G-US 0270

Report SP-120
May 1, 1959
Copy No. ______

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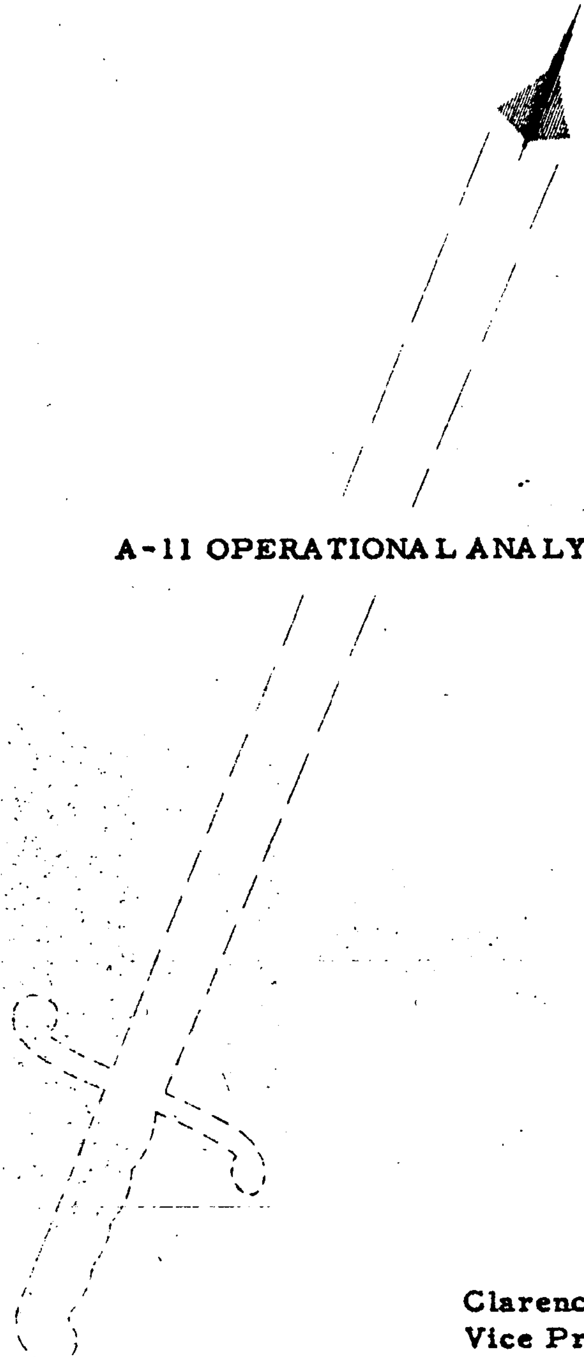
CALIFORNIA DIVISION



A-11 OPERATIONAL ANALYSIS

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INTRODUCTION

This report presents the results of a study made on the effect of air-to-air refueling on the mission capability of the proposed Lockheed A-11 aircraft. The characteristics of this airplane are described in Lockheed Report SP-114. Briefly, it is a single-place, twin J58 turbojet powered supersonic reconnaissance type, which operates at a cruising speed of Mach 3.2 in the altitude range of 85,000 to [redacted] feet. Basic combat range of the type is expected to be over [redacted] nautical miles.

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Previous studies on the effect of various types of refueling missions were always aimed at increasing the penetration capability. They always ended up with the conclusion that little could be gained in operating radius under the ground rules set up (refueling over friendly or neutral territory).

DISCUSSION

In the current study, a new approach is taken. No effort is made to increase the penetration capability, but instead, the problems of basing on foreign soil and use of multiple bases are solved. This is done by the following means:

1. Standard KC-135 tankers, probably based in Fairbanks, Alaska, for most operations, will be used.
2. The basic A-11's equipped for boom air-to-air refueling will be based at Edwards Air Force Base only.
3. Tankers and the A-11's will be equipped with stellar-corrected inertial guidance systems capable of locating each aircraft within a C.E.P. of one mile.
4. JP-150 petroleum-based fuel will be used.
5. The total mission time will not be greater than that of the U-2 research aircraft.
6. The flights to and from the refueling points will be made at the altitude for best range. Penetrations will be flown at maximum altitude.
7. No refueling operation is carried on closer than 100 miles of the Russian border or coast line.

