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PROPULSION SYSTEMS FOR SPACE

Propulsion has always been one of man's basic interests -- from earliest history he has wanted to get from one place to another, and usually to get back. All propulsion up to the present, however, has been in a way tied to the earth, whether a man was sailing the seas, walking or piloting a supersonic plane.

The job of getting away from the earth is a much more complicated one, especially if a return is also wanted. In the first place it means reliance entirely on jet and rocket propulsion -- there is nothing to push against. Modern interest in these propulsion systems has revived only in the last 20 years or so, although crude rocket systems have been known for 2,000 years.

This modern revival of rocket propulsion has been accelerating steadily, and now includes not only the conventional (chemical) rocket propulsion systems, but applications involving nuclear power, and electrically charged particles. The evolution of these propulsion systems and their application to the problems of space travel is one of the most exciting features of contemporary history.

The fact that we can recognize many of the problems of space flight, and can plan development programs well into the future with a great degree of assurance is due to the support which the military has furnished the rocket industry during the past ten years.

Demonstrated military needs for jet and rocket planes and for ballistic missiles, with their extreme requirements for new propulsion systems with accompanying guidance and communication capabilities led to the evolution of a great body of "know how" and of production capability in American industry. Without the results and knowledge generated by this military support, the task of achieving space travel would be almost impossible.

Aerojet-General Corporation is engaged in an across-the-board program on all types of propulsion systems, and I want to tell you what we think the problems are, and what should be done to overcome them.

First, I want to point out, as a basis for later remarks, that there are two fairly distinct aspects to space travel. The earth has a gravitational field and an atmosphere. The first step in getting into space is to get outside the atmosphere, and to neutralize gravitation. At 100 miles we are practically out of the atmosphere, and a horizontal speed of about 5 miles a second will counterbalance the earth's gravity. Once a vehicle has reached this state, which amounts to being in orbit, it is possible to go beyond, and consider actual space travel.

The importance of distinction between reaching orbital conditions and going beyond them lies in the great difference in propulsion requirements. To overcome earth's gravity, a large specific thrust (thrust-weight ratio) is required. At present, the only means we have for doing this is by chemical (solid or liquid) rockets. [There is some possibility that nuclear rockets can be developed for this purpose, if the problems of heat-transfer, shielding and extremely high temperatures can be solved.] This means that improvement in solid and liquid chemical rockets will be required over many years, to increase performance and reliability and to decrease costs.

Once a vehicle has reached orbital conditions, propulsion requirements to send it beyond, to the moon, to other planets, or to travel through space, are much less stringent, since the requirement for high specific thrust is removed. It is a characteristic of the advanced electrical propulsion systems that while their performance (specific impulse) is high, their specific thrusts are low, because of the weight of the powerplant required. While chemical and possibly nuclear rockets can have a specific thrust well above 1, electrical propulsion systems have specific thrusts ranging from 1/100 to 1/1,000,000.

In listing specific problems for the next ten years or so, I will begin with the more conventional propulsion systems and then go on to the exotic ones. There is actually little essential difference between solid and liquid rocket systems in that they both employ the same type of combustible propellants and function in the same way. The propellants burn, are converted to gas, and are accelerated through a nozzle to produce thrust. It is obvious they will both be used for the foreseeable future to escape from the earth, and also for any <u>rapid</u> changes in direction or velocity in space.

Possibly the major problem with both is development of larger sizes. We now have engines in the 200,000# thrust class. The Russians apparently have somewhat larger ones. We are developing engines in the million pound class, and we can at least think of engines with a thrust of 5-10 million pounds as being required to put a space station, or components for a space station, in orbit. There is obviously a practical upper limit to the size of propulsion systems, - we need to find out what it is.

As you doubtless know, all of our satellites and other space vehicles comprise a number of stages of successively smaller size. Again in this case, the largest and most expensive is the first or boost stage to get the vehicle started. In terms of size, weight, cost, and criticality, it exceeds all the other stages put together. We have made a number of studies at Aerojet, which indicate that our most pressing problem is that of reducing the weight, complexity and cost of large first-stage or booster engines.

The problems for solid and for liquids are sufficiently distinct with respect to the above that they are considered separately. We now have solid rocket engines with a thrust of 200,000 pounds, using propellants with a specific impulse of 250 sec. Increase in size to the order of a million pounds involves structural problems in the propellant itself, as well as problems with the pressure case. Improvement in performance which will come will involve the combined efforts of the chemical industry to provide new fuels and oxidizers, of the propellant manufacturers to develop means of preparing usable propellants, and of the engine fabricators to develop means of resisting high temperatures, corrosion, and operating loads.

