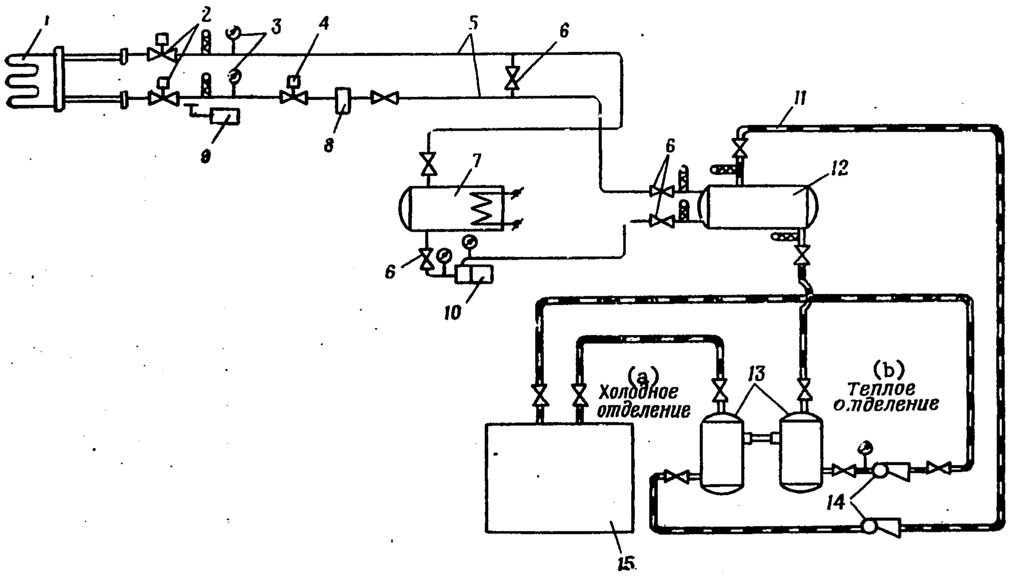

Figure 6.6. Schematic of a stationary liquid thermostating system:
1 -- ZhZhTT of the vehicle; 2 -- valves with electric drive; 3 -- manometer (pressure gauge); 4 -- regulating valve; 5 -- line of the heat-transfer agent (antifreeze) loop; 6 -- shutoff valve; 7 -- tank with electric heater; 8 -- flow meter; 9 -- pressure relay; 10 -- piston pump; 11 -- line for the heat-transfer agent (freon) loop of the refrigeration unit; 12 -- heat exchanger; 13 -- expansion tank; 14 -- centrifugal pump; 15 -- refrigeration center.

Key:
a -- cold division; b -- warm division

Liquid freon formed in the condenser drains into the receiver, from which it goes through the coil of the heat exchanger, the filter-drier and the solenoid valve to two parallel heat regulating valves. The supplied high-pressure coolant (at condensation pressure) is fed through the choke cross section of the heat regulating valve to the evaporator where low pressure is maintained by compressors sucking vapor out of the evaporator. The liquid freon, running through the evaporator space between the tubes, boils at low temperature as a result of the heat influxes from the heat-transfer agent circulating through the evaporator tubes. Then the cycle is repeated.

The temperature of the heat-transfer agent is monitored by a resistance thermometer installed in a mixing tank and an electron bridge; on deviation of the temperature from the given temperature, the compressor is switched on or off.

When operating in the heating mode, the heat-transfer agent is heated by the electric heater of the mixing tank, after which the pump is used to feed it to the ZhZhTT of the vehicle and from there again to the mixing tank.

The stationary ZhSOTR system (Fig 6.6) receives cold from the refrigeration center of the launch complex. In the heat exchanger, heat exchange takes place between the heat-transfer agent (antifreeze) and the intermediate heat-transfer agent (freon) fed by a centrifugal pump from the expansion tank. The antifreeze is heated in the tank of the electric heater and the piston pump feeds it through the system lines to the ZhZhTT of the vehicle from which it is drained back into the tank. The flow rate of the antifreeze is established by regulating valve; the flow rate is monitored by a flow gauge. When the pressure is exceeded at the input to the ZhZhTT heat exchanger the pressure relay switches the pump off.

Thermal Jackets. A thermal jacket without electric heating (passive thermostating) is designed to decrease the heat echange between the elements of the space rocket system and the environment and also for protection from the meteorological effects and solar radiation. The thermal jacket is made up of strips of cloth between there is a filler (foam plastic or other insulating material), with a split along the generatrix covered by the fastening locks with traction belts.

The electrothermal jacket (thermostating by a combined method) insures the thermal regime of the engines of the emergency rescue system, the solid-propellant boosters, fuel tanks and other elements of the space rocket system.

The electrothermal jacket (Fig 6.7) for the engine of the emergency rescue system maintains the temperature above +15°C and is a strip to which electric heaters, resistance thermometers and thermal resistances making up the electrical part of the jacket are fastened. The strip is made of foam plastic covered with rubberized balloon material with a split along the generatrix. Locks are attached on one side of the strip, and on the other, holders with turn buckles which are fastened to rubber shock absorbers. The holders are fixed in the locks by jaws connected to each other by the opening line. At the top there is a ring by which the jacket is held by the service truss crane after opening, and then it is lowered on the platform.

The electric heater is in the form of two strips between which wires are glued which make up the heating elements; the ends of the wires are soldered to the contacts which are taken out through a plug.

The resistance thermometers are the sensors of the ratiometer of the control panel indicating the temperature under the jacket; the thermal resistances are the instrument sensors of the panel that automatically regulates temperature.

During the summer, the top of the jacket is fitted with a protective shell made of rubberized material to which metallized film is glued which has a high coefficient of reflection of sun rays.

The thermal conditions under the jacket are maintained automatically; when the temperature deviates from the given one, sound and light signals are sent. The visual monitoring and manual regulation of the temperature are provided from the monitoring and control panel.

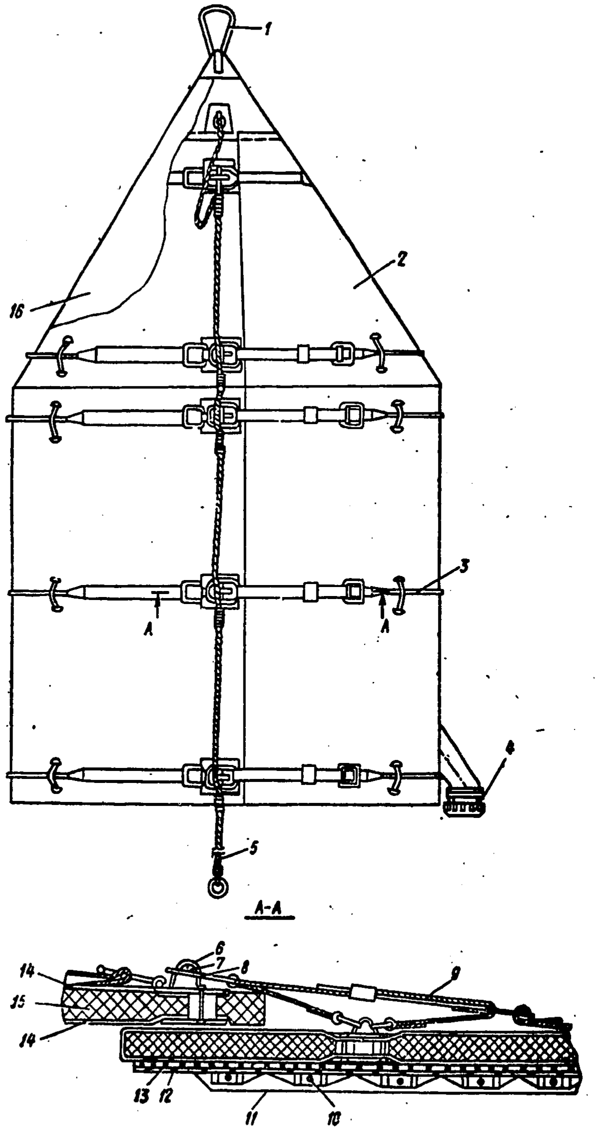

Figure 6.7. Electrothermal jacket:
1 -- ring; 2 -- fabric strip; 3 -- shock absorber; 4 -- plug; 5 -- opening line; 6 -- lock; 7 -- jaws; 8 -- holder; 9 -- turn buckle; 10 -- thermal resistance; 11 -- beds; 12 -- resistance thermometer; 13 -- electric heater; 14 -- balloon fabric; 15 -- foam plastic; 16 -- protective shell

CHAPTER 7. COMMUNICATIONS OF THE GROUND SYSTEMS WITH THE ON-BOARD SYSTEMS (" GROUND-ON-BOARD" COMMUNICATIONS)

7.1. Nature of the "Ground-On-Board" Communications

In order to perform the various operations during preparations for launch (filling with fuel components and compressed gases, various checks and measurements, purging, pre-launch purging of the tanks, maintenance of the thermal conditions of the on-board systems, and so on) the rocket installed on the launch system is connected to the ground launch systems through electrical, pneumatic and hydromechanical plug connections, forming the so-called "ground-on-board" communications.

As the pre-launch operations are performed, the number of couplings with the ground systems decrease as a result of uncoupling the plug connections and removal of the ground lines to a safe distance. Since some of the pre-launch ground operations are joined or close in time to the startup of the first stage engine, many of the plug connections are disconnected in the initial phase of movement of the rocket (Fig 7.1). The organization of these communications, laid still in the design stage, to a significant degree determines the operating convenience, reliability and efficiency of the rocket complex. The classification of "ground-on-board" communications is presented in Fig 7.2.

In order to simplify servicing and decrease the number of plug connections of the numerous lines brought to the rocket,they usually are combined into several groups (trunks).

Both related (that is, hydraulic, pneumatic or electric only) and unrelated lines are run through the plug connections; for safety reasons the combining of the lines, which when damaged will possibly cause an emergency (for example, mixing of self-igniting components) is undesirable.

The lines brought through the plug connections of the rocket are laid along special units -- the service towers (trusses), the fill cable and the fill-drain masts, and so on.

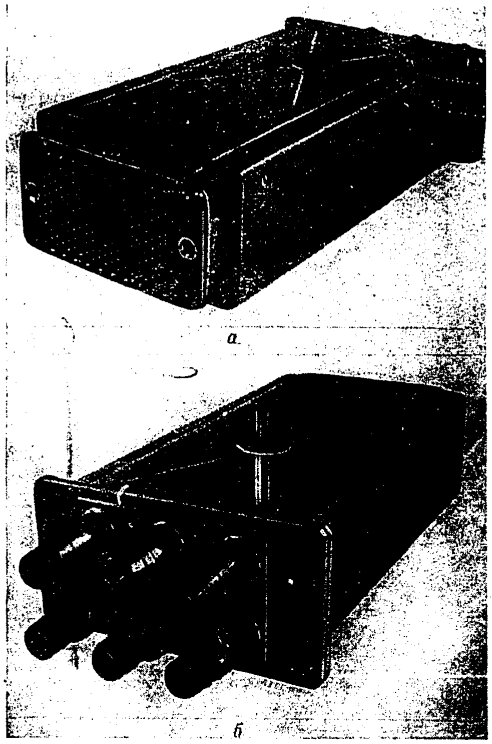

Figure 7.1. Disconnecting the "ground-on-board" communications in the initial stage of flight of the rocket

The plug connections basically have a common design. They are made up of two parts (panels) joined along the plane of the plug, and they insure the required connection of the lines running through them. The lines running from the ground systems are connected to one part of the plug (the ground plug), and the lines of the space rocket system are connected to the other part of the plug (the on-board part). Both parts are kept tightly connected by the special device (lock) which separates them at the required time, pushing the ground part away from the on-board part.

The structural design of the plug connection is determined by such factors as the method (manual or remote) of coupling (uncoupling) the parts of the plug connection, the number and the sizes of the transverse cross section of the lines running through the plugs, their purpose and type.

The plug connections must satisfy the requirements of simplicity and convenience in operation and maintenance, seal of the pneumohydraulic lines and contact coupling of the electric lines, the maximum possible distribution of the mass of the structure on the ground (removable) part and also insurance of reliable remote monitoring of the positions of the parts of the plug, high speed operation of the lock, independent redundancy in the response means and protection of the on-board and ground lines from the environment on uncoupling.

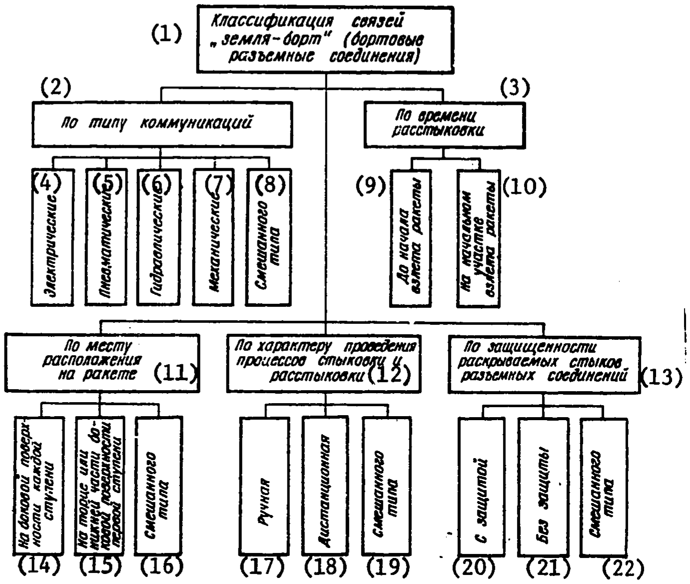

Figure 7.2. Classification of the "ground-on-board" communications

Key:

1. Classification of "ground-on-board" communications (on-board plug connections)
2. with respect to type of line
3. with respect to time of uncoupling
4. electric
5. pneumatic
6. hydraulic
7. mechanical
8. mixed type
9. before the beginning of takeoff of the rockets
10. in the initial takeoff phase of the rocket
11. by the location on the rocket
12. by the nature of performing the connecting and disconnecting process
13. by the protection of the open joints of the open connections
14. on the lateral surface of each stage
15. on the end or lower part of the lateral surface of the first stage
16. mixed type
17. manual
18. remote
19. mixed type
20. with protection
21. without protection
22. mixed type

The manual connection (disconnection) is used for simple plugs of small mass in easily accessible locations and serviced before the beginning of filling the rocket with fuel. In this case the ground part of the plug is connected to the on-board part manually using flanged or threaded connections. The ground part is the end of the line of the corresponding ground system.

The plug connections with a large number of lines having significant transverse cross sections and rigid requirements with respect to seal are most complex with respect to structural design. In order to facilitate the servicing, the coupling of these plugs is completely or to a significant degree mechanized, and sometimes they are remotely controlled and monitored. In this case it is necessary to have complex additional equipment which is placed directly in the service zone of the plug. In order to improve the quality of coupling, it is done at the engineering complex with subsequent connection of the ground lines at the launch complex to the adapters using simple flanges or threaded connections.

Remote uncoupling arises from the fact that some of the plugs must be connected until a defined time of pre-launch preparation of the rocket, and access to them by the service personnel is forbidden by safety engineering requirements and also the effort to decrease the labor consumption of the work done at the launch complex.

The ground lines (especially the large-diameter hydraulic and pneumatic lines) must be sufficiently flexible and strong and provide for significant, especially under high wind blows, mutual displacements of the booster rocket and the service unit on which they are laid. In order to compensate for the mutual displacements with small amplitudes and frequencies of the oscillations, flexible hoses are used; for significant amplitudes and oscillations, a combination of flexible hoses, hinges and other assemblies are used providing for rotation of the lines in the required planes.

The heavy lines require special mechanisms for bringing them in and removing them during the connecting and unconnecting process; the mechanisms take the greater part of the weight of the connected lines, which lowers the load on the plugs and at the same time simplifies their design.

From the point of view of reliability it is desirable to have a system in which the "ground-on-board" couplings are disconnected in advance (before starting the first stage engine), for a failure or delay in uncoupling and removal of the ground lines to a safe (from collision with the ascending rocket) place can result in an emergency. The use of this system is connected with reducing the efficiency of the rocket, for the preliminary discontinuation of the feed of cryogenic components and compressed gases to make up the tanks and bottles and the electric power for the on-board user leads to partial consumption of it before launch and also to the necessity for repeated remotely controlled and monitored coupling of the connection (in case of emergency shutdown of the engine during launch) for the drain lines, the inert gas feed, and so on, which significantly complicates the design of both on-board and the ground parts of the "ground-on-board" communications. Therefore, the rocket has a number of couplings which are disconnected only after starting the engine of the first stage, which in practice coincides with the beginning of the rocket flight. These communications include the topping lines for the cryogenic fuel components, the lines for pre-launch blowing of the tanks, the lines for purging the protective cavities and the systems for fire and explosion prevention, the electric line of the measurement and control systems participating in the launch operations, the lines for which repeated coupling of the connections is complicated as a result of safety requirements and the devices holding the rocket on the launch system until the engines reach full thrust and in certain cases insuring a given change in G-load when separating it from the launch system.

Uncoupling the plug connections and removal of the uncoupled lines at the beginning of flight of the rocket are technically difficult and for implementation require well thought-out and well-developed structural schemes. Primary attention has been given to the problems of high speed of the blocks where the plug connections and the mechanisms for removal with insurance of independent duplication in them of the response, exclusion of the collision of the removed lines and the rocket.

The uncoupled connections of the first stage of the booster rocket usually are taken after the lower part of the lateral surface of the booster rocket or to its end. They are serviced from the launch system or from small size units.

In order to provide couplings for the upper stages of the booster rocket and the space vehicle, two versions are used. In the first version all the lines or the greater part of them are taken out to the first stage, which although it simplifies servicing, significantly complicates and increases the weight of the structure of the booster rocket as a result of the placement of the lines and auxiliary equipment on the lower stages required only for pre-launch preparation of the upper stages. In the second version the plug connections are on the side surface of each stage and are connected to the ground systems through the service tower or the service cable mast which, complicating the servicing, decreases the length of the on-board lines and do not require complex plug connections between stages.

The service towers usually are pulled back from the rocket a significant time before launch; therefore lines are put on them which can be unplugged in advance. The trusses of the service cable towers and the cable mast are pulled back from the rocket directly before launch or during launch; therefore the lines are laid on them which are disconnected in practice when starting the engine.

For modern space rocket systems, as a rule, a combination of various systems of maintaining "ground-on-board" communications is used:

the couplings which are disconnected when the rocket system lifts off are led out through the lower part of the first stage (usually the electrical and pneumatic lines for the entire rocket and the fluid lines for the first stage); through the upper stages couplings are made with advance disconnection (the thermostating system, the system for servicing with high-boiling fuel components, the adjustable plug connections, and so on) and couplings with disconnection of the lines directly before launch or at the time of launch (electrical, pneumatic, topping off, and so on). This variety of systems is caused by the effort to create the most efficient on-board systems for the rocket systems and to maintain operating reliability of all the "ground-on-board" communications.

7.2. Standard "Ground-On-Board" Communications Layouts

The layouts for the "ground-on-board" communications will be considered in the example of the communications over the thermostating line. The on-board plug connections for the gas and liquid lines usually are called pneumatic and hydraulic blocks. The lines for the air thermostating system (VSOTR) are connected to the pneumatic blocks, and the liquid thermostating system (ZhSOTR), to the hydraulic blocks.

The layouts for the "ground-on-board" communications with respect to the VSOTR line (Fig 7.3) operate on the following principle. The air duct of the VSOTR is fastened through the adapter by means of the frame and guide to the sliding lift mechanism which serves not only to feed the air duct, but also to compensate for mutual displacements of the rocket and service tower.

The pneumatic lock of the block is opened when compressed gas is fed to it, and it repels the ground part of the pneumatic block to a short distance from the rocket. The pneumatic block together with the connected air duct is moved by the withdrawal mechanism to the required distance and is fixed by a catch in the terminal position. The kinetic energy of the withdrawal mass is absorbed by the shock absorber. Completion of withdrawal is monitored by a signal which is sent to the system that controls these operations.

The layout of the "ground-on-board" communications with respect to the ZhSOTR line (Fig 7.4) has by comparison with the precedin device all the degrees of freedom for displacement of the hydraulic block with respect to the service tower. Before uncoupling, in order to avoid spilling the heat-exchange agent on the side of the rocket, the lines for the hydraulic block are purged with gas to completely remove the remains of the heat-transfer agent. After uncoupling the withdrawal mechanism is rotated by means of the pneumatic drive, the final position of which is fixed by the signal unit. On completion of rotation, the disconnected part of the hydraulic block with the ground lines is lifted to the extreme upper position.

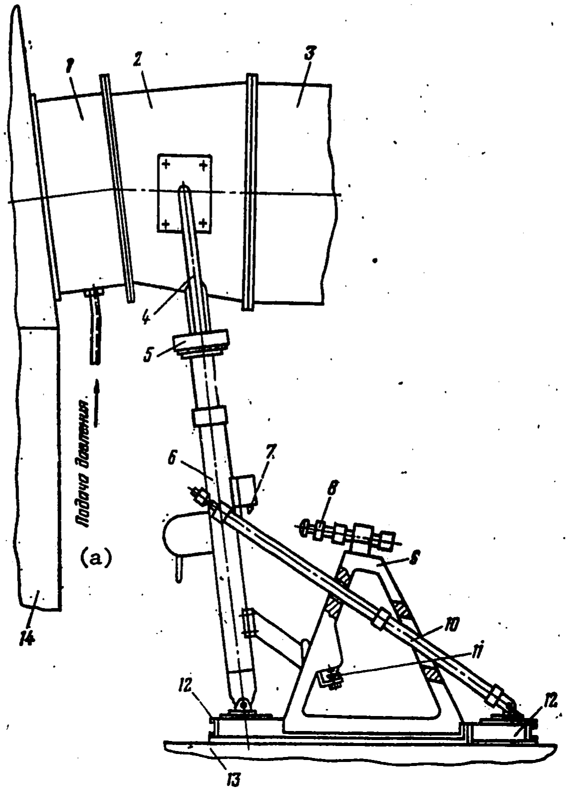

Figure 7.3. Layout of the "ground-on-board" communications with respect to the VSOTR line:
1 -- pneumatic block; 2 -- adapter; 3 -- air duct; 4 -- frame;
5 -- guide; 6 -- lift mechanism; 7 -- catch; 8 --shock absorber;
9 -- support; 10 -- pneumatic drive; 11 -- signal unit;
12 -- base; 13 -- service tower; 14 -- top module

Key:
a -- pressure feed

The "ground-on-board" communications are recognized using ordinary, split (ShR) and contact-breaking (ShO) plug connections and contact-breaking plates which differ from each other by purpose, structural design and method of separation.