SUMMARY

The study reveals the following conclusions:

1. It is entirely practical to use a single operating base for the A-11 type aircraft for the mission involved. This can readily be Edwards Air Force Base or [redacted] STAT

2. The A-11 aircraft is very compatible with the existing KC-135 refueler at altitudes between 25,000 and 40,000 feet and cruise Mach numbers of .70 to .82.

3. Stellar-inertial navigation greatly simplifies rendezvous problems, guaranteeing the ability to mate-up under all conditions.

4. Practically all of Russia can be surveyed using two refueling operations with a normal mission time of about eight (8) hours. With three refuelings, even greater flexibility can be obtained, allowing very complicated routing.

5. Very obvious security advantages are provided by using the proposed system.

6. Operating cost is greatly reduced compared to any other aircraft system.

SUMMARY (cont.)

7. Political problems of basing are eliminated.

8. Flexibility in tactics, avoidance of enemy radar alerts from ground information sources and more rapid data processing are provided by this system.

9. Personnel and morale problems are greatly improved.

10. Much better maintenance, data processing and operational facilities can be provided.

11. The element of surprise is greatly enhanced.

12. The speed of the A-11 is such that tankers for both refuelings are cruising toward their rendezvous before the A-11 takes off. They land after the A-11 has returned to the ground at Edwards Air Force Base.

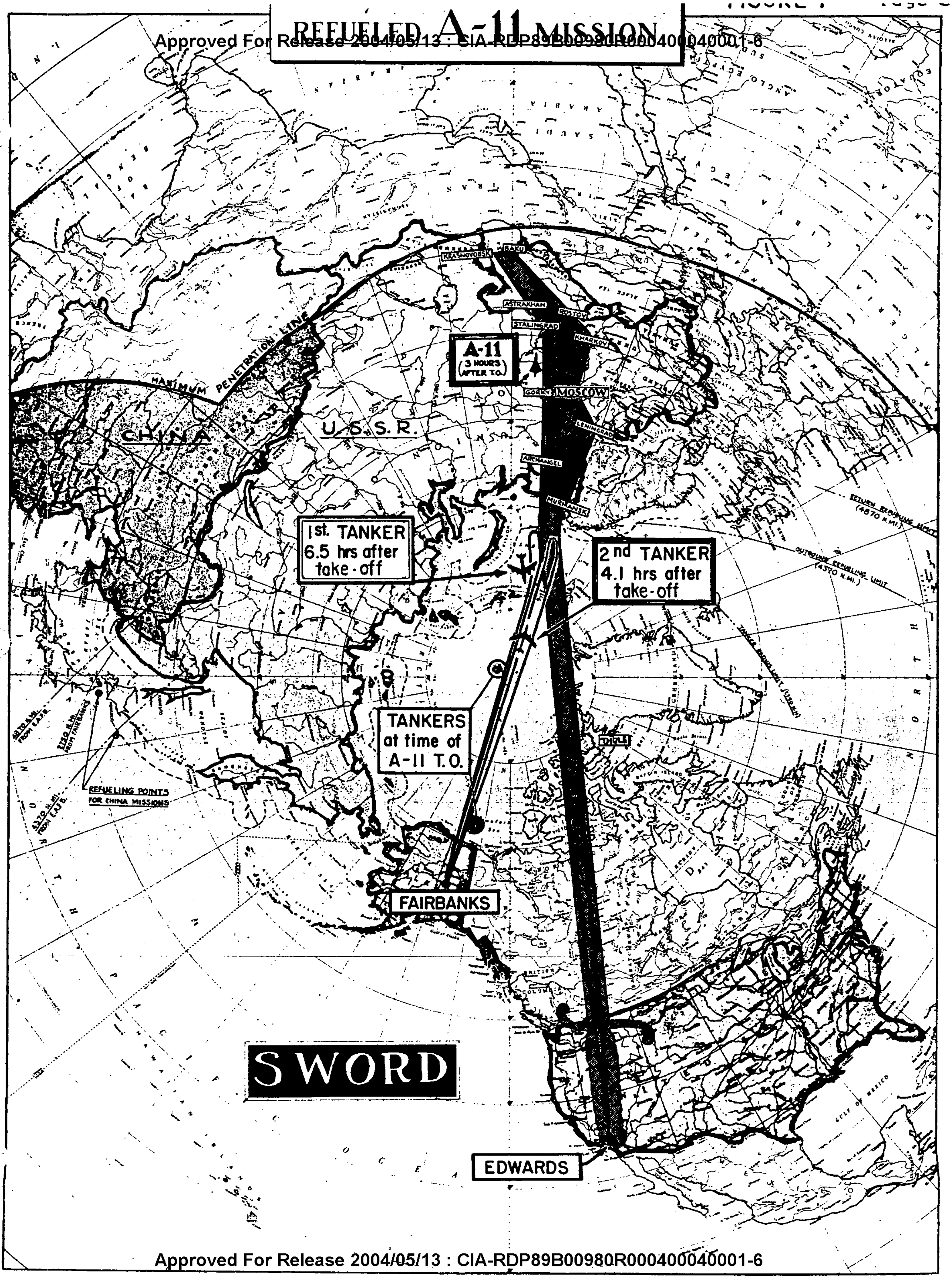
The body of the report presents the basic data from which the above has been derived.