In the liquid field, we have at present propellants of as high performance as it is likely we shall ever obtain. These have been tested on a small scale, but require further development to render them operational on a large scale. A more important problem is that of improving reliability and decreasing cost. In talking of a vehicle of 1,000,000 pounds take-off weight we must consider that this will represent about 500,000 pounds of propellant in the first stage and about 50,000 pounds of hardware (engine, pumps, valves, piping, structure and tanks). Liquid propellants are cheaper than solid propellants, but hardware, even after development is much more expensive, and with present designs, it does not appear hardware costs can be greatly reduced. There are three methods of cutting these costs, all of which are being actively investigated at Aerojet.

The first is to decrease the hardware weight. If we could cut the hardware weight by a factor of 2 in the example above, we could save possibly a million dollars a shot. The second is to adopt some simpler and less sophisticated designs for first stage engines which could make it possible to go to "regular production" methods of manufacture, and cut hardware costs by a factor of three, without any great increase in weight. This, again, would save about the same money per shot. The third method is to develop a recoverable first stage which could be used a number of times over. While such a recoverable stage might cost half again as much per pound, if it could be used for a half-dozen or more times, it would save a major part of the cost.

For the second and following stages, the problems are somewhat different. In the first place, since the following stages make up a part of the pay-load of the first stage, their performance must be as high as possible to decrease their weight. This involves use of the best propellants we know -- liquid hydrogen and liquid oxygen or liquid fluorine. It seems highly improbable that any better propellants will be available for many years. (The development of free-radical propellants, on which Aerojet is working, is a long-range program, and indeed may never produce useable propellants.) There is an immediate need for a comprehensive program to develop operational capability, with a high degree of reliability, in propulsion systems using liquid hydrogen and liquid oxygen or liquid fluorine. The thrust range required for these systems is from 300,000 pounds down to about one-tenth as much.

For rapid propulsion in space, after orbital conditions have been reached, the requirements are similar for high performance, but in addition, the propellants used must be capable of being stored in space for periods of from several days to a year or more. Liquid hydrogen must be kept at a temperature about 400°F. below zero; liquid oxygen and liquid fluorine require temperatures almost as low. We do not know what is required to maintain these temperatures in space. If it proves impossible or too difficult, we must back up and use the best propellants we can maintain in space. The problems of achieving operational capability and high reliability are the same.

When we leave the chemical propulsion systems for nuclear and electrical systems we are going largely into unmapped territory. Some of the principal problems can now be recognized, but any program for utilization must necessarily be long-range; specific problems remain to be recognized.

The principal area of interest in nuclear rockets at present is in simply using a conventional nuclear reactor, instead of a chemical reaction, to heat the rocket gases. If hydrogen is used as the working fluid it is possible to approximately double the performance of chemical rockets. Other substances, such as ammonia, give little or no improvement over chemical systems. This propulsion system can provide a high thrust-weight ratio, but involves serious problems in heat transfer, high temperature materials, radiation hazard if used for take-off, and shielding, especially for manned flight. An advantage is the possibility of achieving single stage operation, and the possibility of using the reactor for other power needs, such as communication and maintenance of environment in manned vehicles.

An indication of the problems involved is shown by the fact that to get worthwhile propulsion, it is necessary to operate the nuclear reactor at temperatures of 4500°F. or higher. Also, generation of a million pounds of thrust requires a heat transfer of some 25 million BTU per second, or the equivalent of a large central station powerplant occupying a city block.

Beyond the nuclear heating propulsion system are the various electrical systems, which are also based on nuclear energy. In addition to a reactor, they require equipment to generate electrical power, and radiators to dispose of the heat not converted to power. These advanced propulsion systems are urgently needed for long-range space missions such as manned probes to Mars or Venus and beyond, since they offer the only presently known means of accomplishing such missions without the expenditure of truly astronomical amounts of propellants.

In addition to the requirements for the light-weight reactors and efficient electrical generators common to all of this new generation of propulsion systems, there are specific problems in each system. These are extremely varied, since these advanced concepts include the use of ions, charged colloid-size particles, plasma jets, and magneto-hydrodynamic devices.

As an example, the use of an ion system to generate only one pound of thrust requires producing an ion beam of 2 amperes at some 20,000 volts. The ion beams which have been studied up to the present are a few milliamperes at most, so a scale-up on the order of a thousand or more is needed.