The split plug connection is used to provide a coupling when preparing the space-rocket system up to launch time, including the initial phase of liftoff, and its separation occurs as a result of the movement of the space-rocket system. The operating principles of such plugs are different: one of them splits as a result of simple separation of the on-board and ground parts; others split as a result of the response of a special lock with a line attached to the launch system. Usually the split plug connections are placed at the end of the booster rocket.

The contact-breaking plugs (Fig 7.5) are designed to provide electrical communications which are broken before liftoff of the rocket. If the communications are separated ahead of time, the cables are laid on the service tower, and the ground parts of the plugs are attached to the corresponding trusses; if the couplings are broken several seconds before launch, the cables most frequently are laid on the cable masts.

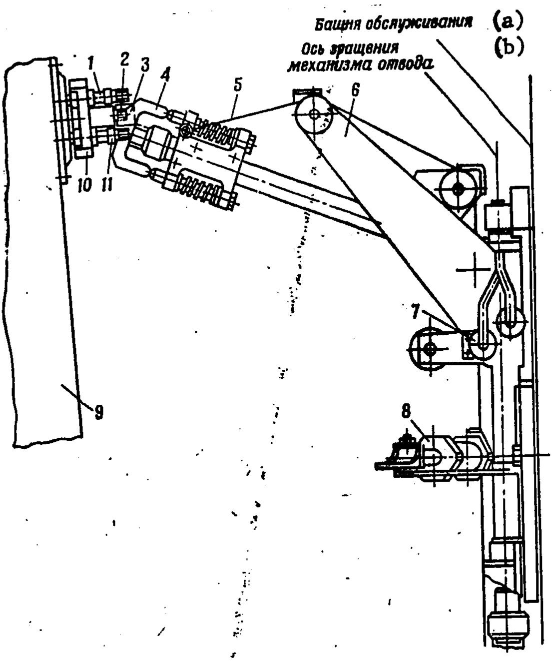

Figure 7.4. Schematic of the "ground-on-board" couplings with respect to the ZhSOTR line:
1 -- connection for feeding the heat-transfer agent; 2 -- connection for the pneumatic block; 3 -- contact sensor; 4 -- clamp; 5 -- line; 6 -- moving part of the withdrawal mechanism; 7 -- signal unit; 8 -- pneumatic drive; 9 -- top module of the rocket; 10 -- hydraulic block; 11 -- connection for removal of the heat-transfer agent (the hoses for supplying the transfer agent are not shown)

Key:
a -- service tower; b -- axis of rotation of the withdrawal mechanism

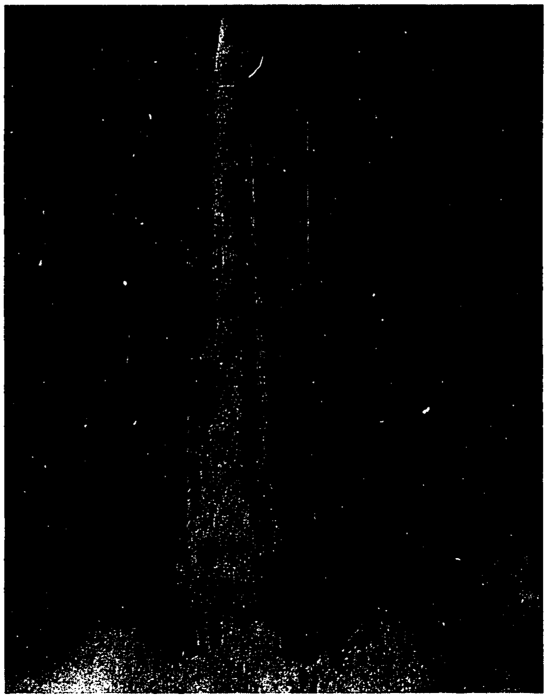

Figure 7.5. Contact-breaking plug connection:
a -- view from the contact sealed side; b -- view from the cable entrance side

The contact-breaking plugs of different designs have the special lock of the pressure (by hand) or electromagnetic type. Usually before beginning to fuel the rocket the plug connections are disconnected manually; after fueling this is done remotely by sending a signal to the electromagnet of the lock from the control panel. The lock responds, the round part of the plug separates under the effect of springs from the on-board part and it is trapped by a basket (trap) on the cable mast.

The contact-breaking plate is used to provide for coupling a large number of electric circuits. It is a massive metal plate with plug connections and it is made up of on-board and ground parts held in the coupled state by a breakaway bolt. The coupling of the plates requires special attachments and usually it is done at the engineering complex. For coupling to the ground cable network the contact-breaking part of the plates has cable adapters.

At the launch complex after issuing the command to the breakaway bolt, separation of the contact-breaking plate into two parts takes place. The released ground part of the plate with the cable adapters is ejected by springs from the side of the booster rocket and withdrawn by special mechanisms to the service truss. The contact-breaking plates have contact devices which signal the control panel about the execution of the command to separate the plates.

7.3. "Ground-On-Board" Communications of the "Saturn-V-Apollo" Space Rocket System

Let us consider the schematic of the organization of the "ground-on-board" communications and the characteristics of its basic elements in the example of the "Saturn-V-Apollo" space rocket system.

The "Saturn-V-Apollo" space rocket system is installed before removal from the vertical assembly building on the upper part of the launch system made up of the launch platform and the cable service tower. All of the "ground-on-board" communications are coupled.

On the launch platform are four supporting clamps at an angle of 90° to each other which hold the rocket system during transportation, while it is at the launch complex and for several seconds after starting the first stage engine. In addition, in the same area there are three tail service cable masts attached to the rocket providing for (in addition to electropneumatic feed) drainage of the liquid oxygen, filling and drainage of fuel and air feed for air conditioning. Uncoupling of the ground communications at liftoff of the rocket takes place through these service cable masts.

The electrical, pneumatic and hydraulic communications, telephone and television cables required for servicing and pre-launch preparation of the booster rocket and the space vehicle at the launch complex are laid on the service cable tower. The coupling of the on-board systems to these lines takes place through the pre-launch (separated before launch) and launch (withdrawn during launch) service truss, the distribution of the lines on which is presented in Table 7.1.

Table 7.1

Distribution of Lines with Respect to the Service Trusses of the Service Cable Tower for the "Saturn-V-Apollo" Space Rocket System

Service trusses	Lines			
	Electrical	Fuel	High-pressure	Air conditioning
Command module	-	-	8	1
Service module	5	-	8	1
Instrument compartment	22	1	22	1
S-IVB engine compartment	8	2	42	1
S-II tool compartment	7	1	20	1
S-II intertank compartment	15	2	46	2
S-IC instrument compartment	3	-	8	2
S-IC intertank compartment	-	2	5	-
Tail compartment (the tail service cable mast)	18	2	21	1

All of the lines of the upper part of the launch system are led out to the service zones of the launch stand (Fig 7.6); after installing the launch platform on the supports of the stand they are connected to the ground systems of the launch complex through the coupling units, and they are disconnected after launching the rocket before withdrawal of the launch platform.

The supporting clamp arms of the launch platform (Fig 7.7) hold the space rocket system until all of the engines develop the required thrust. If one of the engines does not reach operating conditions during this time, the first stage engine is shut down. With normal starting, after a defined time the mechanisms for withdrawing the clamps (the withdrawal of the clamps is made redundant by a pyrobolt if necessary)respond from two identical (redundant) pneumatic systems (high-pressure helium). The liftoff of the rocket is monitored by contact signal elements of diametrically arranged clamps; in this case the signals generate a command to disconnect the fast-disconnect couplings and withdraw the tail service cable masts and the launch service trusses of the cable service tower; this takes place when the rocket has lifted approximately 20 cm.

The tail service cable mast (Fig 7.8) is a balanced structure with pneumoelectric control and hydraulic drive and it is made up of a base, a lever with a counterweight on which the corresponding lines are placed with high-speed plugs and a protective housing. The fast-disconnect coupling has two parts: one is on the booster rocket side and after disconnect is covered by a cover; the other part located on the service cable tower consists of the housing with a special collet-type lock providing for connecting the plugs and uncoupling them with repelling of the ground part away from the on-board part.

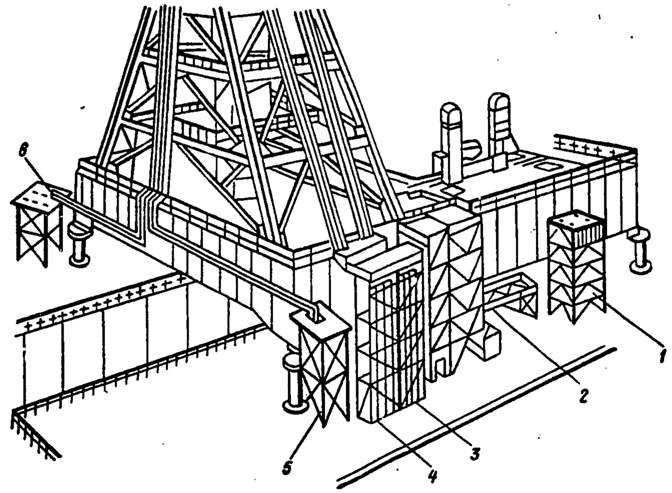

Figure 7.6. Schematic of the exit of the ground lines to the service zones of the launch stand of the "Saturn-V-Apollo" space rocket system:
1 -- electric power mains; 2 -- auxiliary equipment; 3 -- air conditioning mains; 4 -- electric cables; 5 -- liquid-oxygen lines; 6 -- liquid and gaseous hydrogen lines

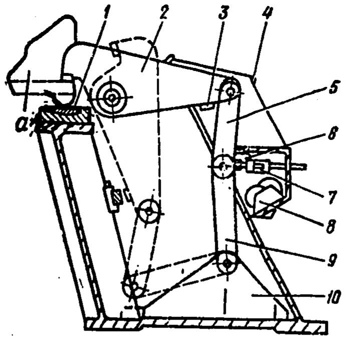

Figure 7.7. Supporting clamp arm:
1 -- adjustable support; 2 -- upper element of the arm; 3 -- stop plate; 4 -- cover; 5 -- central element; 6 -- leveling attachment; 7 -- pneumatic distributor; 8 -- winch; 9 -- lower element of the arm; 10 -- bearing beam; a -- end of booster rocket

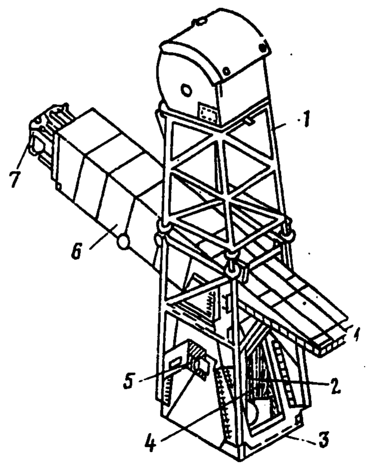

Figure 7.8. Tail service cable mast of the launch platform of the "Saturn-V-Apollo" space rocket system: 1 -- protective jacket and truss; 2 -- feed line; 3 -- base; 4 -- hydraulic and pneumatic lines of the system; 5 -- electric line; 6 -- arm with counterweight; 7 -- ground part of the flow connection

Before launching the space rocket system the pre-launch service trusses of the intercompartment of the second stage are withdrawn (11 hours 30 minutes), the spacecraft compartment (preliminary 43 minutes and final 5 minutes), the intertank compartment of the first stage (50 seconds), the instrument compartment of the second stage (16 seconds before launch), and at launch time, the launch service trusses with the fill and drain lines and the basic electrical and pneumatic couplings.

Provision has been made for mechanical redundancy of the uncoupling of the plugs and the withdrawal of the service trusses operating at liftoff of the rocket system in case of failure of withdrawal system.

Part of the couplings required for servicing the engines of the spacecraft and the auxiliary engine of the third stage operating on long-storable high-boiling fuel components are supported from the movable service tower which is withdrawn from the launch system 10 hours before launch.

CHAPTER 8. GUIDANCE SYSTEMS OF THE SPACE ROCKET SYSTEM

8.1. General Information

The gyrostabilized platform of the booster rocket control system must be oriented a defined way in space relative to the direction of the earth's meridian and the coordinates of the launch pad determined during geodetic preparation for launch in order to support insertion of the space vehicle into a given orbit. The set of operations with respect to orientation of the booster rocket or the elements of its on-board control system before launch to obtain the given flight parameters is called guidance.

As a rule, additional orientation of the space vehicle with respect to the ground geodetic network before launch is not required, for it is structurall connected with the booster rocket, and its location with respect to the rocket is known.

The booster rocket and the control system sensors are oriented during guidance relative to the launch coordinate system $OX_cY_cZ_c$ (Fig 8.1), the origin of which coincides with the center of mass of the space rocket system installed on the launch system. The OX_c axis indicates the flight direction and its position is determined by the launch azimuth A_{π}, the OY_c axis is directed vertically upward, and the Y_cOX_c plane tangent to the trajectory of motion of the space rocket system with the location of the launch system is called the launch plane.

As a result of rotation of the earth and other factors the trajectory of motion of the space rocket system is a line of double curvature; therefore it does not coincide with the launch plane and deviates from it.

The so-called bound coordinate system $OX_1Y_1Z_1$(Fig 8.2, a) is connected with the space rocket system, the origin of which is placed at the center of mass of the space rocket system. The OX_1 axis coincides with the axis of the rocket system, and the direction of the remaining axes is determined by the location of the steering elements placed in the stabilization planes which usually are numbered in roman numerals. The

I-III plane passing through the longitudinal axis of the rocket and the steering elements is called the basic plane of symmetry.

The direction of the axes of sensitivity of the gyroscopic and inertial sensors of the control system determines the inertial coordinate system OXYZ (Fig 8.2, b), and the XOY plane is called the basic stabilization plane. At the time of launching the space rocket system the axes of the bound and inertial coordinate systems are oriented in a defined way with respect to the coordinate axes of the launcher. The required mutual arrangement of all three axes of the coordinate systems is achieved by verticalization, azimuthal guidance and adjustment of the rocket gyroplatform.

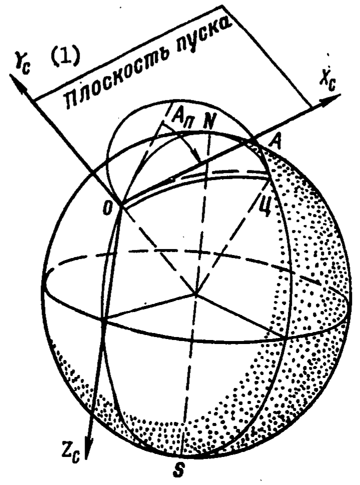

Figure 8.1. Launch coordinate system

Key:

1. Launch plane

As was pointed out previously, verticalization of the rocket is a set of operations with respect to bringing the space rocket system installed on the launch system to a strictly vertical position. The greatest deflection of the axis of the rocket or the element of its on-board control system in the vertical position must not exceed several angular minutes.

Verticalization is achieved by rotation of the support plane of the launch system around two mutually perpendicular axes using lift mechanisms, and it is performed either directly during erection or immediately after erection of the rocket.

Azimuthal guidance is orientation of the OY_1 axis of the bound coordinate system and the space rocket system installed on the launch system, in the horizontal plane to obtain a given flight direction. It is realized either by turning the rocket in the horizontal plane or orientation of individual elements of its on-board control system.

The adjustment of the gyroplatform has as its purpose the matching of the basic stabilization plane with the basic plane of symmetry. It is accomplished by rotation of the base of the gyroplatform with respect to the hull of the rocket after it. In order to guide the space rocket system at the launch complex it is necessary to perform two preliminary operations: geodetic operation of the launch and preparation of initial data.

In the case of geodetic preparation of the launch, the coordinates of the launch system are determined, and the orientation of the geodetic directions at the launch complex is carried out. The coordinates of the launch system together with the coordinates of the flight trajectory of the space rocket system are used when preparing the initial data for launch, and the oriented geodetic directions, directly for azimuthal guidance.

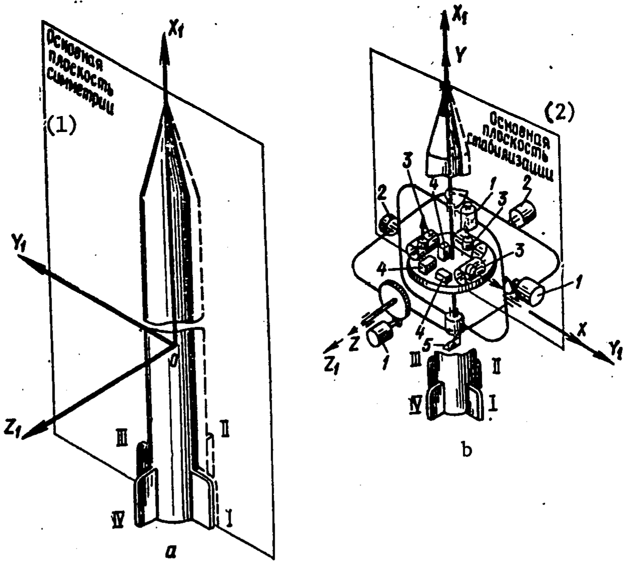

Figure 8.2. Coordinate systems:
a -- bound; b -- inertial; 1 -- stabilization engine; 2 -- angle gauge; 3 -- gyroscopic; 4 -- accelerometer; 5 -- control prism
Key: 1 -- basic plane of symmetry; 2 -- basic plane of stabilization

The orientation of the directions is determination of the azimuth of any straight line taken as the orientation line; for the space rocket system, as a rule, orientation is performed from the geodetic network. When guiding at the launch complex, a large volume of various operations are performed connected with determining the directions, measurement of the angles and rotation of the instruments of the gyroplatform. In order to decrease the time, the operations not connected with the location of the space rocket system at launch are performed in advance, and an effort is made at maximum automation of the guidance system itself.

8.2. Basic Devices of the Guidance System

With respect to physical principles used as the basis for the operation of the elements of the guidance systems, their devices are divided into optical-mechanical, photoelectric, electronic, electromechanical and gyroscopic devices. The optial-mechanical devices are used to determine the azimuth of the orientation directions; the photoelectric devices, for measuring the mismatch angle, the electronic and electromechanical devices, for generation, amplification and conversion of the signals during measurements of the angles, remote transmission of them and processing of the angular mismatches, and gyroscopic, primarily as the measuring elements of the control system or as gyrocompasses for providing azimuthal guidance.

Optical-Mechanical Devices. An example of the optical-mechanical devices is the theodolites which are widely used to determine the azimuth of the oriented directions and for verticalization of the rocket.

For guidance of the space rocket system it is necessary to fix both the position of the launch plane and the position of the basic stabilization plane usually fixed by mirrors and mirror prisms. The mirrors and prisms are fastened to the stabilized platform during manufacture of it and they are oriented with great accuracy with respect to the basic stabilization plane of the rocket.

The rectangular mirror prism is most widely used (Fig 8.3), a characteristic feature of which is the fact that the light beam incident on the hypotenuse face of the prism in some plane P exits from it back in the Q plane parallel to the P plane. At points and d the beam is refracted on the hypotenuse face of the prism, and at points b and c, it is reflected from the silvered faces of the prism making up its legs. As a result of this property it is not necessary exactly to verticalize the prism in the YOX plane, for even if the entering beam will not lie in the XOZ plane, the reflected beam goes in the opposite direction in the plane parallel to its plane of incidence. If the mismatch plane measured by the theodolite between its viewing axis and the perpendicular to the edge of the right angle of the prism is not equal to zero, then the angle between the incident and reflected beams is equal to twice the mismatch angle; if the mismatch angle is equal to zero, then in the case of parallelness of the incident and reflected beams their images in the vertical plane of the eyepiece coincide; consequently; the axis of the theodolite is also perpendicular to the edge of the prism.

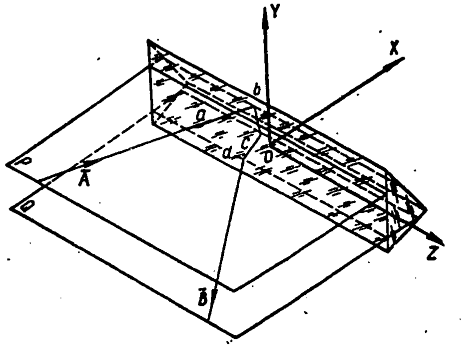

Figure 8.3. Rectangular prism

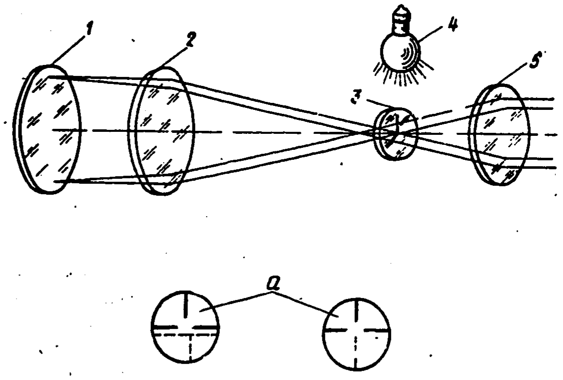

Figure 8.4. Autocollimator:
1 -- mirror; 2 -- objective; 3 -- grid; 4 -- light; 5 --eyepiece; a -- field of view

The azimuthal position of the monitoring elements is determined by the autocollimation principle, that is the path of the light beams for which they exit from the instrument as a parallel beam and, on being reflected from the mirror surface, they pass through the elements of the instrument in the opposite direction. If the surface of the mirror is perpendicular to the viewing axis of the autocollimator (Fig 8.4), the direct and autocollimation images of its grid coincide with each other. Using the autocollimation principle, it is possible also to solve the inverse problem -- setting of the control mirror or the prism of the gyroplatform in accordance with the given azimuth, for which it is necessary to turn it with respect to the vertical axis and, observing the autocollimator, to achieve matching of the direct and autocollimation images of the grid.

Photoelectric Devices. The source of the light signals in the photoelectric devices is the gas light tubes, incandescent lights and lasers. In order to convert the light signals to electric signals, various photoelectric radiation receivers are used (photoelements, photoresistances, photomultipliers, photodiodes and so on). The optical systems of these instruments are designed to create parallel light beams, for focusing, separation, connection and change in direction of the light beams.