MISSION CAPABILITY

The mission of the A-11 airplane requires that the maximum possible land area of Russia and China be covered at the highest altitude and speed possible. Range and altitude requirements are conflicting to a moderate degree; use of maximum-range altitude would increase penetration radius by approximately 285 nautical miles for an altitude loss of 7,650 feet (9%). Since the higher altitude is considered to be of greater importance than range, the penetration limit shown in Fig. 1 was determined by the maximum-altitude radius. Actually, the only significant coverage gained by use of lower altitude is the small portion of Russian territory south of the Aral Sea now outside the penetration limit.

Refueling locations are limited by an arbitrary 100 nautical mile distance from the Russian coast and by the range capabilities of the aircraft from their respective bases. The KC-135's ability to supply a full fuel load to the A-11 at distances up to 2,750 nautical miles from base puts it within reach of all strategically important refueling points when operating out of Fairbanks. The A-11 is capable of reaching these refueling points with adequate reserves from Edwards Air Force Base in 2.6 hours and the penetration leg of the mission is completed in 2.4 hours. When one-half hour is allowed for each refueling contact (15 minutes search and 15 minutes

REFUELED A-11 MISSION



MISSION CAPABILITY (cont.)

for fuel transfer), the total duration for a maximum penetration mission becomes 8.54 hours.

Fig. 2 is a time-distance plot of this mission. The speed difference is such that the A-11 takes off only after the tankers are on their way and lands back at Edwards before the first tanker has returned to Fairbanks.

Many advantages are gained from confining A-11 operations to the Air Force Test Center at Edwards. It is believed that the number of airplanes in operation at any one time will be small -- comparable to the number required for phase testing of new combat types. Close contractor liaison can be conveniently maintained without attracting any undue attention. Tanker operations from Fairbanks would continue to appear routine and no A-11 aircraft would be seen in the vicinity except in case of emergency. The comprehensive facilities at Edwards and its proximity to the contractor's plants should be a definite aid in obtaining early operational status. Since the results of the mission are on film which must be processed and analyzed, the mission should terminate where this work can be done, or from where the film can be quickly transported as required.