The scientific principles associated with these electrical propulsion systems have been established in the laboratory. Efforts to date in this field have been supported primarily by Government research organizations, consequently the funding has been relatively small. We believe that the state-of-the-art is such that reduction to practice through a technical development program to demonstrate the feasibility of an integrated electrical propulsion system should be initiated immediately. We at Aerojet think that a program to develop a flyable electrical propulsion system within the next 5 years will have reasonable opportunity for success. It is now time for much larger effort to develop the electrical propulsion systems for space application.

You may ask what all these complex and admittedly costly developments will do for this country. A simple answer would be to say they will give us capability in space. An answer with more meaning would give reasons for wanting capability in space.

There are three areas which may be concerned and I can give you a few thoughts on each, in what is probably the inverse order of their importance. First, there is the area of military application. Frankly, we do not know what the military applications of space are, especially as we proceed farther and farther away from Earth. Equally importantly, we cannot say there are no military applications until we find out, and our national survival in the face of Communist policy requires that we do find out.

The second area is that of what can be termed propaganda and prestige. The Russians are ahead of us in several fields of solid scientific achievement. We do not object to being left cold in some ways, such as establishing slavelabor camps, but we cannot afford to have world opinion regard the Communist system as being more capable in worthwhile activities.

The third and undoubtedly most important area is that of the extension of human knowledge and activity. For the first time the possibility is arising for man to take a look at himself, his planet, and the universe from points away from the earth's surface. As Dr. Teller recently stated, the only sure advantage from getting into space is an increase of knowledge. But almost as surely, an increase in knowledge will lead to more tangible advantages in the future.

The IGY work of 1958 seems to me to correspond very closely to Columbus' discovery of the new world in 1492. At that time there followed a period of exploration that had a profound effect on almost every aspect of life. I think that in the next decade the preliminary explorations we will make in space will effect the life of everybody on the earth. I think it will serve to improve weather forecasting, to provide storm warnings and might increase our knowledge of weather and climate phenomena and can certainly be used as relays for communications purposes.

I would like to leave you gentlemen with a story which I am sure will be of interest to you as legislators. Something over one hundred years ago, a member of Parliament visited Sir Michael Faraday in his laboratory, where he was conducting some of the first experiments in a new field, electricity. The member of Parliament was interested, but asked, "What use is it?", and Faraday replied, "My dear sir, some day you may be able to tax it!" I am sure if you gentlemen will look at the hundreds of millions of dollars in taxes paid in this country alone by the electric power and equipment industries, you will agree that the pursuit of knowledge can be extremely rewarding.

REQUIREMENTS FOR PROPULSION SYSTEMS DEVELOPMENT

I. Solid Engines

A. 1st Stage or boost

1. Investigate problems of size increase to 500,000 - 1,000,000 pounds thrust, and 500,000,000 pound-seconds total impulse.

2. Improve flexibility of operation.

3. Cut cost of finished propellant in place in engine, e.g., continuous mixing, increased use of chemical industry methods.

4. Improve performance.

B. Following stages or space

1. Improve performance.

2. Improve flexibility.

3. Demonstrate storability in space.

II. Liquid Engines

A. 1st Stage or boost

1. Improve reliability - use present propellants.

2. Decrease hardware cost and complexity.

a. Increase propellant fraction.

b. Decrease storage and pumping problems.

c. Investigate recoverable units.

d. Investigate inexpensive hardware, i.e., mild steel, plastics.

B. Following stages or space

1. Increase performance - very best propellants.

2. Improve reliability.

3. For space - demonstrate storage under space conditions: are cryogenics useable?

III. Nuclear Engines - (Restricted to nuclear heating of working fluid.)

A. 1st stage or boost.

1. Investigate practical feasibility vs chemical - radiation hazard, minimum size, practicality of required heat transfer and high-temperature reactors.

B. Following stages or space.

1. Demonstrate storability of liquid H_2 in space.

2. Investigate integration of propulsion and auxiliary power systems.

IV. Electrical Propulsion Systems. (Confined to space.)

A. Develop light-weight reactors.

B. Develop efficient coverters to electrical power.

C. Ion propulsion systems.

1. Develop efficient, long-life ion sources.

2. Investigate problems of obtaining directed ion beam, electrical neutrality, etc.

3. Investigate problem of reducing specific impulses to useable values.

D. Charged particle propulsion systems.

   1. Continue development of liquid droplet systems.

   2. Develop methods to employ solid particles.

E. Other electrical systems.

   1. Plasma, magneto-hydrodynamics, etc.

   Investigate.