The photoelectric devices are used for automatic measurement of the small mismatch angles between the basic stabilization plane of the space rocket system and the launch plane, the generation of electric signals which depend on the measured angular mismatches, the transmission of oriented directions in the vertical plane and measurement of the azimuthal angles in a large range of variation of them.

Depending on the purpose, the photoelectric devices are divided into goniometers, synchronous transmissions and angle gauges.

The goniometers solve the first two problems and are of two types -- with external and internal light signal source; they consist of a source of radiation, an optical system, a radiation receiver, signal amplifier and converter. The light signal received from the radiation source is incident on the control prism installed on board the rocket and, being reflected from it, is received and analyzed by the goniometer.

The goniometers can operate in the zero and measuring regimes: in the zero regime the mismatch signal generated by the goniometer is fed to the drive of the gyroplatform which is rotated until the base stabilization plane coincides with the launch plane. The mismatch angle is measured for the measuring regime, and the electric signal proportional to the measured angle is generated.

Synchronous transmissions are designed to transmit oriented directions in the vertical plane from the base of the launch system where the guidance instruments are located to the instruments on the space rocket system.

The angle gauges are used to measure large angles of rotation of the various instruments and devices. Their measurement range reaches 360° in this case.

The polarization devices (a version of the photoelectric devices) operate on a polarized light signal and are used in optical synchronous transmissions and autocollimation goniometers. By comparison with the photoelectric synchronous transmissions, these devices have high accuracy.

Their application in the goniometers permits use of splitting of the polarized light beam to generate a mismatch signal in two mutually perpendicular planes, that is, to measure the angles of deflection of the viewing axis of the goniometer from the perpendicular to the mirror surface in two directions -- azimuthal and vertical.

The light beams emitted by ordinary sources are not polarized; therefore the light signal in the polarization devices is converted in advance using polaroids, polarizing and double-refracting prisms. In order to exclude interference from outside light sources the polarized light signal is modulated by the polarization element which changes its optical properties under the effect of an electric or magnetic field.

The amplifier-converters are used to amplify the electric signals picked up from the photoelectric radiation receivers and other sensitive elements having low power insufficient for direct actuation of the regulating and servounits and also for signal conversion. The electron, semiconductor and magnetic amplifiers are the most widespread.

The electron and semiconductor amplifiers are distinguished by high sensitivity. They are capable of amplifying the low-power signals. The magnetic amplifiers permit us to obtain high output power of the signal and they have high reliability.

Modulators and demodulators are most widely used among the conversion units in guidance systems. If the sensitive element operates on direct current, and the servoelement, on alternating current, then the DC signal is converted in the amplifying channel to an AC signal using modulators. Systems in which an AC signal is picked up from the sensitive element are more widespread, for the light flux itself is modulated, and the servoelement operates on direct current; the conversion of the AC signal to DC takes place using demodulators.

The induction synchronous transmissions are designed for remote measurement of the angles of rotation of the various elements, remote rotation of the elements themselves by defined angles and synchronous rotation of several axes mechanically not connected with each other.

The induction synchronous transmissions, in contrast to photoelectric and polarization devices, do not have the property of rigidity (one-to-one spatial correspondence between the orientation of the sensor and the receiver). The sensor and the receiver of the induction synchronous transmission in the matched position can have a spatial orientation and cannot be used for vertical transmission of the orientation directions. In addition, the induction synchronous transmissions have lower accuracy by comparison with the polarization transmissions.

The gyroscopic devices usually are used as measuring devices in the inertial flight control systems. The operation of the guidance systems is closely connected with the on-board gyroscopic instruments, for the goal of azimuthal guidance is orientation of the axes of sensitivity of these instruments with respect to the launch plane.

The application of gyroscopes is based on such properties as stability consisting in an effort to keep the position of the axis of rotation invariant in space and precession consisting in the fact that when applying the moment along one of the axes of the gimbal frames, rotation of the gyroscope around the other gymbal axis takes place. A gyroscope with 3° of freedom (rotation around its own axis, horizontal axis and vertical axis of the gimbal) has these properties. On restriction of one of the degree of freedom the gyroscope loses the property of stability and the property of precession.

Gyroscopic devices are used for guidance of space rocket systems to maintain the oriented geodetic directions, for autonomous determination of the azimuths of the orientation directions and stabilization in space of the elements of the guidance system under the effect of various mechanical disturbances on them.

8.3. Nonautomated Guidance Systems

In the nonautomated guidance systems, the principle of visual determination of the position of the control element of the space rocket system with respect to the ground geodetic network is used. For example, let us consider the method of guidance, the base for which is transfer of the reference direction with the help of a two-channel autocollimation telescope with established base angle (90°) between the viewing lines of the objectives of the two channels (Fig 8.5).

The two-channel telescope is in the form of two autocollimation tubes, the viewing axes of the objectives of which are at an angle of 90° to each other; in this case the image planes of the two objects are matched by special optical elements in the field of view of one eyepiece. In the autocollimation mode only one channel operates, the objective of which is aimed at the control element of the guidance system -- the prism -- the objective of the second channel is aimed at the electric stake giving a defined geodetic direction. At the center of the field of view of the eyepiece on the grid of angular units a line is plotted which must be matched with the autocollimation image from the control prism. The edge of the control prism must be perpendicular to the viewing axis of the autocollimation tube. The second image on the grid of the eyepiece will be from the electric stake. The reading between the two images in provisional units is the angle which must be taken into account in the guidance formula.

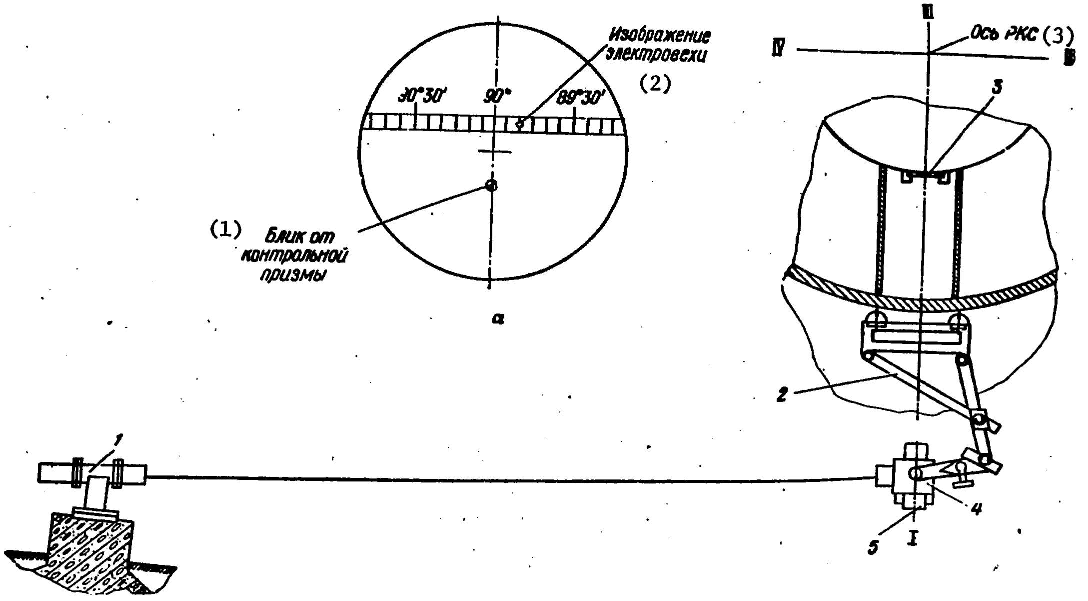

Figure 8.5. Schematic of the arrangement of the visual guidance systems equipment using a two-channel autocollimation tube:
1 -- electric stake; 2 -- bracket; 3 -- control prism; 4 — instrument; 5 -- eyepiece;
a -- view in the eyepiece; I, II, III, IV -- axes of symmetry of the space rocket system

Key: 1 -- view from the control prism; 2 -- image of the electric stake; 3 -- axis of the space rocket system

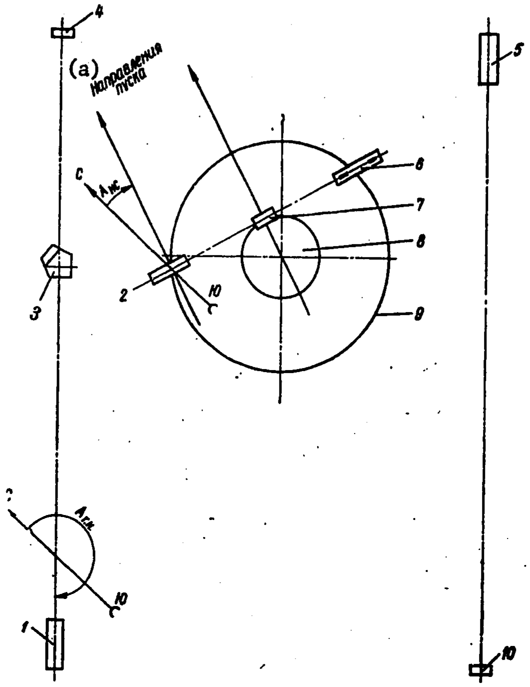

Figure 8.6. Schematic of the arrangement of the visual guidance system equipment -- "goniometer-prism-mark":
1,5 -- collimators; 2 -- goniometer; 3 -- pentaprism; 4,10 -- stakes; 6 -- mark; 7 -- prism; 8 -- space rocket system; 9 -- angular guides

Key:
a -- directions of launch

In the visual nonautomated guidance systems, the "goniometer-prism-mark" method is used (Fig 8.6) based on matching the images of two marks located in two planes at different distances in the field of view of the goniometer. The oriented geodetic directions are formed by two collimators and two stakes (to provide guidance along any azimuth). The "goniometer-mark" direction perpendicular to the launch direction is established through the pentaprism (pentagonal prism) with respect to these directions and considering the direction (azimuth) of launch. The pentaprism provides for rotation of the angle by 90° independently of the degree of perpendicularity of the beam to the plane of the prism face. Rotating the rocket with the prism installed on the gyro, the edge of the prism is matched with the "goniometer-mark" direction and thus guidance is reduced to matching the images of the edge of the prism and the mark in the field of view of the goniometer.

All the guidance operations are performed before putting the fuel components on board the booster rocket, for after servicing, the presence of service personnel in the direct proximity of the rocket is forbidden. Therefore the visual guidance system cannot exclude the errors in azimuthal guidance which occur as a result of deformation (twisting) of the hull of the booster rocket after it is filled with fuel, and it can be used in cases where high accuracy of guidance in the launch plane is not required.

8.4. Automated Guidance Systems

Considering that in the process of preparing the space rocket system at the launch complex complex automation is finding greater and greater application, the nonautomated guidance systems cannot provide for the given requirements.

In modern space rocket complexes for azimuthal guidance of the rockets, completely automated systems are used which provide for automatic output of the required information to the flight control system of the space rocket system. These systems can be of two types: single-channel and double-channel.

The single-channel guidance system (Fig 8.7) includes the autocollimation goniometer which tracks the reflector with the drive, the prism which fixes the orientation geodetic direction, the amplifier-converter unit, the on-board control prism, the drive of the gyrostabilized platform, the television transmitter and the guidance system control unit. Before guidance geodetic gridding of the position of the viewing axis is carried out, and a special prism is used for periodic monitoring of the position of the goniometer.

Using the tracking reflector, the light beams leaving the objective of the goniometer are rotated by 90°, and at an angle of 25° to the horizon they are directed at the on-board control prism. On the basis of the analysis of the light flux reflected from the prism, the control signal is generated which is fed to the drive for rotating the gyrostabilized platform azimuthally. When developing this signal the on-board prism takes up the position in which the perpendicular to it will be perpendicular to the viewing axis of the goniometer.

The on-board control prism does not have a fixed position with respect to the basic stabilization plane of the rocket and is fastened to the stabilized base of the gyroplatform in the gimbal which can rotate by 360° with respect to the gyroplatform. Varying the position of the prism with respect to the basic stabilization plane, it is possible to change the launch direction with a fixed position of the viewing axis of the goniometer.

In order to control the operation of the system, a special control unit is used from which commands are given to the tracking reflector with primary "lock-on" of the on-board prism by the guidance system. The "lock-on" signal is generated in the goniometer and is fed to the control unit. In order to monitor the operation of the guidance system on "lock-on" of the on-board prism and in the mismatch signal generation regime the tracking system for the rotation of the gyroplatform is the television with transmitting camera placed in the goniometer. The receiving chamber is fed part of the light mismatch signal generated by the goniometer. Direct visual control of the accuracy of the guidance is provided for in the goniometer, for which part of the light flux from the goniometer is fed to the viewer.

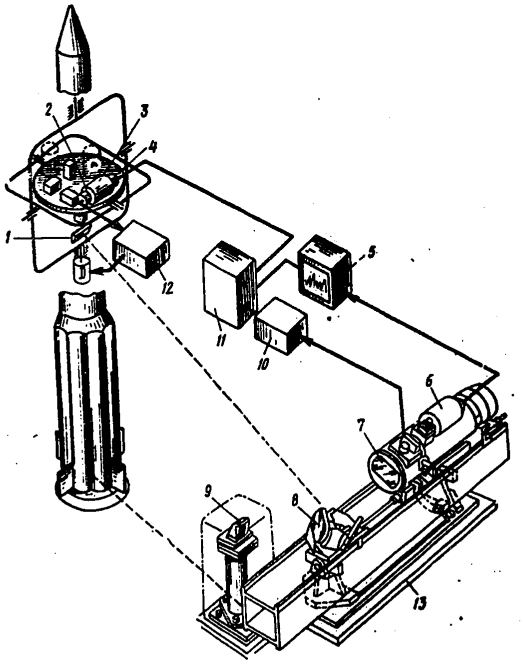

Figure 8.7. Single-channel guidance system:
1 -- control prism; 2 -- precession angle gauge; 3 -- gyroscope; 4 -- moment gauge; 5 -- television receiver; 6 -- television transmitter; 7 -- objective; 8 -- reflector; 9 -- prism; 10 -- azimuthal error signal amplifier; 11 -- control unit; 12 -- engine power booster; 13 -- autocollimation goniometer

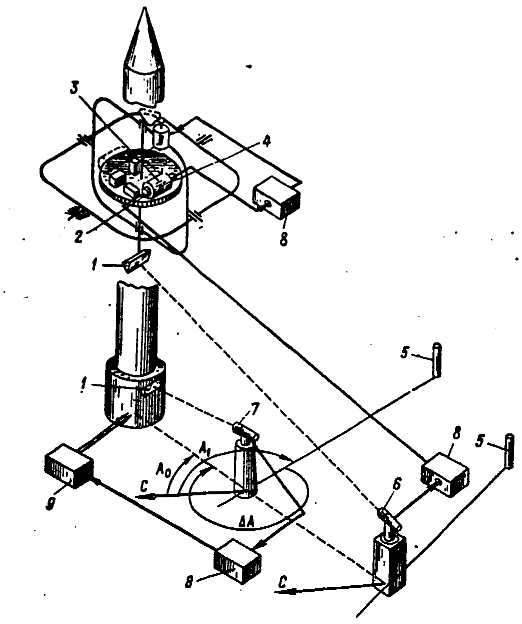

Figure 8.8. Two-channel guidance system:
1 -- control prism; 2 -- moment gauge; 3 -- gyroscope;
4 -- precession angle gauge; 5 -- orientation points;
6 -- long-range goniometer; 7 -- short-range goniometer;
8 -- amplifier; 9 -- drive

The two-channel guidance system (Fig 8.8) includes two autocollimation goniometers and two tracking systems, one of which is used to rotate the space rocket system and the other, to rotate the gyrostabilized platform.

The goniometer of the first tracking system is installed in direct proximity to the launcher and is viewed along the control prism attached to the rotating part of the launcher. The mismatch signal generated by the close range goniometer is fed to the drive for rotating the launch system together with the rocket. The close range goniometer is designed for rough guidance and provision for operation of the nonrange goniometer and also for guidance of the space rocket system with a different direction of launch, for which the launcher has two control prisms: one corresponds to the guidance azimuth in the basic direction and the other, the auxiliary direction.

The long-range goniometer which enters in to the precision guidance tracking system is installed 130 to 150 meters from the launcher. The light flux transmitted by this goniometer is directed at the on-board control prism attached to the gyrostabilized platform. The mismatch signal generated by the goniometer goes after amplification to the drive for rotating the gyroplatform which is rotated azimuthally until the basic stabilization plane of the rocket coincides with the launch plane.

Before guidance the short and long range goniometers are installed so that their viewing axes will coincide with the launch plane. For orientation of it, the launch azimuth A_0 and the azimuths of the oriented geodetic direction A_1 are used. The guidance angle (the angle between the direction of the launch plane and the direction of the orientation point)

$$\Delta A = A_0 - A_1,$$

if this value is negative, it is increased by 360°.

A characteristic feature of the two-channel system is the relation between the launch azimuth of the space rocket system and the location point of the goniometer which must be selected so that the direction of the viewing angle of the goniometer on matching with the launch plane will simultaneously coincide with the direction of the control prism. This means that the launch plane must pass through the axis of the launch system and the location of the goniometer. If the launch direction changes, the point of location of the goniometer must be shifted along with the arc of a circle.

At the present time when building a launch complex and its structures, the launch direction is taken into account. Here the launcher and the goniometer are arranged so as to exclude preliminary (rough) guidance. In addition, the modern control systems provide for a change in flight direction by rotation of the control prism with respect to the gyroplatform.

In cases where the flight control system has two or three autonomous gyroplatforms in order to increase its reliability, the guidance system also must have the corresponding number of independent azimuthal guidance channels.

Special attention by the specialists is attracted by the guidance method using gyroscopic compasses, the axis of which has selectivity with respect to the direction of the north thanks to the effect of the directional moment manifested as a result of rotation of the earth.

The on-board gyroscopic instruments of the control system (accelerometers, gyroscopes) can operate in the general compass mode. In this case the guidance becomes autonomous and the presence of oriented geodetic directions and ground equipment at the launch complex is not required. The deficiencies of this guidance method are the relatively long time (20 to 40 minutes) required to determine the direction of the north and the technical complexity connected with obtaining the required accuracy characteristics of the gyrocompasses.

CHAPTER 9. MONITORING AND CONTROL SYSTEMS FOR TECHNOLOGICAL PROCESS OPERATIONS

9.1. General Information

The automatic monitorng and control systems for technological operations of preparing the space rocket system for launch at the engineering and the launch complexes with respect to their organizational and functional characteristics belong to the large systems, for they contain a significant number of different servo, power and measuring equipment and control units connected to each other by branched, multifaceted communications for automatic performance of a complex of functions under conditions of complex environment in the presence of interference and counteracting factors.

The automatic control systems usually are classified by the information about the control process or system used. The information plays a significant role in the control processes, and the means of obtaining it are important elements of the control systems. Two types of information are distinguished: initial (a priori) and operating (arriving during the process of performance of given functions by the system). Beginning with the characteristics of the initial and operating information the automatic control systems are divided into ordinary, adaptive and game.

The technological process of preparing the space rocket systems for launch has a game nature. The problems of controlling the preparation operations can be interpreted as the problems of automatic playing of a game of two sides, of which the first is the control system, and the second, the object of control. The actions of the control system are subject to a defined program within the limits of a number of solutions depending on the action of the second side. The actions of the object of control are also subject to certain rules, but there can also be random deviations The object of control is not antagonistic with the control system. This type of game system belongs to the class of games with nature.

In systems with a set of standard solutions from a set of versions of actions of the first side, an optimal choice is made in advance, and in systems with automatic search for the solutions, the control machine itself solves the problem of optimal choice for each current step of the control operations.

For example, let us consider the operation of fueling two tanks of a booster rocket (Fig 9.1). Depending on the order of receiving the signal "П1" of passage of the level in tank A or B, valve 2K or 3K must be shut off; the sequence of shutting off the valves depends on the random causes leading to various combinations of passage of the level. An analogous situation occurs also with respect to the "Yp" signal in tanks A and B with valves 4K and 5K.

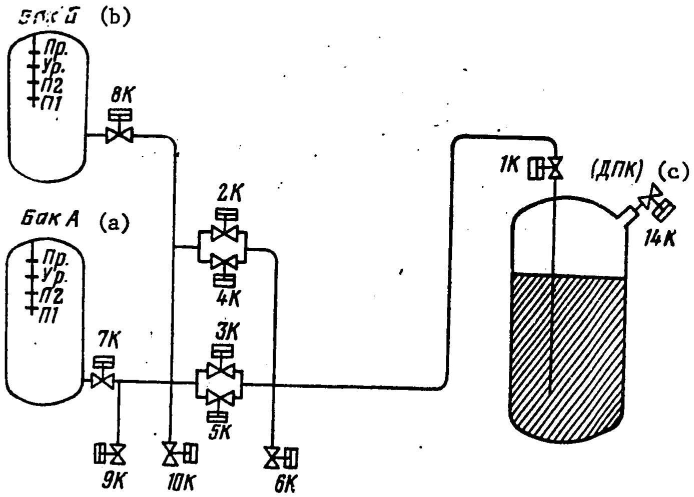

Figure 9.1. Pneumohydraulic system for filling the tanks of a booster rocket

Key:

a -- Tank A; b -- Tank B; c -- (DPK) -- drainage safety valve

In case of failure of one of the valves 2K, 3K, 4K, 5K (failure to close) the filling is stopped and transfer of the fuel components from the tank with the emergency to the other tank and filling of it to the required level begins and also topping off the tank with the emergency under special conditions. Depending on which valve has failed, four different combinations of operation of the systems are possible; consequently, only for the given simplest system do eight game situations occur, and the entire technological process of preparation has significantly of them.

The control system for pre-launch preparation, beginning with the game nature of the technological process would be expediently carried out with automatic search for the optimal solution, but in this case it will become very complex and awkward.

The insufficient reliability of the control elements forces us to do away with the embodiment of all possibilities of game nature of the preparation process, and one or several standard solutions, the optimalness of which has been checked in advance, are written into its operating program.

The operation of the automatic launch preparation system (ASPS) consists of successive steps, as a result of which the preparation control takes place discretely by formation of a sequence of control instructions for the systems of the space rocket system and the space center.

The automated launch preparation systems must maintain fitness with respect to their purpose and effectiveness for any action on the part of the object of control, and by this attribute they belong to systems with minimum necessary information about the target (at the beginning of operation they only have minimum primary information based on the result of the preceding adjustment operations or checks, and minimum initial information about the state of the systems, the failure of which can lead to emergencies).