Operating efficiency and safety should be at a maximum when operating

MISSION CAPABILITY (cont.)

from a versatile base with near-ideal weather conditions. There is hardly any doubt that pilots would prefer a single round trip from home to a flight with stopovers at a remote base where weather is a serious problem. The pilots' pre-flight preparations for high altitude missions is another factor in favor of a single long flight instead of two or three shorter segments. Reliability is certainly not enhanced by breaking up a mission into several flights.

Although the dual-refueled mission based at Edwards is believed to be the optimum, combining maximum security and efficiency, it is realized that many diverse factors influence the choice of operation methods. Not the least of these is the desire for flexibility to avoid establishing a predictable operating pattern which would allow counter-measures to be set up in advance by the Russians.

For this reason, the three-refueling mission capability is included in Fig. 3 and the non-refueling and single-refueling missions are shown in Fig. 4. From the data in this report, and by using these missions as a guide, any number of optional missions utilizing currently available bases can be analyzed.

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MISSION CAPABILITY (cont.)

[redacted]

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Although this situation is by no means typical, since most targets permit much greater range margins, the extremely serious consequences of a missed refueling strongly suggest the dispatch of two tankers to each refueling rendezvous. The fuel expended by the extra tanker is surely

MISSION CAPABILITY (cont.)

a modest price to pay for the added protection provided for the A-11 pilot and the reduced possibilities of mission aborts from tanker operational problems.

The reliability of all aspects of the refueling operations, including precision in meeting rendezvous schedules, is greatly enhanced by use of dual tankers. Whether they navigate independently, or average their navigation errors while cruising in company, the probable rendezvous error which must be closed by search maneuvers will be reduced. The added target for the A-11 pilot to detect visually will also simplify his problem and enable him to accomplish the hookup in reduced time.

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REFUELING

Complete refueling of the A-11 can be made by a KC-135 tanker at points up to 2,750 nautical miles from the tanker base. The operation requires between 10 and 15 minutes after mating. Fig. 5 shows the fuel transfer capability of the KC-135A as a function of radius and is based on data obtained from T.O.-135(K)A-1.

A typical refueling contact would begin with the A-11 starting a descent and deceleration from a cruise altitude of 90,000 feet [redacted] and a cruise speed of Mach 3.2. This descent would begin about 100 nautical miles from the pre-designated contact point. During the descent, radio, radar, and visual contact would be established, leading to the mating operation at about 35,000 feet and a subsonic Mach number of about 0.78.