Thus, for example, in the system for controlling the fueling of booster rockets with fuel components, the initial information is the readiness of the power supply, air supply and fuel storage systems, and as a rule, the initial state of the level control system in the booster rocket tanks, although this process is participated in by the set of electropneumatic valves, pumps, a large number of elements in the automatic control system itself, the pneumohydraulic system of the booster rocket, the information about the fitness of which is not available at the beginning of servicing.

The operating information obtained during the control process about the state of the object of control comes to the control machine (system). In the ASPS, the game algorithms of the operation are directly put in the special modules (or autonomous systems) which control the individual technological processes in the form of a defined set of standard solutions. The modules themselves (autonomous systems) interact with each other by a program given in advance.

Beginning with the investigated peculiarities of the operation of the ASPS, they are classified as game systems with program control and the set of standard solutions (Fig 9.2). The most characteristic feature of such systems is the use of the control instructions obtained from the operating information on the basis of the algorithms. In the ASPS, there is no "struggle" of two or more algorithms in the operating process, but a "struggle" of the algorithm with the random disturbing factors. The criterion on the basis of which the various versions of the algorithms are compared usually can be expressed in the form of the basic function of state of the operation, the so-called "payoff function" and additional conditions. The choice of an efficient "payoff function" for the operation of the ASPS is the most important part of the development of the alogrithm and requires profound study of the technological processes of launch preparation considering all factors, circumstances and relations existing under actual conditions. When designing the ASPS for this purpose the results of experimental and full-scale tests are used.

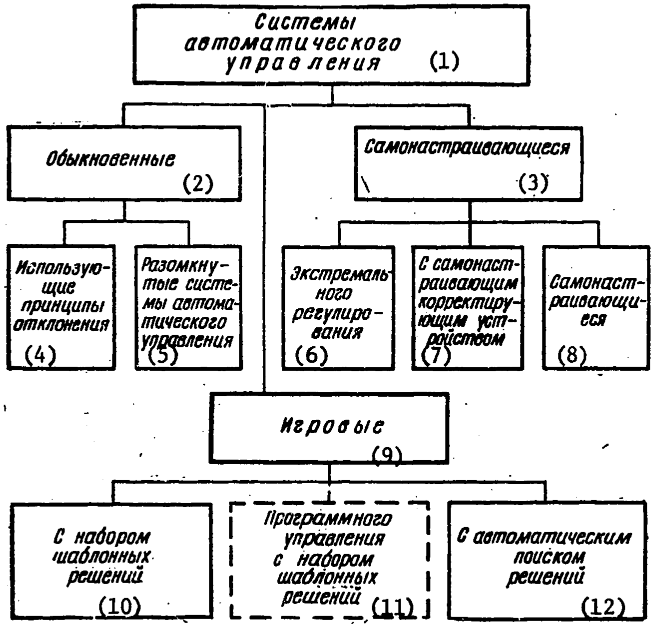

Figure 9.2. Classification of automatic control systems

Key:

1. Automatic control systems
2. Ordinary
3. Adaptive
4. Using the principles of deviation
5. Open automatic control systems
6. Experimental regulation
7. With adaptive correction device
8. Adaptive
9. Game
10. With a set of standard solutions
11. Program control with a set of standard solutions
12. With automatic search for the solution

The automatic monitoring systems in the general theory are classified with respect to the most varied attributes, for example, with respect to the type of controlled variables, the purpose, sphere of application, technical execution, and so on. However, classification by these attributes has practical significance which would be common to all the automatic monitoring systems and which would characterize their internal structure and functional peculiarities (Fig 9.3).

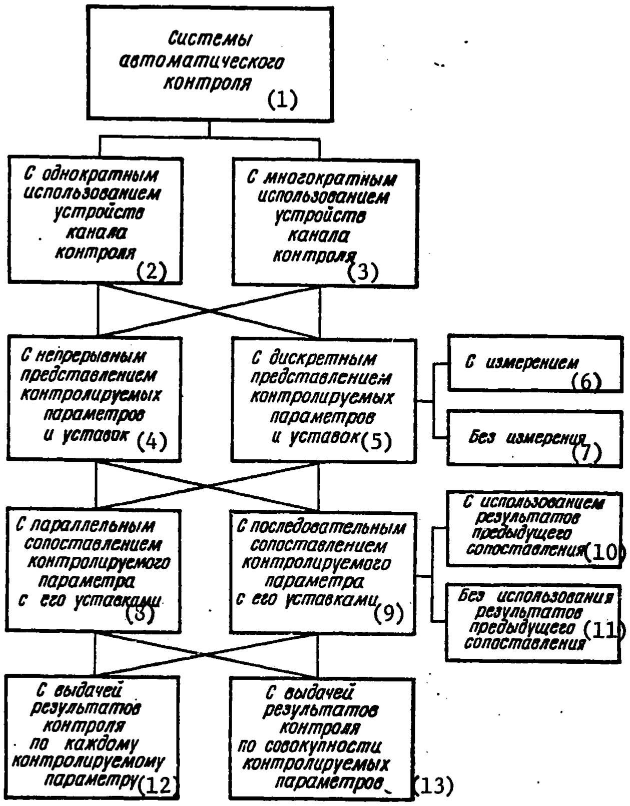

Figure 9.3. Classification of automatic monitoring systems

Key:

1. Automatic monitoring system
2. With single use of the monitoring channel devices
3. With multiple use of the monitoring channel devices
4. With continuous representation of the monitored parameters and settings
5. With discrete representation of the monitored parameters and settings
6. With measurement
7. Without measurement
8. With parallel resistance of the monitored parameter with its settings
9. With series comparison of the monitored parameter with its settings
10. With the use of the results of the preceding comparison
11. Without use of the results of the preceding comparison
12. With output of the monitoring results with respect to each controlled parameter
13. With output of the monitoring results with respect to the set of controlled parameters

The process of monitoring the pre-launch preparation of the space rocket complex can be realized by a sysstem of any one type, for each technological process imposes its requirements on the system. Even for one technological process certain parameters must be monitored continuously; others must be monitored discretely, and a third set, only during the process of deviations from the given values. Therefore, the existing classifications do not reflect the functional purpose of the systems for monitoring the technological operations of pre-launch preparation.

9.2. Purpose of the Systems

The systems for monitoring and controlling technological process operations are a set of equipment designed for the performance of technological operations of pre-launch preparation of the space rocket system and also monitoring its state and the state of the ground system during the preparation process.

During the preparation of the booster rocket for launch, control reduces to the performance of various operations causing defined, previously provided for process conditions. These conditions are repeated under the given conditions always in the same form. In addition, the control systems maintain a constant value of the regulatable variables with respect to a given law, and they protect the complex from emergency situations on occurrence of uncounted operating conditions of both the ground systems and the booster rocket systems. For example, if for any reason the launch of a booster rocket filled with cryogenic fuel components (liquid oxygen or hydrogen) is delayed, then heating of the fuel begins and, as a consequence, an increase in volume and level in the tanks, which can cause an emergency. In this case the level and temperature gauges located in the booster rocket tanks generate emergency signals for the ground service control system which provides for correction of the level and thermostating of the fuel in the tanks.

The monitoring and control are continuously related to each other. The objects of monitoring are not only the technological systems, but also the control systems themselves and even the space rocket system.

The purposes of monitoring and preparing the space rocket systems at the engineering and launch complexes can be the following:

Output of information to the operator about the condition of the space rocket system, the technological process systems and their operating conditions in the process of pre-launch preparation;

Obtaining information about the state of the object for variation of the control conditions or generation of the required control input;

Correctness of the execution by the control system of the process algorithm and also correspondence of the system parameters to the given values;

Determination of the location and causes of failure of the control system in case of its failure;

Mechanical and electrical failure, seal and reliability of fastening the elements and modules;

The state of good repair of the control system in storage, without reproduction of its actual operating conditions.

As a rule, in order to perform each technological operation there are special monitoring and control systems which, depending on the degree of automation are divided into manual, semiautomatic and automatic.

The manual monitoring control system is a control system which requires the participation of an operator. Estimation of the monitoring results and observation of the defined sequence in the output of the control commands are also the business of the operator.

The semiautomatic monitoring and control system is characterized by the fact that the main part of the operations are performed automatically. The operator only switches the individual monitoring and control elements on and off, but he cannot introduce changes into the process of execution of the cycle and its sequence. When working with such systems the operator usually manually controls more than 50% of all of the operating time of the systems.

Automatic monitoring and control systems do not require operator intervention except to switch the systems to a given regime and individual manual operations as a rule amount to less than 2% of the total operating time. The selection of the operation, the control and the decision making of such systems are all automatic.

The complexity of the space rocket systems, the large number of operations, the limited test time and the performance of the launch at a previously established time give rise to the necessity for maximum automation of the pre-launch preparation process. This reduces the preparation time for the launch, it increases the accuracy and reliability of monitoring, it permits operations to be performed which cannot be performed by man on the basis of his limited capabilities, it decreases the wear of the equipment and also essentially reduces the service personnel.

Beginning with the necessity for complex solution of the control problems, it is expedient to develop a united system including the entire complex of automated control devices for individual units and systems which participate in the pre-launch preparation. Such a system includes both the control systems and the systems for monitoring the general engineering and special technological process ground systems. On completion of the operation, it outputs the general availability to the ground equipment of the engine starting control system.

In individual cases, for very large complexes it is expedient to create not an automatic, but automated preparation system, for a number of operations, especially decision making, are more efficiently performed by the human operator.

The control of the ASPS units and systems is realized from a central preparation panel (TsPP) designed to monitor the operation of the pre-launch preparation operations control system and locate it at the command post of the launch complex. Usually all of the information about the course of the performance of the pre-launch preparation operations is concentrated at the TsPP. The signals and commands from the central preparation panel go in generalized form to the launch panel which is located at the command post of the space center or in the launch control center building.

A flow chart for the control of the technological operations of launch preparation of space rocket systems is shown in Fig 9.4.

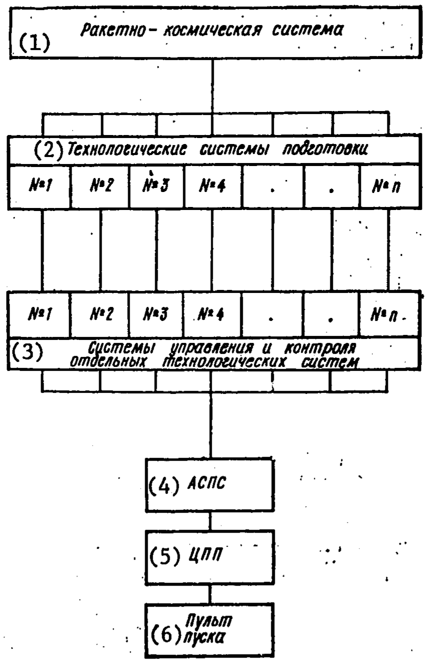

Figure 9.4. Flow chart of the control of the technological operations of launch preparation

Key: 1 -- space rocket system; 2 -- technological preparation systems; 3 — monitoring and control systems for individual technological systems; 4 -- ASPS; 5 — TsPP; 6 — launch panel

The command to perform the final operations of pre-launch preparation are fed from the launch panel, the subsequent burning of the transparencies on which permits monitoring of the course of their performance. By the command of the operations director the operator sets the LAUNCH SWITCH to the required position and presses the LAUNCH button, after which the pneumatic valves of the drain lines of the oxidant and fuel tanks are closed, the fuel tanks are blown, the engine is started, and on reaching a defined thrust the space rocket system separates from the launch system.

9.3. Classification of Systems

The most specific attributes of the ASPS are the principle of their construction and monitoring techniques (Fig 9.5).

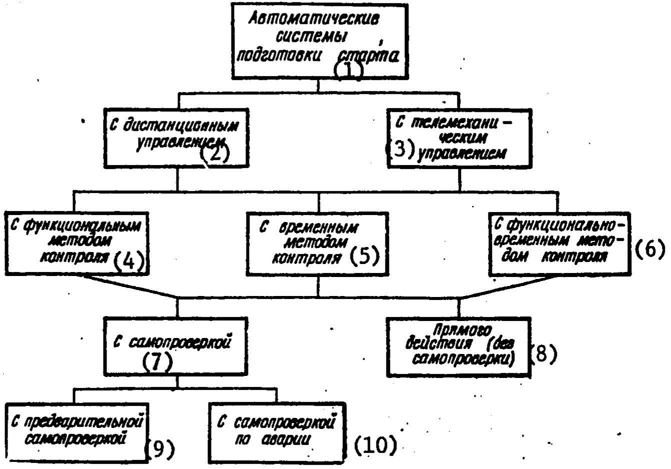

Figure 9.5. Classification of automatic launch preparation systems (ASPA) by the principle of construction and method of control

Key:

1. Automatic launch preparation system
2. With remote control
3. With telemechanical control
4. With the functional monitoring technique
5. With time monitoring technique
6. With functional monitoring technique
7. With self-checking
8. Direct action (without self-checking)
9. With preliminary self-checking
10. With self-checking on emergency

The automated control systems for the pre-launch preparation of space rocket complexes can be executed both in the form of a remote control system and a telemechanical control system. The former are characterized by the fact that the control of the monitoring and adjustment equipment take place over wire communication channels, and the equipment is at a comparatively short distance from the object of preparation (to 500 meters) and it is placed at the command post of the launch complex, and at the servoelements of the technological process systems. In the second group the control of the monitoring and regulation equipment takes place over the telemechanical channels. The command post, as a rule, is located at a significant distance from the technological preparation and launch systems.

With respect to principle of construction the automatic monitoring systems are divided into systems with functional, time and functional-time monitoring techniques.

For the ASPS with functional monitoring technique the sequence of transmission of the commands and the beginning of operation of the individual systems are related to each other by strong functional relation: each subsequent command can be generated only after monitoring the execution of the preceding one. If for any reason there is no signal of completion of the operation, then the next command is not output, and a transparency burns on the operator panel signalling emergency shutdown of the process.

The ASPS with the time method of monitoring are distinguished by the fact that the next command will be issued after a strictly defined time following the preceding one, in spite of the fact that the preceding command has already been executed and all the conditions for executing the next operation have been met. If the preceding command has not been executed and the conditions have not been set up for execution of the next command, then automatic disconnection of the system and return to a safe (initial) position are provided for.

For the ASPS with functional-time methods of monitoring it is characteristic that there is a rigid functional relation between the control commands which, in addition, is time controlled.

All of the investigated types of ASPS can be executed with self-checking and without self-checking. Self-checking is realized either before the beginning of operation of the system or during operation by the monitoring system signals. In the first case on the "preparation" command initially the equipment self-checks, and after receiving a positive result, permission is given for further operations; in the second case, the system halts its operating cycle and begins a self-check to find and indicate the location of the failure. The systems with self-checking are more complicated and expensive, but this is compensated for by the convenience of their operation. When preparing to launch space rocket systems and especially in emergencies when the decision-making time is strictly limited, the systems with self-checking offer the possibility of quickly finding the failure and prevention of abortion of the launch or an emergency.

The automatic launch preparation system usually includes a number of individual systems executing functionally different missions; such systems have come to be called subsystems (Fig 9.6). The ASPS subsystems can operate both in the pre-launch preparation process and in the period between launches (the so-called duty period).

The systems operating during the duty period maintain the technological systems of the launch complex in a state of readiness for reception of the space rocket system. These launch complex systems include the storage areas for the fuel components, the receivers, compressor stations, the power feed systems, thermostating systems and so on.

The duty systems can be divided into the systems with cyclic effect, systems operating by deviation of the regulatable variable from the given racing, and the systems with combined effect.

The cyclic action systems operate not during the entire duty time, but periodically, with defined cyclicity (once a day, every hour, and so on); here all of the measurement, regulation and control processes in them are performed only during the operating cycle. Such systems as a rule are used for technological processes having high inertia in which the failure of the individual elements cannot lead to emergency during the period between the monitoring systems. Thus, the temperature in the level of the fuel components in the storage tanks are usually monitored once a day, for their variation takes place slowly, and even in the case of failure of the thermostating means, tens of hours are required for them to go beyond the admissible limits.

The systems operating by the deviation of a regulatable variable begin to function only when this variable goes beyond the admissible limits, after which it will be monitored continuously. Such systems are used when the deviations of the given variable from the rated value can lead to an emergency. Thus, for example, the vacuum insulation of the liquid hydrogen storages is monitored, for on loss of seal, an explosion-hazardous mixture can be formed, and an explosion can occur.

The combination-action systems combine both periodicity of action and the principle of beginning operation on deviation of the regulatable variable from the given rated value.

The systems for monitoring the technological operations of launch preparation are divided by purpose into systems for functional and operative monitoring and systems for monitoring the control process (Fig 9.7).

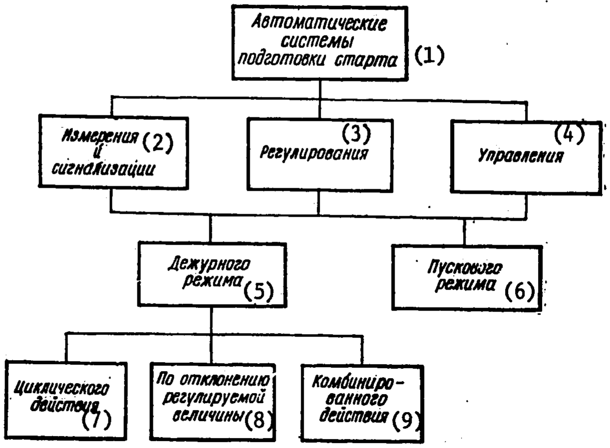

Figure 9.6. Classification of the ASPS subsystems

Key:

1. Automatic launch preparation systems
2. Measurements and signal units
3. Regulation
4. Control
5. Duty regime
6. Launch regime
7. Cyclic effect
8. On deviation of the regulatable variable
9. Combined effect

The functional monitoring systems provide information about the state of the object for the generation of defined control inputs conditioned by the technological process algorithm. These systems usually measure the physical parameters (temperature, level, pressure, vacuum, flow rate, displacement, and so on). The interaction of monitoring systems with the control system takes place automatically and is determined only by the technological preparation process.

The operative monitoring systems provide information about the state of the technological launch complex systems and all the systems of the space rocket system. As a rule, these are several multichannel systems capable of recording and monitoring parameters (from several tens to several hundreds) determining the degree of readiness of the space rocket system for launch, the temperature and pressure in the various compartments of the booster rocket, the condition of the pneumatic and hydraulic equipment of the engine, the seal of the instrument compartment and the operation of the on-board electrical systems. Considering the large volume of parameters which must be encompassed by visual observation and also the necessity for document recording of the preparation process, the majority of the operative monitoring systems are designed considering the recording

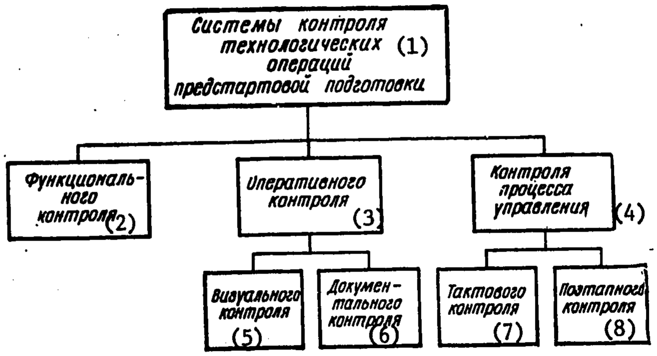

Figure 9.7. Classification of systems for monitoring the technological process operations of pre-launch preparation

Key:

1. Systems for monitoring the technological operations of pre-launch preparation
2. Functional monitoring
3. Operative control
4. Monitoring of the control process
5. Visual monitoring
6. Document monitoring
7. Cycle monitoring
8. Step by step monitoring

of the operating process on photographic film, paper or magnetic tape. In these systems, along with the recording equipment preparation is made for the possibility of visual monitoring of the interesting parameter as the operator desires. The visual monitoring systems are primarily used to observe the operation of the ground technological systems or for monitoring the auxiliary parameters of the space rocket system during the development and first flight testing of them.

The control process monitoring systems provide information about the correctness of execution of the given algorithm and they form a signal to stop preparation in case of emergencies. These systems usually are divided into two independent types: the cycle monitoring systems which monitor each discrete change in state of the object and the control system and by the monitoring results, permitting or forbidding subsequent operations, and the step-by-step monitoring systems which monitor a defined completely technological step -- cycle -- including part of the overall technological process. The step-by-step monitoring is used in cases where the technological process can be broken down into individual steps and there is a possibility of halting the process or repeating it.

9.4. Estimation of the Efficiency of the ASPS

The efficiency of the technical device is the characteristic of the degree and quality of performance by this device of the functions for the execution of which it is intended. Consequently, for the automatic launch preparation system the efficiency criterion will be the probability of the execution of technological preparation algorithm with estimation of the basic parameters of the monitoring and control systems for the technological operations by their criteria in different stages of their development.

The parameters of the monitoring and control systems most significantly influencing the structure and the direction of the developments usually are estimated in the stage of preliminary design with simultaneous selection of the control principles, the construction of the structural diagram of the system and its elements, determination of the structure of the subsystems, and so on.

The variation of the relative number of estimates in different stages of development and their importance are illustrated in Fig 9.8. As is obvious from the figure, the frequency of the estimates in the detailed design stage increases, and their importance is reduced. The cost of redoing the system caused by the implementation of suggestions increases as it is developed.

The concept of efficiency of the systems can include various components which reflect the time and cost of development, the cost of manufacture and servicing, the degree of realization of the basic specifications of the system. The efficiency of monitoring control systems for technological operations at launch can be estimated by the procedure constructed on the basis of the model of estimating the efficiency of such systems where the model of the efficiency is depicted in the form of a graph not containing loops (Fig 9.9) and having three branches: readiness, reliability and compatibility.

The readiness branch for the space rocket complex $P_{\Gamma}=1$, for the preparation and operation of the space rocket system take place in a previously defined time and there is no necessity for keeping it constantly in a ready condition. For the monitoring control systems for the preparation of space rocket complexes, the basic criterion probability of insurance of the launch at the given time

$$P_e = P_H \cdot P_c,$$

where P_e is the efficiency system (the probability of insuring the launch in the given time);

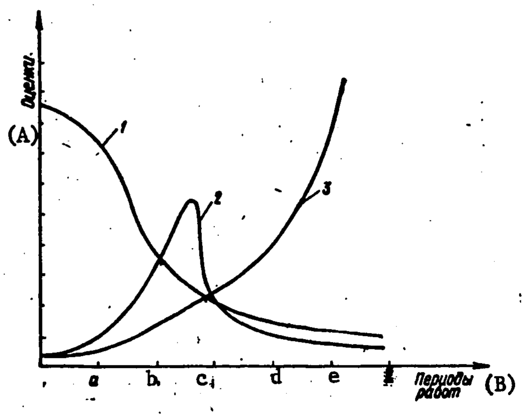

Figure 9.8. Graph of the variations of the relative number of estimates in different development stages: a -- selection of basic parameters of the system; b -- preliminary designs; c -- detailed design; d -- manufacture; e -- test; f -- operation; 1 -- relative importance of the estimate; 2 -- relative frequency of the estimate; 3 -- relative cost and delay connected with changes

Key:
- A. estimates
- B. operating periods

P_H -- probability that the system will operate for a given period of time insuring the characteristics within the tolerance limit;

P_C -- compatibility defined by the probability that the actual conditions of application will correspond to the conditions under which the control system carries out its mission.

This equation is valid if P_H and P_C are independent.

The reliability P_H determines the probability that the ASPS systems will function without the parameters within the tolerance limits for a given time. Consequently,

$$P_H\ (t) = e^{-t/T_{mean}},$$

where t is the given time;

T_{mean} is the mean fail-safe operating time.

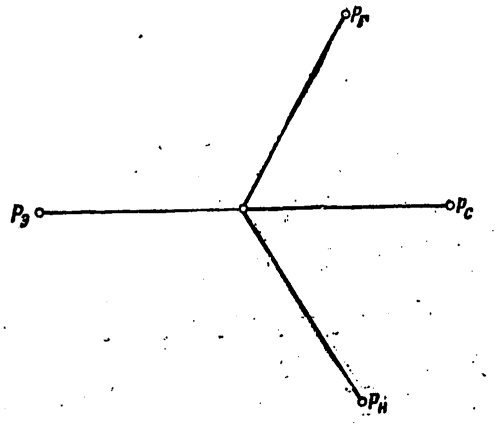

Figure 9.9. Graph of the efficiency model:
P_e -- efficiency of the system (probability of insuring a launch at the given time); P_Γ -- readiness (probability that the system will be ready at the required point in time); P_c -- compatibility (probability that the actual operating conditions will correspond to the conditions under which the system will carry out its mission); P_H -- reliability (the probability that the system will operate for the given period of time insuring the output characteristics within the tolerance limits).

This equation is valid if adjustment and repair operations are not made during the process of regular functioning of the system.

For the ASPS in the modular synthesis step (the drawing design) the goals of the system are defined, the systems are broken down into individual modules, the general plan is made for the exchange of information in commands between the systems and modules. The general reliability of the performance of the stated goals between individual systems and subsystems of the ASPS is also distributed in this step.

The equal reliability of all systems (modules) means identical basing when distributing the general reliability among the individual systems or modules. This distribution is not uniform, for as a result of the difference in functional problems and their complexity it is impossible to insure identical reliability of all systems in practice. For systems carrying out simple functional missions and having few component elements, it is simpler to obtain high reliability than for systems with a large number of elements. Therefore the overall reliability of the ASPS between individual systems is distributed differentially, for which the concept of the provisional "weight" of the system is introduced

$$B = \alpha N\ (\Phi + K),$$

where N is the number of servoelements which the system controls (for the monitoring system, the number of monitored parameters);

Φ is the number of functional operations performed by the system;

K is the number of monitored states or operating conditions of the system which lead to emergency shutdown of the technological operations or a change in operating conditions of the control system;

α is the coefficient reflecting the importance of the individual system or module overall; usually $\alpha=1$, but for especially important systems or modules, the reliability of which must be appreciably higher than in the remaining systems, $0<\alpha<1$, for the reliability distribution is in inverse proportion to the provisional "weight."

In the detailed design phase, an optimal relation is selected between the reliability and cost of the system using the criterion of the efficiency of expenditures:

$$Э_{\text{ср}_{(1)}} = n\frac{1}{C(1-P)},$$

Key: 1. mean

where P is the system reliability;

C is the cost of the system;

n is a coefficient introduced for convenience of obtaining the result and identical for comparison of the various systems (for the ASPS, $n=10^2$).

This criterion is more sensitive to a change of reliability than the others, for it is connected with the reliability of the nonlinear function; it offers the possibility of estimating whether the redundancy is effective considering the economic expenditures on its execution; what the reliability of redundant module must be so that increasing its cost from C_1 to C_2 will be efficient; after obtaining the defined reliability of the redundant module, its possible maximum cost is determined for the same efficiency, and so on.

The compatibility P_c defines the probability that the actual conditions of application will correspond to the conditions under which the system performs the functions invested in it. All the factors determining compatibility are probability events, and the value of P_c is defined as a probability product. Considering that the ASPS system equipment, as a rule, is located in facilities where the temperature and moisture conditions are maintained at defined values, the effect of the uncounted-on conditions on it must be understood as a probability of failure of the devices to maintain given temperature and moisture regimes.

The necessity for insuring fitness of the systems under the conditions of mechanical, electromagnetic and other types of effects leads to careful selection of the elements for the construction of the system and the application of additional design solutions considering the possibility of the system being affected by several factors simultaneously.

The compatibility is calculated by the formula

$$P_c = \prod_{i=1}^{n} P_i.$$

Proper consideration of the compatibility factors when designing the systems in the final analysis determines the reliability of the systems.

The automatic launch preparation systems for execution of the functions can have different systematic solutions and also their own specific functional requirements. The complexity and volume of the technological process algorithm (A) which must be executed by the ASPS depend on the number of servoelements of the complex and the number of functional operations which must be performed considering the number of monitored parameters, and they are estimated by the formula

$$\mathrm{A} = N(\Phi + \mathrm{K}).$$

The quality of the planned operations (K_π) of the developer of the ASPS systems is defined by the number of elements of the electric circuits used to realize the given technological algorithm:

$$\mathrm{K}_n = \frac{\mathrm{A}}{\mathrm{M}} = N\frac{\Phi + \mathrm{K}}{\mathrm{M}},$$

where M is the total number of elements of the ASPS system.

The K_π criterion makes it possible to estimate the technical level of the design development of the automatic launch preparation systems before introduction of redundant elements into the system to insure given reliability and after introduction of them. A comparative analysis is performed for identically executed systems (for those without redundancy or with it). In order to estimate the quality of the planned operations considering the reliability and cost characteristics, the technical efficiency criterion is used:

$$Э_т = \underset{(1)}{Э_{ср}} \cdot \mathrm{K}_n = n\frac{N(\Phi + \mathrm{K})}{\mathrm{MC}(1 - P)},$$

Key: 1. mean

which offers the possibility of determining the level of technical development of the flow charts from the automatic launch preparation system and the qualifications of the developer.

CHAPTER 10. SPACE CENTER MONITORING AND CONTROL SYSTEMS

10.1. Basic Characteristics of the Object of Monitoring and Control

The object of monitoring and control when preparing the space rocket systems for launch at the launch complex is both the technological systems of the ground equipment and part of the systems and units of the space rocket system itself participating in the technological preparation process.

The servoelements of the technological systems, as a rule, are the monitoring and control elements which in the modern automated general industrial equipment, but here the control system itself must provide for the processing of a large volume of information, for the complex has several thousand measurable parameters and several thousands of signals, and up to 10,00 control commands are generated.

If we introduce the concept such as "information pickup from a cubic meter of equipment," then it turns out that with respect to saturation with equipment the space rocket complexes exceed by several times the general industrial complexes, and they are comparable only to the systems used in aviation.

In addition, the servoelements in the monitoring equipments of the ground technological systems, as a rule, are distributed nonuniformly with respect to the individual facilities and structures of the launch complex. Here the servoelements are placed in basically compact groups, and the monitoring elements are concentrated with respect to the entire object of control and the combination of them into large groups is complicated.

The information going from the object can have regular and irregular nature: the regular information comes at defined points in time or during interrogation by given programs; the irregular information, from the emergency sensors and when considering priority of its processing as a function of importance.

The basic characteristics of the object of control influencing the control system parameters are the cycle time and the given volume of operations; the number of technological operations and the maximum number of intermediate results of information processing stored during the launch preparation process; the limiting load and labor consumption of control; the maximum number of operations per unit time and the efficiency.

The technological systems of the launch complex as an object of control can be divided into those operating only during preparation of the space rocket system for launch; those operating during the period when the space rocket system is not at the launch complex or it is at it in storage or during adjustment checks, and those operating both during the period of preparation of the space rocket system and during its preparation for launch.

The technological algorithm for the operation of the object of control can be written by various methods. Depending on the form of expression of the information its amount is different.

At the present time three basic types of writing the technological algorithm are the most widespread: literal writing, tabular notation and cyclogram notation.

The literal notation is the most traditional of the existing forms of writing in which all of the interrelations of the individual elements, their sequence and operating conditions are described in words.

For example, literal description of the operation of the pneumohydraulic system of the oxygen servicing system (Fig 10.1) will have the following form. Before beginning the filling process, valves 1K and 2K are opened, the blowing of the oxygen storage tank is started by opening the valve 4K and the blowing pressure is maintained in the response range of the pressure signals CD1 and CD2 by closing and opening this valve. Cooling of the pump and lines takes place in 7 minutes, after which the pump is switched on and begins to feed oxygen to the small connection of the lines and partially to the large connection of the lines. Ten minutes after switching the pump and under the condition that the pressure behind the pump is equalt the response value of the CD5 signal, the normally open valve 17K is closed, and cooling of the large lines begins.

The deficiencies of this form of notation are poor visibility, large volume, insufficient representation of the interaction of the individual operations in real time.

The tabular notation of the above-investigated cycle is presented in Table 10.1. Its deficiencies are absence of clarity and interaction among the individual operations of the technological process and the fact that on introduction of time delays into the technical cycle with respect to generation of instructions to the servoelements or when a number of individual conditions are needed (response of the pressure signals, presence or absence of a level signal, and so on) these must be written out literally in the form of notes or intermediate cycles must be artificially introduced, which makes the table awkward.

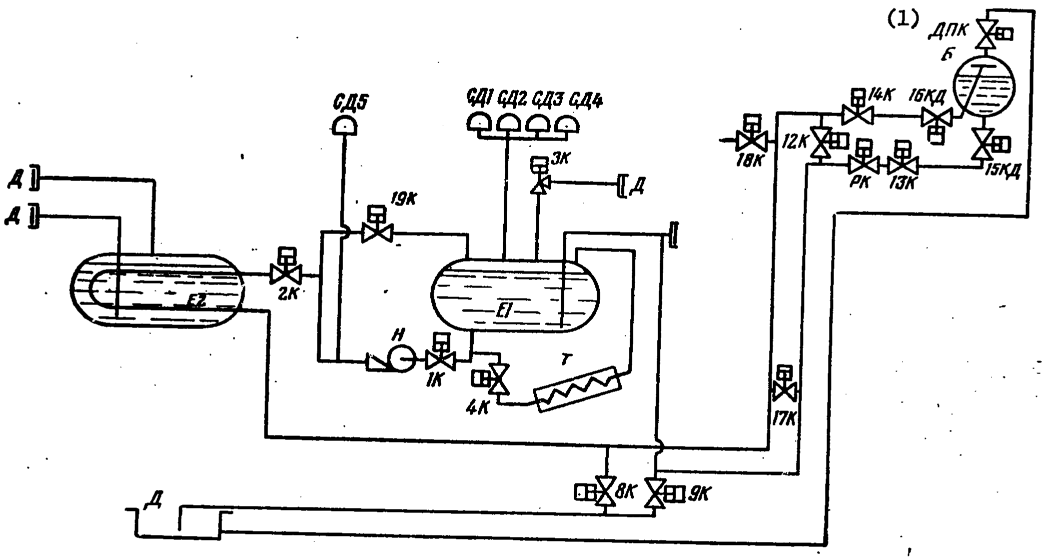

Figure 10.1. Pneumohydraulic system of the liquid oxygen fill system:
D -- drainage; H -- pump; T -- heat exchanger; K -- electropneumatic valve (EPK); E1 -- fill system tank; E2 -- tank for supercooling components; B -- filled tank; CD -- pressure signal; PK -- adjustment valve; DPK -- drainage safety valve
Key:
1 -- DPK

Table 10.1. Operation of the Valves (Beginning of Filling)

Операция (1)	(2) Номера клапанов и их положение																	(3) Примечание
	1К	2К	5К	6К	7К	8К	9К	10К	11К	12К	13К	14К	15К	16К	17К	18К	19К	
Исходное положение (4)	3	3	3	3	O	3	3	O	O	O	O	O	3	3	O	3	O	Клапан 3К работает от СД1 и СД2 (5)
Заправка (6)	O	O	3	3	O	3	3	O	O	O	O	O	3	3	O	3	O	Включается СПИД емкости Е1 — клапан 4К работает от СД1, 3К — от СД2 (7)
Команда „РВ1" 7 мин (8)	O	O	3	3	O	3	3	O	O	O	O	O	3	3	O	3	O	Включается насос (9)
Команда „РВ2" (через 10 мин после „РВ1") (10)	O	O	3	3	O	3	3	O	O	O	O	O	3	3	3	3	O	К моменту выдачи команды „РВ2" СД5 должен замкнуть контакт (11)

Key:

1 -- Operation; 2 -- Numbers of the valves and their position; 3 -- Note; 4 -- initial position; 5 -- valve 3K operates from CD1 and CD2; 6 -- filling; 7 -- SPID of the tank E1 is switched on -- the valve 4K operates from CD1, 3K, from CD2; 8 -- PB1 command 7 minutes; 9 -- pump switched on; 10 -- PB2 command (10 minutes after PB1; 11 -- At the time of issuing the PB2 command the CD5 must close contact.

Notes:
1. From the time of issuing the PB1 command and to the "drain" command the signal units for separation of the fill connections and the pneumatic blocks are monitored. On opening the contacts of these signals, the filling is automatically shut down (APZ).
2. If at the time of issuing the PB2 command the closure of CD5 takes place or CD6 opens before issuing the "drain" command, APZ [automatic stopping of filling] occurs.
3. 0 -- valve open; 3 -- valve closed.

At the present time cyclograms are being more and more widely used as the notation for the operation of the system (see Fig 10.2). They give a clear representation of the operation of the system in real time, for their representation is constructed along the time axis. Every change in state of the system is depicted as an event on a united time axis in the form of a square or a circle, and the content of this variation is recorded in the frame of the "flag" above the corresponding square (circle). Under the time axis the possible emergencies are indicated, the absence of which from a given point in time must be constantly monitored. The operation completed in each time interval between events is written above the time axis in the square located after the event "flag."

For execution of the preparation algorithms, specialized automatic monitoring and control systems can be used which are designed for a strictly defined problem or universal systems which are capable of executing any operating cycle of a defined class.

The specialized systems are the simplest and cheapest, especially if they are designed for mass production, and their functional cycle is sufficiently developed.

The modern space rocket systems are large, complicated complexes in which it is impossible to check the control system jointly with the technological systems under bench or mockup conditions, for the total assembly of the technological systems takes place at the launch complex. Therefore, the technological preparation cycle is tested and worked out, as a rule, during the test, in connection with which the introduction of changes into the control program is possible only at the launch complex. For specialized systems the introduction of changes into the manufactured equipment is connected with great technical difficulties and expenditures of time, it leads to an increase in the systems development times and, consequently to a delay in putting the launch complex into operation. The advantages of the specialized systems are manifested in an operating cycle that is simple and changed little during full scale development.

It is also necessary to consider that modification of the space rocket system and launch of space vehicles of various types from one launch system are possible. Therefore the monitoring and control systems must have the capacity to insure preparation and monitoring of various versions of the space rocket systems, which forces the creation of all-purpose monitoring and control systems which would not be connected with the specific space rocket system.

The all-purpose monitoring and control systems must provide for the possibility of design manufacture without being tied to a defined technological process or complex, a change in the number of information and command channels, replacement of various versions of the programs from the control panel during the operating process, halting and further continuation of the program without returning to the initial position and also the possbility of beginning operations from any point in the program, the monitoring and control of the preparation of the various versions of the space rocket system in one launch complex.

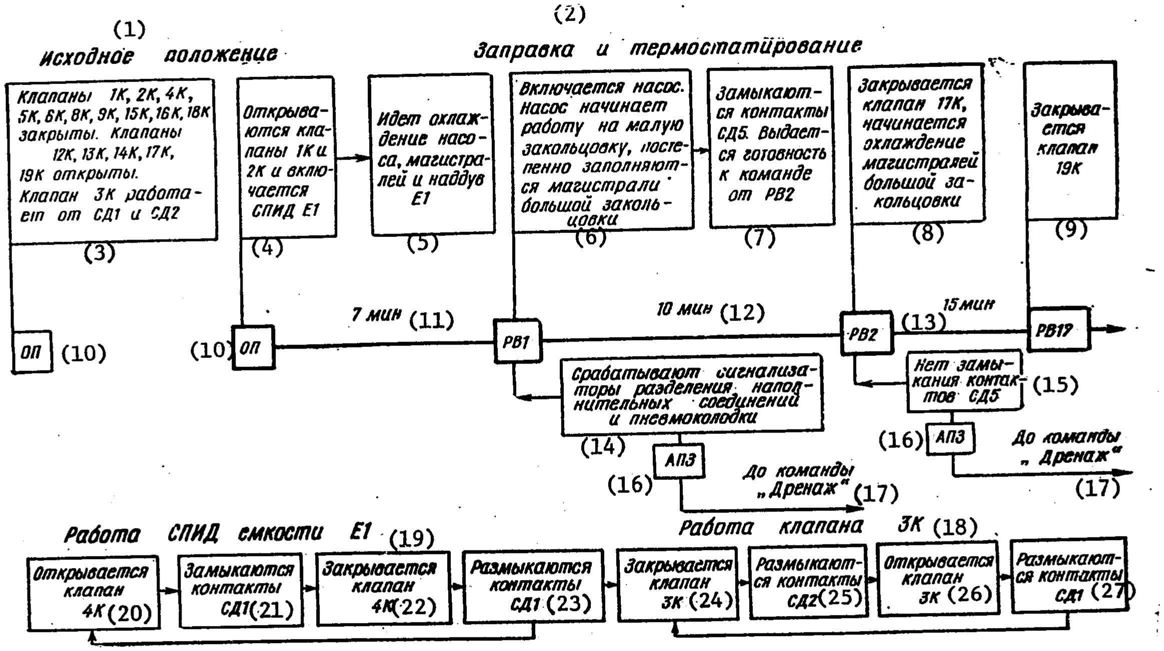

Figure 10.2. Cyclogram for the operation of the filling system

Key: 1 -- initial position; 2 -- filling and thermostating; 3 -- valves 1K, 2K, 4K, 5K, 6K, 8K, 9K, 15K, 16K, 18K closed. Valves 12K, 13K, 14K, 17K, 19K open. Valve 3K operates from CD1 to CD2; 4 -- valves 1K and 2K open, and the SPID E1 switched on; 5 -- cooling of the pump, lines and blowing E1 proceeds; 6 -- Pump switched on. Pump begins to operate on small fitting, gradually the lines for the large connection are filled; 7 -- The contacts CD5 close. Readiness for the command from PB2 generated; 8 -- Valve 17K closes, cooling of the large connection line begins; 9 -- Valve 19K closes; 10 -- Oπ; 11 -- 7 minutes; 12 -- 10 minutes; 13 -- 15 minutes; 14 -- the signals to separate fill connections and the pneumatic block respond; 15 -- no closure of the contacts CD5; 16 -- APZ*; 17 -- to the drain command; 18 -- operation of valve 3K; 19 -- operation of SPID of tank E1; 20 -- valve 4K opens; 21 -- contacts CD1 close; 22 -- valve 4K closes; 23 -- contact CD1 open; 24 -- valve 3K closes; 25 -- CD2 contacts open; 26 -- 3K valve opens; 27 -- CD1 contacts open.

*automatic stopping of filling.

The principles of the construction of the all-purpose monitoring and control systems are discussed in Section 10.4.

The functional structure of the ASPS can be constructed by the principle of concentrated structure with all of the automatic control modules assembled in one place and are connected to the object of control by cables or by the principle of disseminated structure where the automatic control modules are taken to the location of the servoelements directly at the object of control, and there is only a control panel at the command post.

The structure of the automatic preparation system is selected on the basis of the planning of the launch complex, the location of the servoelements and the location of the command pot. The concentrated structure of the ASPS is expediently used in cases where the distances between the control system and the servoelements do not lead to complication of the schematic solutions of the control systems, an increase in the cable network and increased cost of it. The operating characteristics of the concentrated structure are higher, for all the control and monitoring modules are assembled in one place, which makes it possible to monitor them and facilitates the adjustment operations.

10.2. Automatic Systems

Modern science and engineering are permitting the creation of automatic monitoring and control systems which provide for a significant reduction in the time required to check the equipment out, decreases the number of service personnel, reduces the cost of the checkout equipment, provides for fast location of damage with indication of the required measures to eliminate the damage, the possibility of predicting the system reliability. Thus, the analysis of the preparation of various versions of the "Atlas" booster rocket demonstrated that the reduction in ready time with simultaneous increase in reliability became possible as a result of the application of electronic automatic programmed equipment for pre-launch checks.

In the opinion of American specialists, the automatic launch preparation system must be built on the basis of discrete systems which sharply reduce the number of wires and cables connected to the space rocket system. Thus, on the "Atlas" and "Titan" rockets, several hundreds of wires run to the GROUND-ON-BOARD plug, but on the "Minuteman" rocket there are only 46.

The execution of the technological operations with respect to launch preparation of a space rocket system is insured by the set of systems and launch complexes which control the operations connected with storing the fuel components, the coupling of the fill and drain lines, the electrical and pneumatic connections, filling the booster rocket tanks, draining the fuel components, checking the on-board systems and certain auxiliary operations of which, as a rule, checking out the on-board systems, preparation for filling and filling itself are automatic, drainage is semiautomatic, and the auxiliary operations are manual.

Each system usually consists of a control panel on which the monitoring and control modules are mounted, days with logical modules, cable connections and other elements. The entire complex of automated control systems for the individual units and systems of the launch complex is encompassed by the automatic launch preparation system.