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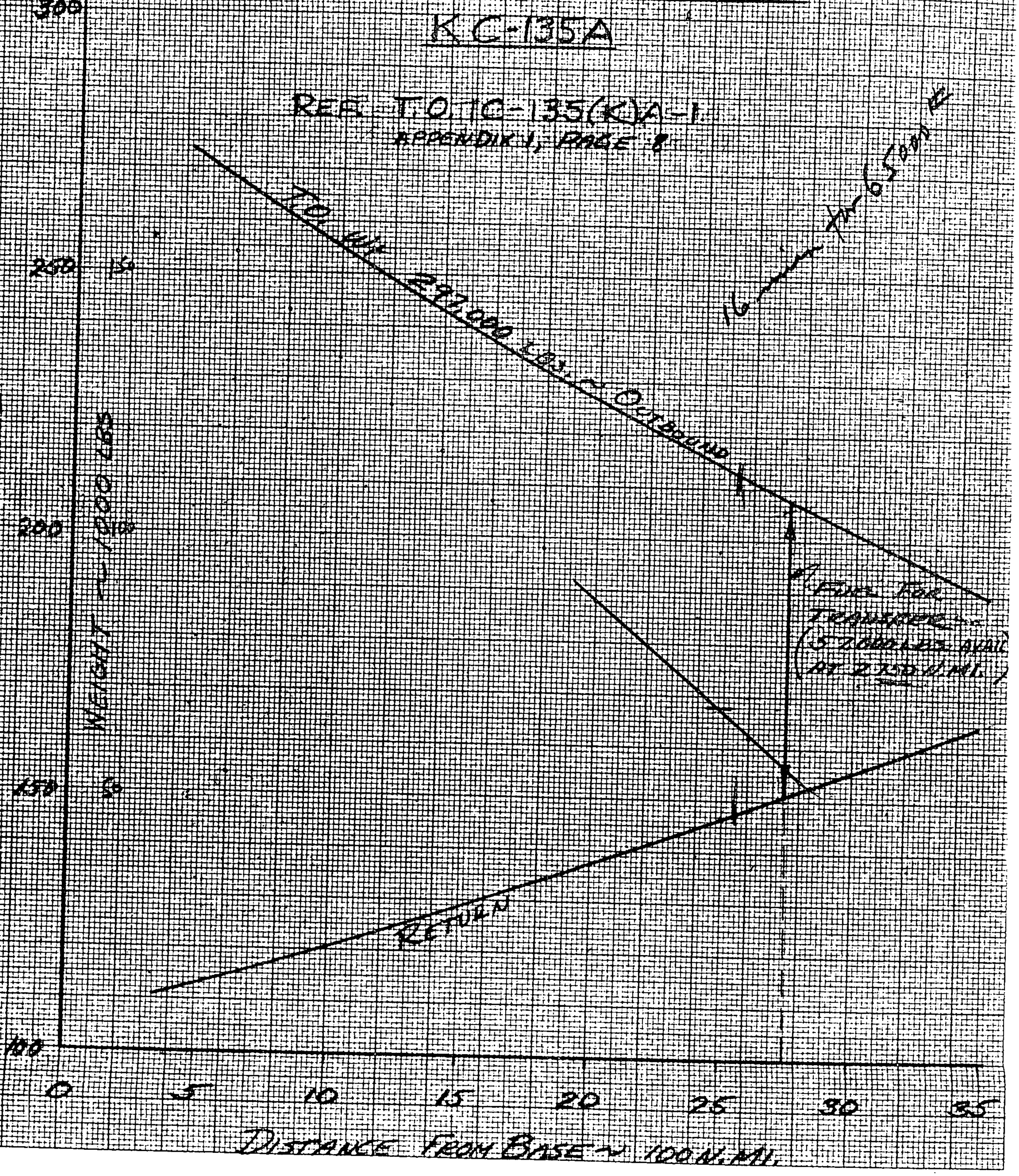
The compatability of the A-11 and the KC-135 is such that the refueling operation can be carried out within an altitude-speed band of between 25,000 to 40,000 feet and Mach 0.70 to 0.82. Mach 0.78 and 35,000 feet are chosen as typical. Fig. 6 shows the variation in angle of attack of both the A-11 and KC-135 as fuel is transferred. The total angle change between the airplanes is only about 4.5 degrees, well within the limits of the refueling equipment. The thrust required for the A-11 is shown