Any complex control systems for the technological operations of preparation can be created on the basis of some of the simplest logical elements giving as a result the "Yes" signal or "No" signal with the help of both contact devices and various contactless elements characterized only by two input and output states. These include the magnetic logical elements, semiconductor relays, ferrite transistor cells, gas discharge relays, pneumatic relays, relays based on magnetic read contacts, electromechanical relays, semiconductor integrated and film elements, and so on.

The control systems for the general engineering systems, as a rule, have a simple technological operating cycle which reduces to remote control of the individual groups of servoelements with insurance of the required blocking. Therefore, for such systems most frequently contact elements are used (electromechanical relays and remote switches), for they do not require additional auxiliary devices (special power supplies, converters, amplifiers, matching devices, and so on). The choice of the type of contact groups of these elements is basically influenced by the schematic peculiarities of the structure in which the most widespread are the normally open contacts excluding the intermodular connections and simplifying the system.

The control systems for the special technological systems have appreciably more complicated technological cycle, the realization of which requires the presence of a logical automaton operating in real time. Here the necessity arises for multiplexing cable lines which, combined with the logical automaton leads tothe application of modern microradioelectronic elements.

When developing the ASPS in order to improve the reliability, simplification of the systems, the creation of systems with limited consequences of failure, systems with wide tolerances, and so on are used. However, nevertheless, the reliability of the nonredundant systems, as a rule, does not satisfy the given requirements, which forces the adoption of special measures to insure it (Fig 10.3), the most effective of which is the redundancy method (Fig 10.4).

The active redundancy elements of the ASPS are ineffective, for the devices which disconnect the damaged section and switch on the reserve are complex and themselves require special measures to improve reliability. In addition, the majority of the technical processes especially connected with servicing the rocket with fuel components do not permit interruption of operation or a change in operating conditions of the servoelements which can occur when switching to the reserve.

Among the passive redundancy methods it is possible to isolate the most acceptable two for the ASPS: common and separate redundancy.

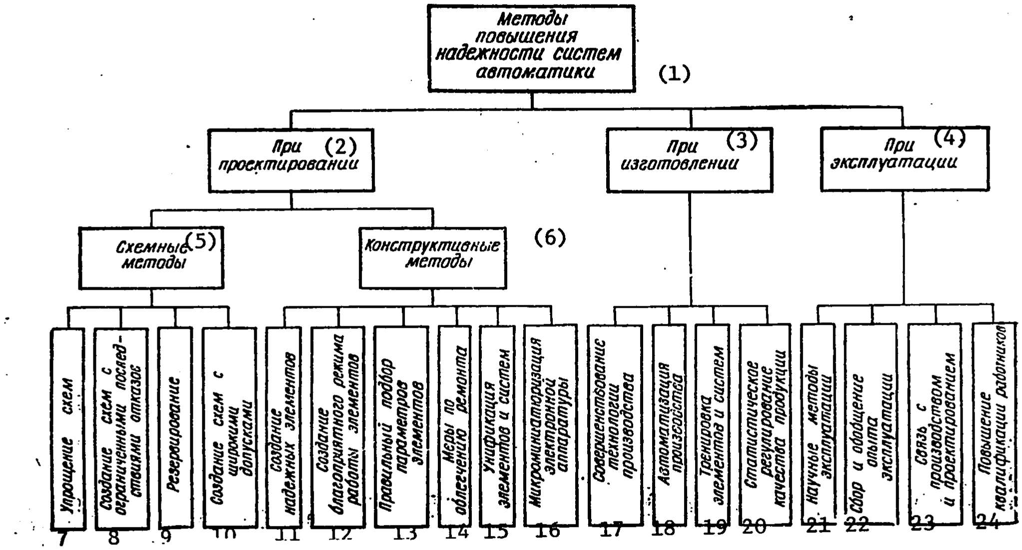

Figure 10.3. Groups of measures to improve the reliability of automation systems

Key: 1 -- Methods of improving the reliability of automation systems; 2 -- During design; 3 -- During manufacture; 4 -- During operation and maintenance; 5 -- Schematic methods; 6 -- Structural methods; 7 -- Simplification of the schematics; 8 -- Creation of schematics with limited consequences of failure; 9 -- Redundancy; 10 -- Creation of systems with wide tolerances; 11 -- Creation of reliable elements; 12 -- Creation of favorable operating conditions of the elements; 13 -- Proper selection of the parameters of the elements; 14 -- Measures with respect to facilitating the pair; 15 -- Unitization of the elements and systems; 16 -- Microminiaturization of electronic equipment; 17 -- Improvement of the production process; 18 -- Automation of production; 19 -- Break-in of elements and systems; 20 -- Statistical regulation of production quality; 21 -- Scientific methods of operation and maintenance; 22 -- Collection and generalization of operating experience; 23 -- Connection with production and design; 24 -- Improvement of the qualification of the workers.

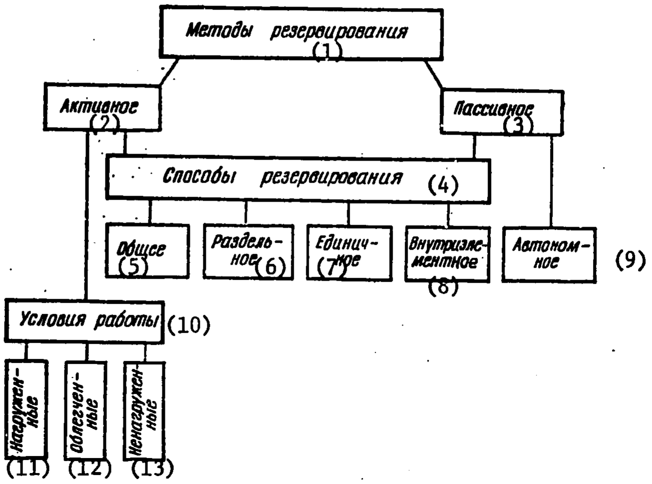

Figure 10.4. General diagram of the classification of systems with functional redundancy

Key:
1. Redundancy techniques
2. Active
3. Passive
4. Redundancy procedures
5. Common
6. Separate
7. Unit
8. Intraelement
9. Autonomous
10. Operating conditions
11. Loaded
12. Light
13. Unloaded

Practice shows that separate redundancy is more effective than common, but its application in control systems is limited as a result of difficulties occurring when monitoring the fitness of the system elements during the plant and regulating tests. In the case of failure of one of the elements in the case of separate redundancy normal functioning is not interrupted, the defect in the element does not appear, which can lead to the accumulation of failures in the control systems and a sharp reduction in their actual reliability. In order to exclude this, a large amount of work is being done to create special tests and develop complex test equipment. For control systems constructed from contact elements, special circuit solutions are used. All of these methods are based on the fact that during the check period the system is artificially converted to a system with common redundancy, and each channel is checked autonomously, which is insured as a result of supplying the basic and the reserve elements from individual buses (at the same time as the buses are usually connected together).

As was pointed out in Chapter 9, during operation of the ASPS when preparing for launch, two methods of monitoring are used: cycle and step. In the first method each change in state of the object of the monitoring and the control system is monitored, and by the results obtained, the performance of the following operations is either permitted or forbidden. In the second method a defined completed technological cycle is monitored as part of the overall technological process; this method is used if the technological process can be broken down into individual cycles, halting of the preparation at any point and repetition of one step or another are possible.

The cycle method of monitoring is applicable in practice for any technological process, but in this case the monitoring system becomes complicated, and its reliability decreases sharply, for each control cycle depends on the reliability of monitoring the preceding cycle.

When developing the control systems for technological process operations and the technological cycle itself, the output commands of the control system and the operation of the servoelements are recorded by special recording instruments. The investigation and analysis of these recordings jointly with the measurement and recording of the physical parameters of the object of the test make it possible to draw a conclusion regarding the correctness of the execution of the given process. However, this method of monitoring is not suitable for analyzing the state of the control system and the position of the servoelements of the object of control in an emergency when operative information is needed directly after the occurrence of the emergency. In order to analyze the state of the control system and the servoelements at the time of an emergency and directly after it, special memory modules are used which are capable of outputting a sufficient volume of information about the position of the servoelements in the output commands of the control system at the time of the emergency after automatic or manual shutdown of the process and return of the system to a safe state and also prolonged storage and multiple access to the information.

The narrowly specialized control systems are protected from erroneous operator actions by the operator panel blocking of the autonomous systems from a special coordination panel or the panel of the technical operations director, the composition of the control elements on the panel considering the psychophysiological characteristics of the operator, mechanical blocking of the control elements, preventing the possibility of accidental inclusion of them and the presence of two control elements for output of commands, of which the first forms the command, the correctness of the preparation of which is checked by the operator visually, and the second issues it for execution; in this case erroneous inclusion of one of the elements does not lead to output of the command.

10.3. All-Purpose Systems

The universality of the ground control systems for the process of preparing space rocket systems can be achieved both by the development of an all-purpose logical automaton and the development of special control computers.

The system constructed by the principle of the all-purpose logical automaton is a set of standard logical elements providing for the obtaining of the necessary control system from them in correspondence with the technological operating cycle. Here all of the inputs and outputs of the system elements are led to a special device where they are connected to the common circuit of the control system by crosses (soldering the wires in accordance with a defined circuit diagram) or using special cross connection caps. The use of special cross connection caps requires less time; it permits several sets of prepared programs to be maintained, but it creates excess multi-contact connections. The method of cross connection by soldering is free of this deficiency, but the replacement of the program takes a significant amount of time and is connected with opening up the equipment and mandatory checking of the correctness of the installation.

The all-purpose systems constructed on the basis of the logical automata have advantages by comparison with the specialized systems, for they provide for the design and manufacture of the system without tying it to a defined technological operation process, and the changing of the operating program has small influence on them.

The use of computers to control the process of preparing the space rocket systems permits the creation of more flexible all-purpose systems than the systems based on logical automata.

However, the use of an individual computer for each technological system is economically and technically inefficient, for the use coefficient of the equipment will be low, and a large number of the machines at the launch complex will cause difficulties in servicing them. In addition, for some of the technological systems, as a result of simplicity of their operating cycle and the small volume, it is inexpedient to use a specialized control machine.

From analysis of the control systems it is obvious that although the process of the operation of the technological systems is long in time, the control inputs during this process are completed comparatively rarely, and all of the remaining time the control system keeps the servoelements in an unchanged position.

In the control systems constructed on the basis of logical automata, the servoelements, as a rule, are controlled by the following principle: inclusion of the servoelement — output of the control signal -- switch-off (removal) of the signal (Fig 10.5, a). For the entire output time of the control signal, the chain of its formation passes through the logical automaton and remains constant.

For control of servoelements it is possible also to use the method of impulse output of the control input: the individual brief switch-on signal and an individual switch-off signal (Fig 10.5, b). In the interval between signals the control system can perform other functions. In this method, in the case of using computers considering the peculiarity of the technological preparation systems such as the small number of changes of positions of the servoelements over a prolonged period of time, at the launch complex it is possible to have one control computer to control several or even all of the technological operations of the complex. In this case the operation of the control computer must be set up by the principle of time sharing, and in each technological system there must be an autonomous control panel.

The flow chart for the control of the technological operations of preparing space rocket systems using a common control computer is shown in Fig 10.6. From this flow chart it is obvious that each technological system or several interconnected systems have their own individual control panel. The panels can be standardized and distinguished from each other only by the mnemonic circuits of the systems and the names of the signal transparencies and the control elements.

In the regime with time sharing the operating cycle is broken into small intervals during each of which a defined circuit of the machine executes some program. On completion of this program, a new one is introduced into the machine (a previously executed program usually is copied into the external storage element) which is performed for the next time interval, and so on.

One of the main problems in systems with time sharing is the organization of the servicing of the individual technological systems which usually is done by a dispatcher program or monitor in real time determining the sequence of execution of the programs and generation of information. The selected sequence has a significant influence on the efficiency of the machine and the degree of its use by each technological system. The dispatcher or monitor program must find a compromise between reducing the number of technological systems weighting in its queue, a decrease in weighting time and degree of importance and urgency of executing the individual programs. The development of the optimal service algorithm is a complicated problem requiring study of the operations and the use of the methods of mathematical statistics. The most important method of distribution is that each of the technological systems operating simultaneously receives the same time for the execution of programs in turn; this procedure is quite efficient if the required volume of logical operations for the technological systems is unknown in advance.

As the equivalent base of the common control computer, a computer complex constructed on a microelectronic basis from ASVT-M modules and developed as an entire series of assemblies (unit modules) having standard connections with each other can be used.

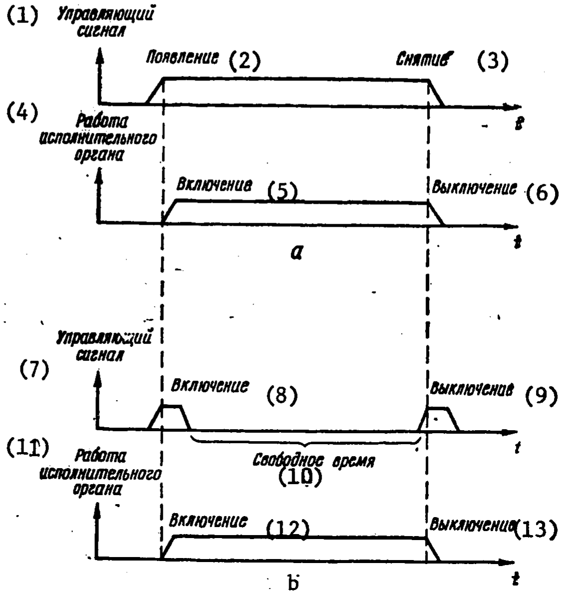

Figure 10.5. Time diagrams for the output of a control signal to the servoelement:
a -- constant; b -- brief

Key:

1. Control signal
2. Appearance
3. Drop
4. Operation of the servoelement
5. On
6. Off
7. Control signal
8. On
9. Off
10. Free time
11. Operation of the servoelement
12. On
13. Off

The control systems, the basic element of which is the control computer, are a new design field. The use of control computers as the basic controlling element provides for the solution of the logical and computational problems, universality and relative ease of modification of the control system as a whole. In this case almost all the specifics of the design of the control systems are concentrated in the algorithms and programs.

The control algorithm must be universal with respect to the technological processes of a defined class (that is, the variation of the old and introduction of new technological processes in the system not only cause variation of the control algorithm), to insure high reliability of the system and its operation with several parallel process in real time, occupy minimum memory volume and have maximum simplified programming process.

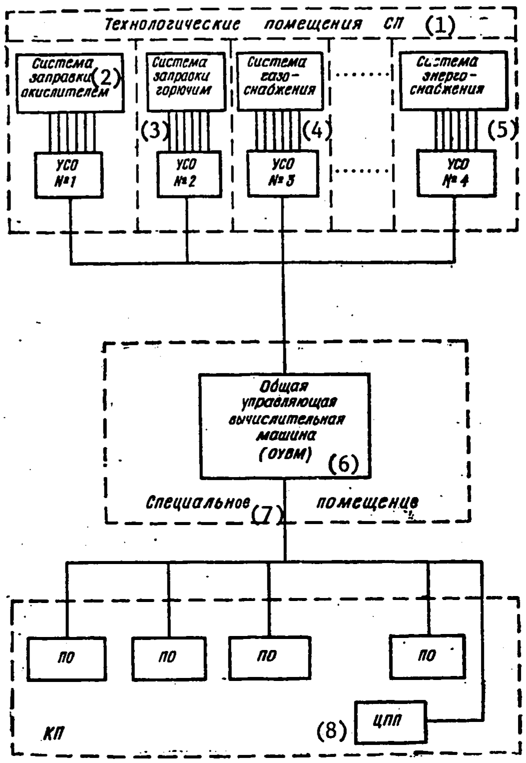

Figure 10.6. Flow chart of the control of the technological operations of preparation using a common mathematical control machine

Key:
1. Technological facilities SP
2. Fill system for the oxidizing agent
3. Fill system for the fuel
4. Gas supply system
5. Power supply system
6. Common control computer (OUVM)
7. Special facility
8. TsPP

Summing up, it is possible to state that the all-purpose technological operations control systems constructed on the basis of the control computer have, by comparison with the systems constructed on the basis of the logical automaton, the possibilities of interchange of the operating programs from the control panel without intervention in the equipment with the control of the preparation of various versions of the space rocket system on one launch system, checking of the program on a test bench and transfer directly to the launch position, halting of the program at any point and further continuation of it without return to the initial position, complete automation of the compiling of the program to introduction of it into the control system and use of the control computer for the performance of other missions of the launch complex (compilation of a model to predict the probability of a successful launch, diagnosis of systems during their operation, and so on).

In the opinion of foreign specialists, the universality of the ground control systems for the preparation process can be achieved by transferring part of this equipment directly on board the space rocket system. The return to earth and repeated use of booster rocket stages in space systems for multiple use presuppose the installation on them of part of the auxiliary electronic equipment which usually is considered ground equipment. The necessity is then excluded for equipment of all of the check panels with a complete set of equipment where its use coefficient is quite low, and the increase in weight of the booster rocket stages is very small. The placement of the check equipment on board the booster rocket significantly facilitates the modification problem, for changes in the booster rocket systems lead to minimum changes in the ground equipment. The installation of part of the intermediate monitoring equipment on board also significantly simplifies the communications between booster rocket and the launch equipment, cutting down on the number of "ground-on-board" cable connections.

10.4. Functional Monitoring Systems

The functional monitoring systems (SFK) are systems which put out information about the state of the space rocket systems and ground equipment for the formation of defined control inputs arising from the preparation algorithm. Just as the control systems, they can be specialized and all-purpose.

The specialized functional monitoring systems give rise to the appearance at the launch complex of a large number of different systems and panels, for during the process of developing the space rocket systems and versions of it, as a rule, the necessity arises for measuring new parameters which have not been provided for in the previously designed systems. The parameters are monitored either continuously or discretely, that is, periodically, after defined time intervals. The monitoring technique is selected in accordance with the operation of the systems in the launch preparation process. Frequently it is necessary to observe the parameters during the entire pre-launch preparation, which arises from the technological cycle. Therefore, all of the functional monitoring systems existing at the present time are basically multichannel continuous-action systems. This offers defined advantages: reliability of the information obtained (each sensor has its own measuring channel); in case of failure of a secondary instrument or communications line, information is lost only about one parameter; switches are absent in the sensor circuit (the accuracy of the measurement is increased) and, finally, the operation and maintenance of the system when performing regulating and check operations is simplified. However, the continuous-action systems also have deficiencies: an increase in the number of information channels and, consequently, electric circuits on board the space rocket system and the ground complex, a large number of secondary instruments, which requires an increase in the dimensions of the operator panel and sometimes the number of panels. This leads to an increase in load on each operator during the operating process or to an increase in the number of operators. The functional monitoring systems with discrete interrogation of the parameters require significantly smaller number of communications lines and secondary instruments, but they have a large measurement error and the possibility of loss of all of the information in case of failure of the communications lines. In spite of the deficiencies, the functional monitoring systems with discrete interrogation of the parameters are the most prospective, for the reduction of the cable network, decrease in the panel dimensions, the possibility of monitoring a large number of parameters and their unitization offer defined advantages by comparison with the continuous interrogation system.

For the functional monitoring systems located at the launch complex, the mass and size of them do not have significance, but, considering the great distance between individual parts of the systems and especially the remoteness of the command post, an effort is being made to reduce the cable connections, the total extent of which sometimes reaches hundreds of kilometers. For the elements of the functional monitoring systems located on board the space rocket systems, the mass and overall dimensions of the sensor and conversion equipment and cable network are an important factor, for this equipment does not operate in flight and is only deadweight. In this case an effort is being made for maximum lightness of especially the cable network, the weight of which reaches tens, and on large rockets, even hundreds of kilograms.

The procedure of discrete interrogation of the parameters finds broad application in the centralized monitoring machines (MTsK) a characteristic feature of which is multiple use of the same circuits and assemblies of them for processing the monitored parameters interrogated in turn. In the centralized monitoring machines (Fig 10.7) the converters which match the sensors with the rest of the equipment, insure standard output signals from the sensors of various types, which makes it possible to develop a secondary conversion unit without tying it to the specific measured parameters.

The functional monitoring system can be both independent and make up part of the control computer.

Independently of the construction of the system -- specialized or all-purpose using the centralized monitoring machine -- its information characteristics are determined to a great extent by the primary sensor equipment. When measuring the parameters of some of the components (for example, kerosene,

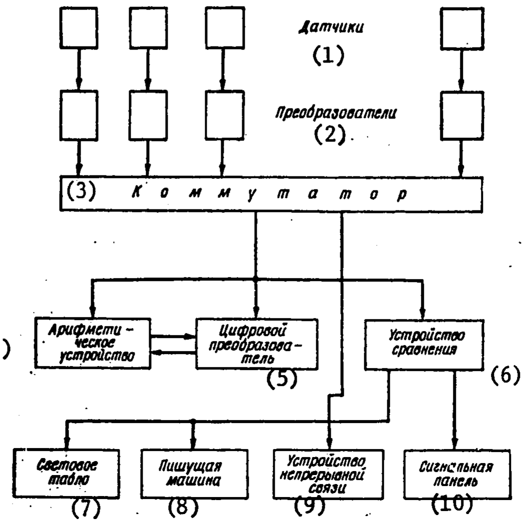

Figure 10.7. Standard layout of a centralized monitoring machine

Key:

1. Sensor
2. Converter
3. Commutator
4. Arithmetic circuit
5. Digital converter
6. Comparison circuit
7. Light display
8. Typewriter
9. Continuous communications circuit
10. Signal panel

hydrazine) it is necessary to use explosion-safe sensors which creates additional difficulties. The solution of this problem is connected with the application of light, small sensors of usual execution combined with spark-free secondary instruments which feed the sensors with currents lower than the maximum admissible ones. For the ground complex the sensors are made in the explosion-proof execution (their cases do not transmit an explosion on the outside) with massive cases and a fire barrier in the input line.

Usually platinum resistance thermometers are used to measure the temperatures (they are usable in the temperature range from -260 to +650°C, and they have stable characteristic temperatures from -180 to +150°C); to measure low temperatures, carbon and semiconductor resistance thermometers, gas and condensation thermometers are used, and for temperatures above 650°C, thermocouples.

In order to measure the pressure in the functional monitoring systems, potentiometric and differential-transformer sensors are used.

A vacuum is monitored using instruments that operate on thermoelectric, magnetoelectrodischarge and ionization principles.

To measure the level, several methods are used: the float method with inductive pickup of signal, capacitive, ultrasonic and the method based on measuring the pressure gradient created by a column of liquid.

The great variety of sensor equipment also leads to variety of their output signals. The reduction of these signals to a signal output takes place in the primary converters which output signals of 0-10 volts, 0-5 volts and 0-5 milliamps most convenient for the monitoring systems.

In order to increase the accuracy of the monitoring, narrow measurement ranges are expedient which are provided using a set of individual converters or an all-purpose converter with range switching circuit. The centralized monitoring machines, being a component part of the functional monitoring system, are connected during the operating process to a mathematical control computer which automatically controls the entire process. The flow chart for obtaining and processing the information is shown in Fig 10.8.

The centralized monitoring machine must signal deviation of the parameter from the rated conditions, measure the parameters when asked for by the operator, process measurement data, record information and provide for visual monitoring. Here the entire measurement range, as a rule, is broken down into three zones: "standard" -- where the parameter in the zone providing for the normal course of the process, "above normal" -- where the parameter goes beyond the upper admissible limit and "below normal" -- where the parameter goes beyond the lower tolerance limit.

Printers (printers and recorders) and digital recorders are used for recording a large number of parameters. The latter, calculated for the same number of points, are appreciably more compact than the analog multipoint recorders, for it is possible to locate a strictly defined number of points or lines on the chart paper, and with tabular representation the number of symbols is in practice unlimited.

The visual monitoring in the centralized monitoring machine gives rise to the necessity for matching many of the sensors of nonuniform parameters with the input of one or several visual monitoring instruments. This leads to the fact that it is necessary to do away with reading the value of the measured parameters in technical units or the application of multiscale instruments with automatically variable scales or leads to digital indicators. It must be noted that in addition to the necessary universality, the digital indicators give higher measurement accuracy than the other methods of visual monitoring.

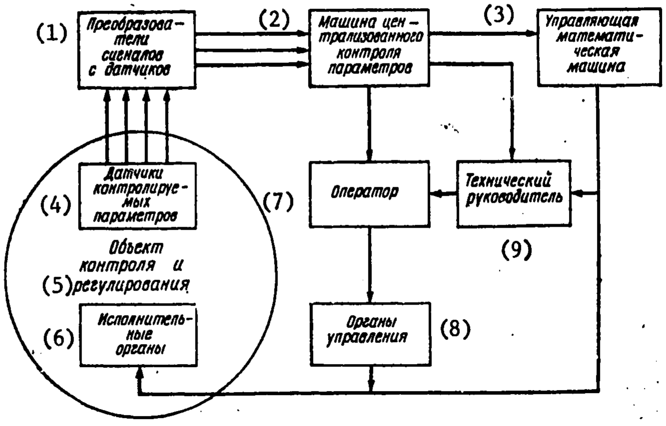

Figure 10.8. Flow chart for obtaining and processing information

Key:

1. Signal converters for the signals from the sensors
2. Machine for centralized monitoring of the parameters
3. Mathematical control computer
4. Sensors of the monitored parameter
5. Object of monitoring and regulation
6. Servoelements
7. Operator
8. Control element
9. Technical director

10.5. Interaction of the Monitoring and Control Systems

During the control of the operations of preparing the space rocket systems at the launch complex the interaction of the monitoring and control systems to each other defines the technological cycle, the structural diagrams of the process system and the control systems. It is considered here that the monitoring elements complicate the system and its operation and maintenance, they increase the cost and, what is especially important, they influence the reliability characteristics of the control system.

In addition to checking the fitness of the control system itself, the monitoring systems usually also monitor the operation of the servoelements of the technological systems and the operation sequence.

In the systems for preparing the space rocket systems for launch, the monitoring can be used as a means of obtaining data on the state of the control process for transition to the next step of the process cycle or as purely information signal to the operator. Here it is necessary that the operator not be overloaded with excess information provided "for information" and not used for control by him. This especially pertains to monitoring the irreversible processes where the operator in practice cannot influence the course of events.

In the general theory of automatic search for failures the fitness of the systems is determined by three methods: by the state of the individual elements, by the reaction of the system to the monitoring signal and by the fitness of the system during the operating process.

The third method is applicable only for the ASPS. The first method is not used in connection with awkwardness, and the second, as a result of the necessity for disconnecting the servoelements for the monitoring time.

The fitness of the systems in operation is determined by the correctness of execution of the given technological program by the servoelements. The monitoring system can obtain information at the output of the control system, at the input of the servoelement and at the output of the servoelement on performance by them of the given functions (Fig 10.9).

In the first and second cases the monitoring is usually realized by the voltage or current, and when using an electropneumo valve as the servoelement, at its input with respect to a pneumatic relay monitoring the control pressure feed. In the third case the monitoring is done, as a rule, with respect to the terminal contacts or other elements. It must be considered that the transmission of the displacement from the moving elements of the servoelements to electrical contact is frequently connected with a complex kinematic diagram, which sharply reduces the monitoring reliability.

When designing the monitoring system and determining its interaction with the control system it is necessary to know the probability of the output of false information by the system. If we denote the reading of the system as "correct" G, "incorrect" $\bar{G}$, the correct state of the monitor element S and the incorrect $\bar{S}$, then the error probability can be of two types:

Type I - $\alpha = P(\bar{G}/S)$;
Type II -$\beta = P(G/\bar{S})$.

Since for the space rocket complex the delay or interruption of the launch as a result of an improper reading of the monitoring system is better than a launch with a failure, for it the type β errors are the most dangerous.

Considering that the information of the monitoring system can contain type α or β errors, the operator of the control system can also use it erroneously. If event A is a fact of permitting the control system to perform the operations, event B is the actually proper state of it, and if we assume that B is the control system in good working order; $\bar{B}$ is the control system in a state of disrepair; A is the control system permitted to perform the operations; $\bar{A}$ is the control system permitted to perform the operations, then in this case the following errors are possible:

Category I - $\gamma_k = P(\bar{B}/A)$;
Category II - $\delta_k = P(B/\bar{A})$.

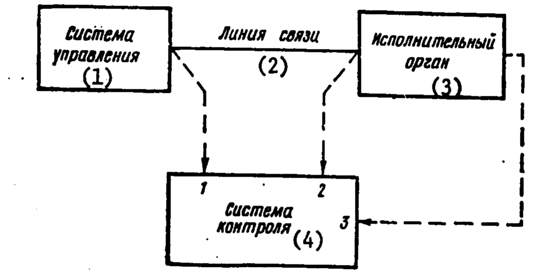

Figure 10.9 Flow chart of the possible obtaining of information by the monitoring system:
1 -- at the output of the control system; 2 -- at the input of the servoelement; 3 -- at the output of the servoelement

Key:

a. Control system
b. Communication line
3. Servoelement
4. Monitoring system

The errors in Category I are a control system in a state of disrepair permitted to perform the preparation operations; the error in Category II is the control system in a state of good repair not permitted to perform the operations.

Various requirements are imposed on the monitoring systems, depending on the reliability of the monitored object. For the monitor preparation systems by the monitored object, as was noted previously, we mean the control system for the technological operations itself and the servoelement of the technological systems. The requirements on the monitoring system reliability can be defined as

$$P_{\text{с.к}} = \frac{P_0 + P_{\text{д}} - 1}{P_0 \cdot P_{\text{д}}},$$

where $P_{c.k}$ is the probability of fail-safe operation of the monitoring system;

P_o is the probability of fail-safe operation of the monitored object;

P_D is the confidence probability of estimating the reliability of the object using the monitoring system.

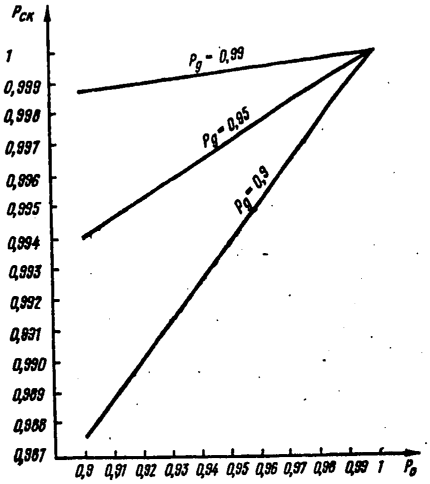

Figure 10.10. Graph of the monitoring system reliability as a function of the operating reliability of the object

The function $P_{c.k}=f\ (P_0)$ is shown in Fig 10.10 for $P_D=0.9$, $P_D=0.95$ and $P_D=0.99$. From the figure it is obvious that the monitoring system reliability must be appreciably higher than the reliability of the monitored object, for when $P_0=0.95$ and $P_D=0.95$ the reliability of the monitoring system $P_{c.k}=0.9972$.

Depending on the value of the probability error characteristics, the reliabilities of the monitoring system and the peculiarities of the technological process of launch preparation the monitoring systems can interact with the control system as follows:

By the emergency signal the monitoring system automatically initalizes the preparation system;

The monitoring system automatically shuts down the preparation process, the system itself remains in the position in which it was at the time the signal arrived, but the necessary measures were taken to create a safe situation (in this case the control system must insure the possibility of continuation of the process after elimination of the failure);

The monitoring system gives a signal about improper execution of the technological algorithm, by which the operator makes the necessary decision.

10.6. Telemetering Systems

The systems for measuring the parameters with telemechanical communications channel are called telemetering systems. The essence of telemetering consists in conversion of the measured variables to the signal equivalent to it, the parameters of which are selected in such a way that on transmission over a communications line the distortions will be minimum. The measured parameters can be both electrical and nonelectric variables.

The telemetering is used wherever the ordinary measurement methods either are theoretically impossible (transmission of measured parameters from moving objects -- aircraft, spacecraft and so on), either are inexpedient as a result of large errors occuring during transmission of variables to significant distances but also when measuring a large number of parameters requiring a significant number of communication lines. The telemetering systems are basically classified by the parameter by means of which the value of the measured variable is transmitted over the communications channel. By this attribute all of the telemetering systems can be divided into three groups: the intensity systems also called the near-action systems, frequency systems and impulse systems.

In turn, the intensity systems are divided into unbalanced (uncompensated) current systems, balanced (compensated) and potentiometric voltage systems, frequency systems -- into AC and frequency impulse systems -- and the pulse systems, into numerical pulse, time pulses and code pulse systems.

Depending on the number of measured variables, all of the telemetric systems can be single-channel (when only one measured variable is transmitted over the communications line) and multichannel (where several measured variables are transmitted over the communications line). As a rule, multichannel telemetering systems have been used which make use of the frequency or time method of signal separation distances in remote control.

The remote measurement systems belong to the operative monitoring systems, and with respect to functional purpose they are separated into remote measuring systems that measure the state of the technological systems and monitor part of the on-board parameters of the space rocket system during the pre-launch preparation process and the remote measuring systems that measure the state of the system and the elements of the space rocket system during flight which can begin their operation when the rocket is at the launch complex.

The basis for constructing the remote measuring systems is successive monitoring of the parameters. Therefore the requirements on the telemechanical channel with respect to speed and reliability are contradictory to a known degree, for the application of noiseproof coatings to achieve given reliability leads to a reduction in speed. The parameters of the technological systems in the pre-launch preparation process, as a rule, belong to the slowly varying ones which offers the possibility of obtaining high reliability of the information by simple coding methods.

In the remote measurement systems the received signals are depicted after separation and coding in a form which is convenient for further processing and analysis. One of the methods of depicting the information obtained is recording it, that is, recording in the form of visible or latent images.

The procedure for depicting the information is determined by its purpose. With respect to purpose the information is divided into three groups: operative, statistical and accounting. The operative information is needed by the operator or the automatic control system for direct action to change the measured parameters; the statistical information is used for processing and generalizing the results of measuring the parameters in the monitored object, and the accounting information, for documenting the results of the measurement.

The last two information groups can be depicted by various methods. The selected method of depicting the measurement results must satisfy convenience and ease of surveying the nature of variation of the parameter, the possibility of combination of several parameters for investigation of them and also determination of the magnitude of the parameter or the time of appearance of the event with the required accuracy. In case of necessity, it must have the possibility of preliminary feeding of the remote measurement results to the display for operative monitoring and also maintenance of these measurements for further processing of them.

The selection of the method (analog or digital) of recording depends to a high degree on the type of information received. With the analog method the information is depicted in the form of continuous or discrete values of the parameter as a function of time. The recorded values are proportional to the measured value. The classification of the analog recorded is presented in Fig 10.11. The discrete values of the parameter are recorded using discrete recorders, the classification of which is presented in Fig 10.12. The digital recording will make it possible to obtain values of the parameters in the form of numbers after defined time intervals.

Depending on the method of obtaining the image, three recording techniques are isolated:

The application of a layer of any material to the material (ink, graphite or paint can be used as such material);

Removal of a layer of material from the material (with this method the layer of material is removed by drawing tracks or punching);

By using the properties of the material to change their state under the effect on them of various types of energy or chemicals entering into reaction with them.

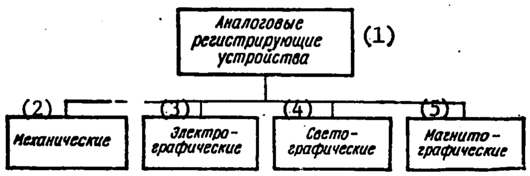

Figure 10.11. Classification of analog recorders

Key:
1. Analog recorders
2. Mechanical
3. Electrographic
4. Light-graphic
5. Magnetographic

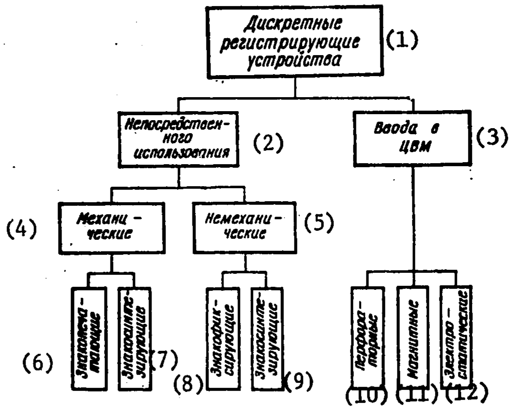

Figure 10.12. Classification of digital recorders

Key:
1. Digital recorder
2. Direct use
3. Input to computer
4. Mechanical
5. Nonmechanical
6. Symbol printing
7. Symbol synthesizing
8. Symbol fixing
9. Symbol synthesizing
10. Punch
11. Magnetic
12. Electrostatic

The advantages of digital machines and also digital reproduction and recording the information have given rise to the broad development of digital telemetric systems. Whereas in the first stages of the development of telemetric systems, a great variety of structural principles were characteristic of the analog methods of telemetry, at the present time a transition to digital methods is being more and more observed. Analog systems are being maintained in cases where the number of measured parameters is small and it is necessary to have simple equipment.

10.7. Cable Communications

Depending on the principle of constructing the communications channel between the control element and the servoelement, the control systems are divided into local, remote and telemechanical control systems.

In systems with local control, the control element and the servoelement are connected by cable lines over which all of the electric current flows which is necessary for operation of the servoelement. The laying of such cable lines is expedient only for comparatively short distances and, as a rule, it is used in general engineering systems where the control elements are located at an insignificant distance from the general engineering systems themselves.

For devices with remote control, the presence of individual lines of force and control lines between the servoelements and the control element is characteristic.

Telemechanical control is connected with multiplexing the communications channel, that is, with respect to one control line transmission of several commands with time, frequency or code separation of them is possible.

The basic form of telemetric control systems is the multiwire systems using the combination of wire lines for transmission of the commands. In such devices the number of wires is several times less than the total number of monitoring and control signals. The multiwire systems occupy an intermediate position between the remote and the telemechanical systems. At the present time primarily remote control systems are being used in the ASPS.

In specialized control systems for the technological operations, depending on the placement of the control system and the technological systems, three methods of arranging the equipment are used which determine the structure of the cable network.

In the first method the automation modules are located at the command point in direct proximity to the control panel. Here the cable network connects the days to the servoelements of the technological systems (Fig 10.13). The advantages of this system include the possibility of using a set of automated equipment to control several identical technological systems, the convenience of operation of the modules and performance of the regulation operations with them, short time required for replacement of the field module, and the deficiencies include the long length of the cables from the output element of the control system to the servoelement, which leads to significant losses of voltage in the cable lines and requires the application of cables with large cross section.

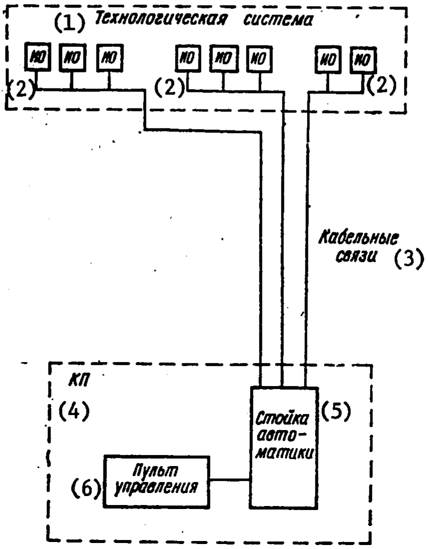

Figure 10.13. Diagram of the arrangement of the equipment

Key:

1. Technological system
2. Servoelements
3. Cable communications
4. Command post
5. Control panel
6. Automation bay

With the second procedure the automation lines of the control panel are arranged analogously, but in this case the control bays are connected to the servoelements through a bay of high-resistance repeater relays located near the servoelement, which permits a significant decrease in the cable cross section (for response of high-resistance repeater relay relatively low current is required) and a reduction in the number of cable lines. This procedure retains all the advantages of the first one, but increasing the number of contacts and relays in the operating control circuit leads to some decrease in the control reliability.

In the third procedure the automation units are located in direct proximity to the servoelements of the technological systems: here they are connected to the control panel located in the command post by cables. In this case the number of cable connections is reduced sharply; there are no relay repeaters in the control circuit, and the servoelements are controlled from the modules through short cables laid inside the structure, which significantly increases their reliability.

The choice of one method or another of constructing the cable communications depends on the specific planning of the launch complex and the location at it of the servo and monitoring elements of the technological systems. Considering that for every control or information signal, in the absence of multiplexing of the cable lines two to four strands are needed, the complexity of this method of constructing cable communications is obvious, which sharply complicates the "ground-on-board" communications.

The analysis of the cost benefit indicates that with a communications line more than 5 km long, telemechanical means are required; at distances to 1 km the application of telemechanical means, as a rule, is inefficient, and it is more efficient to use remote systems. At distances from 1 to 5 km the application both remote and telemechanical systems is possible. It is possible to give preference to one method or another only after specific technical-economic analysis.

When selecting the telemechanical means for application in space center systems it is necessary to consider the forms and the extent of the communications channels, the forms and volume of information and the control commands, the method of processing and reproducing the information, the requirements with respect to speed, accuracy and reliability and also the operating conditions and reliability requirements.

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CHAPTER 11. CONTROL OF THE SPACE ROCKET COMPLEX

11.1. Organization of Control

During the first years of development of rocket engineering the preparation time of the space rocket system at the launch and the engineering complexes was not strictly limited. Each technological system had its own autonomous control system with manual or semiautomatic regime. The monitoring and control systems of the same complex were designed on the basis of various electroradio elements and by different structural principles (on the part of the degree of automation, structural form, reliability characteristics and so on), and they were not connected to adjacent systems. Finally, the coordination of the operations of the individual systems and the general technological preparation process was realized by the operations director, and the information about the operation of the systems, by the operators.

All of this led to the fact that the preparation time of the space rocket systems for launch was large, and to make the preparations a significant number of service personnel were required. In subsequent years various systems were developed for organizing the process of controlling the preparation of the space rocket systems.

For the single-level control system all of the technological systems are in an equal position, and the choice of the optimal preparation process is solved in a united control center, after which the solutions are output to all the systems for implementation.

The hierarchical control system is characterized by multilevel structure both on the functional and on the organizational level. This system is necessary wherever contradictions arise between the information flow in the complex and the limited carrying capacity of its control elements. Absolute decentralization (the guarantee of independence in the control of changes of any element to the parts of the system) converts the space center from a united complex to an accumulation of disconnected separate systems, and absolute centralization (concentration of control in a united center) promotes the formation of an indivisible whole, which makes the complex difficult to manage.

For control of the preparation of the space rocket system at the engineering and launch complexes usually the three-level arrangement of the monitoring and control systems turns out to be acceptable in which the lower (first) level directly controlled technological operations of preparation, the second coordinates the operation of the systems of the lower level, and the upper (third) level realizes communications among the systems of the engineering or launch complexes engaged in preparation and the remaining parts of the space center.

Let us consider the hierarchical system of organization of the preparation process in the example of the "Saturn-V" booster rocket and the "Apollo" spacecraft. For testing and preparing them at the engineering complex (the vertical assembly building) and the launch complex (the launch stand) an automatic system is used which is based on the RCA-110A computer placed on the launch platform and connected to the analog system, display devices and monitoring and measuring equipment at the launch control center.

The upper level of the hierarchical structure -- the computer at the launch control center -- issues commands, and the second level -- the computer at the launch platform -- provides for the execution of the commands and data output. In the control room for each stage or compartment of the space rocket system there are individual monitoring and control panels which permit either selective checking of individual systems or calling on a complete test program from the computer (the lowest level).

The commands and requests are input to the system by the corresponding buttons on the control panel, and the complete test program, by a signal from the control panel. The output signals of the sensors go to the control computer of the launch platform which processes them and transmits the results to the computer at the launch control center, and from there to the display system.

In the future the process of controlling the preparation for launch must be carried out with still greater use of control computers. The computer means of the systems on the first level will process data in real time.

The software of the lower level must be quite simple. The central processes of the first and second levels are conveniently selected identical, but the set of external devices on the second level usually is broader. An increase in system reliability can be achieved as a result of program compatibility of the processes on the two lower levels. The second level processor can be used to monitor the operation of the first. On the third level a high-output computer must be used which, in particular, can operate in the time sharing mode.

The system reliability must be calculated considering the reliability of communications between the operator and the system and also the high-capacity memories. On occurrence of failures the efficiency of the system will be lowered, but on all levels of degradation of the hierarchical control system emergency-free operation of the space rocket complex must be guaranteed which is determined to a great extent by the correctness of selecting the location of the operator in the overall organization of the control process, its functions and method of generation with the computer.

11.2. Human Operator in the Control Process

In spite of the intensified trend toward the use of automatic systems and in practice unlimited possibilities of the computers, the performance of the operations with respect to preparing the space rocket system for launch even at prospective complexes is impossible by computers alone. In order to make the basic decisions and implement them by manual control a human operator will always be necessary, for practice indicates that his presence promotes increased operating reliability of the ASPS, broadening of the functions performed by it and improvement of the monitoring and control.

Many papers have been written on the interaction of operator and computer; therefore, we shall consider only the peculiarities which are specific to the process of controlling the preparation of a space rocket system for launch.

The flow chart of the closed "man-machine" system in which the monitoring and control functions are performed by a human is presented in Fig 11.1; a more complex "man-machine" system which is made up of an automatic control system and an operator observing displays and actively intervening in the control process when the automatic system does not deal with the problem for any reason is shown in Fig 11.2, and a system with a mathematical control computer which realizes automatic control by an optimal program considering the state of the object prevents emergencies, signals disturbances of the process, indicates the locations of their occurrence, and so on is shown in Fig 11.3. In the case of thermal operation the operator does not intervene in the control process, and only if the machine fails to take on monitoring and control functions.

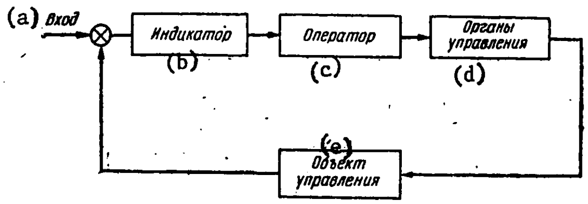

Figure 11.1. Structural diagram of the "man-machine" manual control system

Key:
(a) input
(b) display
(c) operator
(d) servoelements
(e) object of control

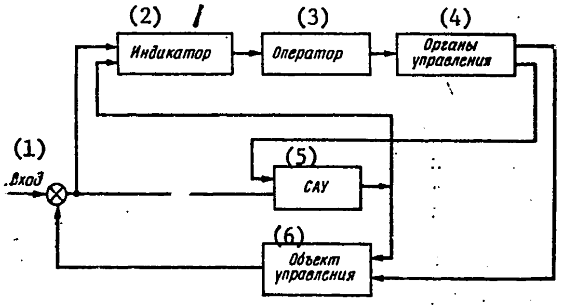

Figure 11.2. Structural diagram of the "man-machine" system with automatic monitoring and control

Key:

1. Input
2. Display
3. Operator
4. Control elements
5. Automatic control system
6. Object of control

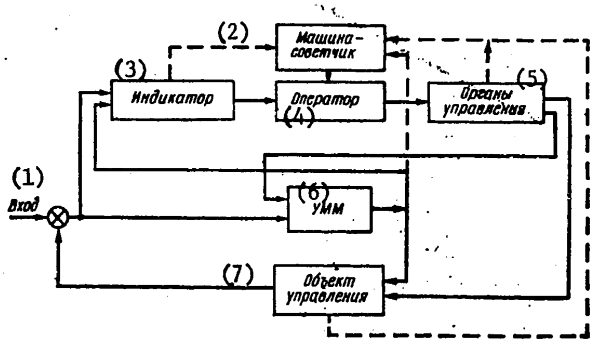

Figure 11.3. Structural diagram of the "man-machine" system in the presence of a mathematical control computer

Key:

1. Input
2. Machine adviser
3. Display
4. Operator
5. Control elements
6. Mathematical control computer
7. Object of control

On investigation of the structural diagrams it is obvious that as they become more complicated the man is relieved of a number of functions transferred to the machine, and he takes on more responsible problems with respect to overall monitoring and control of the preparation process. When necessary, an adviser computer can be also introduced in the system, for the volume of document type material frequently is so large that the operator is forced to expend a great deal of time on finding the required instructions when the preparation process deviates from the previously planned course. The adviser computer is capable of informing the operator of the necessity for intervention in the automatic control cycle and the actions which he should take in case of emergencies, when issuing a manual command, it can give the operator advice how it is executed and to what monitor; during the automatic cycle it can indicate to the operator what displays he should watch at the given time; it can predict the preparation process and indicate to the operator possible deviations of the given process cycle.

In the various phases of the preparation process, the operator load is different: when operating at the engineering complex where there are no rigid restrictions with respect to time, the operator carries out more missions than at the launch complex where the time is strictly limited and the missions are more responsible. Independently of this, strict requirements are always imposed on the operator of the space rocket complex with respect to accuracy, reliability and speed of the performance of the manual operations.

The reliability, operativeness and accuracy of the operation of the operator depends on many factors; therefore, the optimization of his activity in practice reduces to matching the characteristics of the technological process devices with the possibility of the individual characteristics of even one operator. Here the degree of loading the operator defined by the load factor has great significance:

$$K_{з}=\frac{t_{ф}+t_{в}}{\tau},$$

where $t_{ф}$ is the time required to realize that a transparency is burning;

t_V is the time for switching on the control element;

τ is the minimum time of the preparation flow chart during which the operator must realize that the transparency is lit and must take control action.

The operator reliability for $K_3<0.75$ (the usual mean load coefficient) can be estimated by such quantitative indexes as the reliability of recognizing that a transparency is lit $P_{ф}=0.97$ and the reliability of taking control action $P_y=0.99$. Consequently, the reliability of the operator of the monitoring control systems who is charged with the mission of controlling the recognition that the transparencies are lit can be estimated in $P_0=0.96$.

Considering the functions of the human operator in the process of controlling the preparation of the space rocket systems, it is necessary to discuss the form of his activity and how decisions are made. In recent years, the theory of decision making by a human has arisen and developed rapidly as a problem having independent significance. and located at the junction of two sciences -- control theory (cybernetics) and engineering psychology.

In the general case decision making by a human is broken down into the following problems:

Compiling the decision making model;

Collection and analysis of information about the situation that is occurring;

Determination of the number of goals and establishment of their importance;

Development of possible actions in the direction of achieving the goals;

Selection of the optimal method of taking action;

Completion of the action itself.

When preparing the space rocket system, the factor of selecting the time of implementation of a responsible decision has great significance.

For the launch preparation director the primary difficulty consists not in planning the possible methods of taking action (there are few of them and they are clear), but in their alternativeness, in the responsibility of selecting one of them, determination of the optimal time for taking the action itself.

The process of launch preparation of space rocket systems is always connected with some risk. This process can have the following outcomes: favorable completion, halting as a result of failures, disaster. Practice shows that it is insufficient to know the degree of risk[1] before the beginning of the test; it is also necessary to know how to determine the change in degree of risk during the course of preparation and properly to estimate the situation from the point of view of expediency of continuing or stopping the operations.

The decision to halt preparations must be made only if it is necessary, and the limited time for thinking about it and the almost unavoidable state of stress as a result of the feeling of responsibility usually inhibit serious comprehensive analysis and can lead to erroneous decisions. A negative role is also played by improperly interpreted prestige arguments.

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[1] In the given case, by the degree of risk we mean the probability of a disastrous outcome considering the failures occurring during the course of preparation and the possibilities of eliminating them.

Let us consider the possible methods of substantiated decision making to stop the launch preparation process.

Qualitatively the picture looks like the following (Fig 11.4). On appearance of comparatively small failures which cannot be eliminated which have an irreversible effect on the course of preparations, the risk function $P_k=f(t)$ after an arbitrary point A increases smoothly (curve a); at the time of intersection of the curves $P_k(t)$ and $P_k^*(t)$ at point B it is necessary to stop launch preparation. On occurrence of the large failure directly threatening a disaster, the risk function $P_k(t)$ goes discontinuously from point A to point C. In this case it is necessary to stop preparations only when the predicted risk function $P_k(t)$ continues to grow after the point C (curve b) or it decreases, but not to the intersection with the curve $P_k^*(t)$. If by the forecasting data the risk function is reduced to the level of $P_k^*(t)$ (curve c), it is expedient to continue launch preparations. When predicting changes in the risk function $P_k(t)$ such data as the probability of the appearance of certain failures, the probability of eliminating them, and so on, are taken into account. The possibility of sharp discontinuities of the function Pk(t) and, consequently, the possible necessity for making rapid decisions require preliminary development of the algorithm for the problem and the compiling of a matrix of possible combinations of failures with their probabilities. When training the operators on the computer, the basic versions of launch preparation of the space rocket system are played out with the participation of the operators and the preparation systems directors.

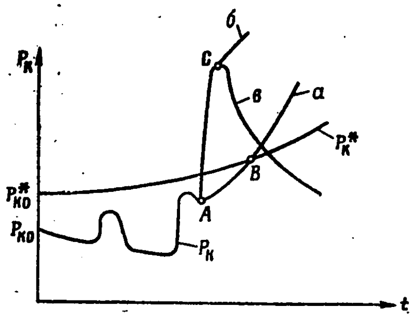

Figure 11.4. Graph of the risk function $P_k=f(t)$ during the launch preparation process for space rocket systems:
P_{ko} is the predicted probability of disaster; P_{ko}^* is the threshold value of the admissible disaster probability

11.3. Information Display and Communications During Launch Control

The operations director and the operators, as a rule, do not have the possibility of directly observing the behavior of the systems and units of the complex both for safety engineering reasons and because of their great territorial spread. Therefore, the information about the state and the functioning of the systems and units of the space rocket system comes to displays.

Thus, the operations director and the operators interact not with the space rocket complex itself, but with its information model -- the set of information about the state and functioning of the complex.

The volume of information included in the model and the rules of its organization must correspond to the problems and the methods of control. The information model for the operations director and the systems operators is the source on the basis of which they form their opinion of the actual situation, they analyze and estimate the developed situation, they plan control inputs, observe and estimate the results of implementation of them. The information about the state of the object must be represented in the form which insures direct use of it. The necessity for decoding, conversion, calculation and interpolation must be reduced to a minimum.

The organizational chart of the space center contains a complex hierarchical structure of control elements arising from the sharp difference in functions of the lower and higher control levels. Whereas at the lower level the attention of the operators is concentrated on analyzing the operation of the systems and units, the primary problem of higher levels (directors) is qualitative evaluation of the system as a whole and making decisions theoretically important for the entire space rocket complex.

This characteristic of the higher control levels requires the use of integral methods of coding in the information models permitting representation of the information for the directors in pre-processed and generalized form.

An essentially important feature of the information model determining the nature of information reception is the volume of information included in the model. On the one hand, the model must be laconic, not attracting attention to secondary details, and on the other hand, the speed of the occurrence of the process requires redundant information which is necessary for making decisions in unforeseen situations.

In the majority of cases the operator deals with an information model, the state of which is a time function. Under these conditions it is necessary to match the information flows with the carrying capacity of the operator, which, in turn, depends on the conditions under which he works, including the external environment, which requires experimental processing of the correspondence of the information flow to the capability of the human under actual or close to actual conditions.

The correctly designed information model must first be sufficiently abstract to reflect the structure of the processes occurring in the system and present the operator not only with a set of information about the state of the space center systems, but also the relationship of the information to the given control quality criteria; secondly, it must be clear and insure integral perception and, thirdly, have the possibility of predicting the situation, the necessity for which arises when high reaction speed and significant preliminary information are required.

The information must come to the operator in laconic form, and the speed and accuracy with which he evaluates the signals must be proportional to the number of elements which he must keep under observation.

The integral models can be recommended for use in cases where decision making requires that the operator make a simultaneous evaluation of several parameters of different quality or parameters which vary with respect to time, that he sum up a large volume of uniform information, compare contradictory or interrelated data of different degree of importance and make a qualitative evaluation of the developed situation.

The variety of problems and the possibility of occurrence of unforeseen situations require that the information model be flexible, which is achieved by regrouping the information, recoding, partial abbreviation or expansion of the volume and also alteration of the order of its arrival.

The organization of the information flows during the space center control process must exclude both overload and underloading of the operators and operations directors. Overloading the operators arises from too large a number of rapidly occurring events and also information coming from systems with constant interrogation cycle. A decrease in the overload is achieved by representation of the information insofar as possible with warning with respect to the beginning of execution, a reduction in the flow of incoming information to the required minimum, separation of randomly incoming information in such a way that it can be obtained on request, and the possibility of filtration of it. Overloading leads to overfatigue of the operators, the appearance of mistakes in his work and, in the final analysis, to the possibility of making incorrect decisions. Underloading is also undesirable, for it leads to loss of attention. A decrease in the underloading is achieved by reducing to a minimum the time from interrogation to reproduction of the information, insurance of a sufficiently intense information flow (with intensity on the order of 10 signals per hour complete absence of attention can be observed), an increase in "noticeability" of the information (blinking, brightness) and restriction of the area over which it is placed, the use of sound signals, especially for emergencies, insurance of a sufficiently long display, which makes it possible to receive it up to implementation and insurance of feedback monitoring of the actions of the operators.

The necessity for creating information models in large automated control systems and systems for coordinating the process of preparing the space rocket system for launch and also the improvement of the monitoring and testing equipment have essentially increased the requirements on the parameters of the displays such as reproduction of large volumes of information, the set of various complex symbols, reproduction of lines, and so on, and, correspondingly, the operating requirements with respect to reliability, resistance to mechanical and thermal effects and also a decrease in size and weight.

Thus, the information model is a representation of activity and at the same time it is the direct object of perception and action for the human. The information model insures transformation of the general knowledge about the laws of the processes and the phenomena to the specific knowledge of the space center control.

In the information models the following methods of data display are used.

The method of display using cathode ray tubes is based on the application of small ordinary cathode ray tubes as a display (0.5 m^2). The information in the form of a binary parallel-series code comes to the input distributor and from its output after the corresponding processing in the form of pulse binary signals, to the "code-analog" converter. The thought groups converted from the binary code pulses to the corresponding currents and voltages serve as signals for controlling the cathode ray tube under the effect of which the beam reproduces the symbol for the given information on the screen of the cathode ray tube. Depending on the type of luminophor, the color of its glow and the external illumination, the frequency of repetition of the frames fluctuates from 20 to 50 hertz to create integralness of the image.

Along with the ordinary cathode ray tubes (kinescopes), special symbol-forming tubes (charactrons) are used, the basic distinguishing feature of which is the formation of the symbols inside the tube by using type matrices which communicate the shape of the symbol which must be displayed on the screen to the electron beam crossing them.

When prolonged glow and storage of the generated information on the screen is needed, a version of the charactron -- the typotron -- is used, the distinguishing feature of which is the presence of an additional reproducing gun in addition to the recording cathode gun which operates briefly at the time of formation of the symbols.

The cathode ray tubes of the charactron-typotron type make it possible to form not only alphanumeric information on the screen defined by the range of symbols on the matrix, but also various graphical information (drawings, graphs, and so on) for which in many models there is a round hole in the matrix which offers the possibility of passage of a spot electron beam, focusing it and forming any graphical figure on the screen analogously to the process in an ordinary tube.

A significant disadvantage of the charactrons and typotrons is the fact that the formation of the symbols is realized inside the tube, and the symbol range is limited to a set of symbols in the matrix. On conversion to a new set of symbols this leads to the replacement of the entire tube which in practice is impossible during operation in a broad and variable range of symbols.

The effort to eliminate these deficiencies has led to the creation of a new type of symbol cathode ray tube -- the compositron with the matrix outside the tube and correspondingly with external input of the symbols, especially prospective for use when realizing various information-logic problems.

The photography method is also based on using a cathode ray tube, but with the application of an intermediate carrier, which makes it possible to separate the processes of the accumulation of information and the projection of the symbols of defined configuration on a large beam without the necessity for holding a frame of given frequency on the screen of the cathode ray tube. The information is photographed from the cathode ray tube on film and projected on a large screen. The opening and closing of the camera shutter, high speed development and fixing of the film and also projection of it realized by control signals.

The electrography method differs from the preceding one in that a photoconductor in the form of vitreous selenium or zinc oxide is used as the intermediate carrier. Under the effect of light signals on the photoconducting plate, a potential relief is created corresponding to the emitter on the cathode ray tube which after treatment with powdered developer is converted into a visible image projected on a screen.

The method of digital display elements consists in the fact that the entire area of the screen designed for displaying the information is broken down into a large number of elementary sections, the dimensions of which depend on the volume and the form of the displayed information, the required resolution, the size of the screen, the distance of the absorber, and so on. Each elementary section of the screen is equipped with a display element (incandescent lights ordinarily used with optical devices, light-valve cells, electroluminescent elements, light emitting diodes, and so on), which is excited by feeding special control signals. The control of the digital displays is complicated inasmuch as it requires feed of the signals to each elementary cell, the number of which can reach a million for large screens.

The use of the displays in the systems for coordinating the preparation process offers the operations director the possibility of more objective decision making about the subsequent course of the tests. In order to output the corresponding commands to the operators of the special systems, in addition to the electric signals, commands can also be sent with respect to the various communications devices from which inside the facility or structures the most widespread is the headphone, and between the structures, the telephone and telegraph.

For communications inside facilities, telephone has become widespread using special sets which provide for two-way telephone communications through an amplifier among several operators and offer the operators included in the network of the given device the possibility of hearing the conversations simultaneously.

The operations director can be connected to any communications channel, and in addition he has a microphone for a loudspeaker in the form of a special radio with speakers at all points of the engineering and launch complexes where operations are being performed. This gives him the possibility of sending commands when necessary and coordinating the operation of all personnel engaged in the launch preparation directly.

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Yekhlakov, V. P.; Makov, L. V. IZMERENIYA I KONTROL' PARAMETROV TEKHNICHESKIKH KOMPLEKSOV (VOPROSY METROLOGII) [Measurements and Monitoring of the Parameters of Engineering Complexes (Problems of Metrology)], Moscow, Voyenizdat, 1978 (II kv.), 5 illustrations, 10,000 copies, 19 kopeks 11204.

The equipment of all of the various types of armed forces with radio-electronic equipment has required the organization of careful monitoring of its condition and operation. These functions have been turned over to the metrologic service.

In this book a study is made of the basic theoretical principles of metrology, measurement methods, types of systematic and random errors. Practical advice is given with respect to selecting the methods and means of measurement, the preparation and performance of measurements. An estimate is presented of the accuracy of the measurement results, and the effect of this estimate on the accuracy of monitoring the parameters of the technical complexes is indicated.

The book is intended for engineering and technical personnel servicing armament and materiel and for inspectors of the military testing facilities.

Karnozov, L. I.; Kiselev, A. M. AZBUKA IZOBERETATEL'STVA [ABC's of Invention], Moscow, Voyenizdat, 1978 (III kv.), 10 illustrations, 20,000 copies, 47 kopeks, 11204.

The role and the significance of technical creativity in the army and navy in all phases of development of the armed forces are indicated in this book. The characteristics of the new effective law with respect to invention and the structure of the organization of invention and efficiency expert work in the armed forces are presented. Practical advice and recommendations are given for inventors and efficiency experts, the directors and organizers of their work.

The book is designed for the general reader in the armed forces and for youth.

Klementenko, A. Ya.; Panov, B. A.; Sveshnikov, V. F. KONTAKTNYYE POMEKHI RADIOPRIYEMU [Contact Interference of Radio Reception], Moscow, Voyenizdat, 1978 (III kv.), 6 illustrations, 20,000 copies, 22 kopeks, 30402.

In this book the principles of the theory and practice of contact interference of a radio reception are presented. The physical essence of contact interference is discussed, and the spectral composition and amplitude characteristics of it are analyzed. Recommendations are made with respect to the control of contact interference and the methods of insuring electromagnetic compatibility of the radio electronic means of mobile targets.

The book is designed for radio specialists dealing with the development, operation and maintenance of mobile communications units.

Konofeyev, N. T. TRANSPORTIROVKA RAKET [Transportation of Rockets], Moscow, Voyenizdat, 1978 (II kv.), 7 illustrations, 10,000 copies, 27 kopeks, 31902.

The transportation of rockets is one of the inseparable parts of the operation of rocket weapons.

The book familiarizes the reader with the transportation of rockets by highway, railroad, air and water transportation. Primary attention is given to road means of transporting the rockets.

The book is designed for a broad class of military and civilian readers interested in rocket engineering.

Latukhin, A. N. BOYEVYYE UPRAVLYAYEMYYE RAKETY [Combat Guided Missiles], 2d edition, revised and supplemented, Moscow, Voyenizdat, 1978 (I kv.), 7 sheets with illustrations, 21 kopeks, 15,000 copies, 27 kopeks, 31902.

Under modern conditions the role of the combat guided missiles has increased sharply, and the class of problems solved by them has expanded significantly. All of this is explained by the stormy qualitative development of rocket weaponry and improvement of the degree of its combat effectiveness.

The book familiarizes the reader with the structure and the operation of second and third generation guided missiles and also the basic areas of their improvement. It was written by the materials of the open Soviet and foreign press, and the problems of the combat application of the rockets and the prospects for their development are discussed from the point of view of foreign specialists.

It is designed for a broad class of military and civilian readers interested in rocket weaponry.

Panov, V. V. NADEZHNOST' RAKET [Reliability of Rockets], Moscow, Voyenizdat, 1978 (I kv.), 5 sheets with illustrations, 10,000 copies, 19 kopeks, 31902.

The unforeseen failure of a modern technical system, as a rule, inflicts great losses, and in individual cases is inadmissible. Hence the increased attention which is given in recent times to the problem of reliability, and especially reliability of rockets.

In this book a study is made of the problems of estimating and analyzing the reliability of the rockets during operation and combat application, factors determining the level of reliability and the means of insuring it are described. It was written by the materials of the open Soviet and foreign press.

It is designed for officers, cadets at the military schools and civilian youth interested in the problems of rocket weaponry.

Rossov, Yu. B.; Fedorov, N. A. REMONT SREDSTV SVYAZI [Repair of Communications Means], Moscow, Voyenizdat, 1978 (III kv.), 10 sheets with illustrations, 30,000 copies, 52 kopeks, 30402.

The maintenance of communications means in working order and constant readiness for application, especially in the case of complex automation of troop control processes, is acquiring decisive significance under the modern conditions of combat and training activity of the troops.

This book contains a discussion of the basic information on material science and the tools and measuring instruments used for repairs. The procedure for finding and eliminating failures (damage), the procedures and methods of repair, adjustment operations and monitor testing of the communications means after repair are presented.

The book is designed for radio, radio relay, telephone and telegraph military masters, civilian specialists and ham radio operators.

The books of the Voyennoye izdatel'stva [Military Publishing House] can be acquired at the Voyennaya kniga [Military Book] stores and stands and also C.O.D. at the home address by sending orders to the nearest "Voyennaya kniga - pochtoy" [Military Book Store -- Mail Order Division].

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