FIGURE 5

FUEL TRANSFER CAPABILITIES
KC-135A

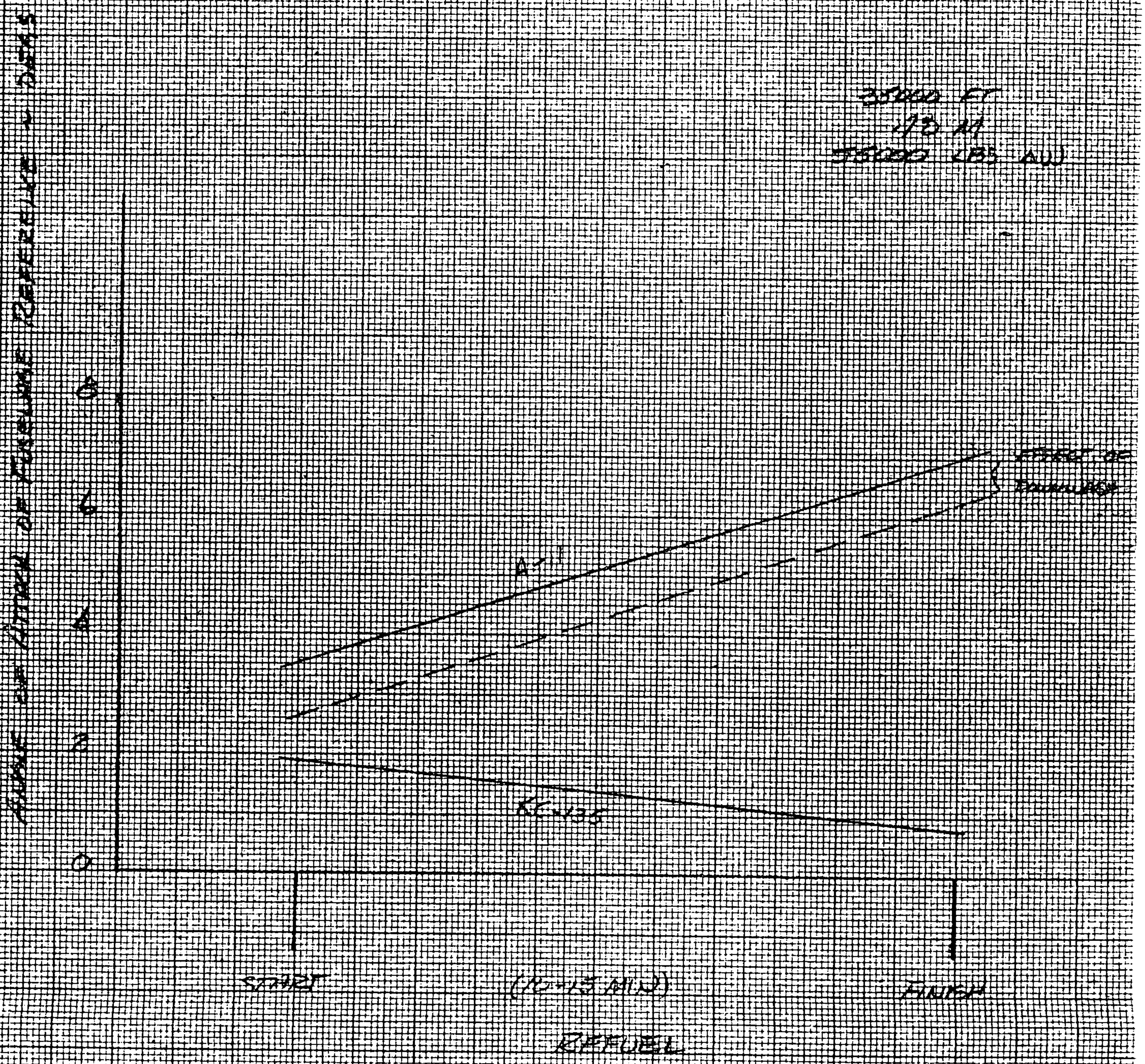
REF. T.O. 1C-135(K)A-1
APPENDIX 1, PAGE 8



A-11

FIGURE 6

ESTIMATED
ANGLES OF ATTACK
DURING
REFUELING



REFUELING (cont.)

on Fig. 7 , and falls within the operational range of the engine.

The relatively low wing loading of the A-11 that is dictated by the high altitude cruise condition results in the A-11 flying at lift coefficients of between .12 and .29 during the refueling operation. Consequently, the A-11 is flying well below the stall condition and close to L/D maximum.

In the analysis of the mission, fuel required for one-half hour at 35,000 feet altitude is assumed to be burned during the process of locating and mating with the tanker. The tanker is required to make good the fuel burned by the A-11 during the refueling and leaves the A-11 with full tanks at time of break-off.

During the time the A-11 is flying the same course as the tanker prior to hook-up and while fuel is being transferred, it will cover from 75 to 110 nautical miles before starting its climb back to cruising altitude and course. Due to geographical limitations and the uncertainties involved in predicting the exact point where hook-up will occur, no range credit is taken for this distance on the approach leg. It is assumed that refueling will be made along the 100 nautical mile territorial limit line parallel to the Russian coast and the A-11 will turn to its penetration

A-11

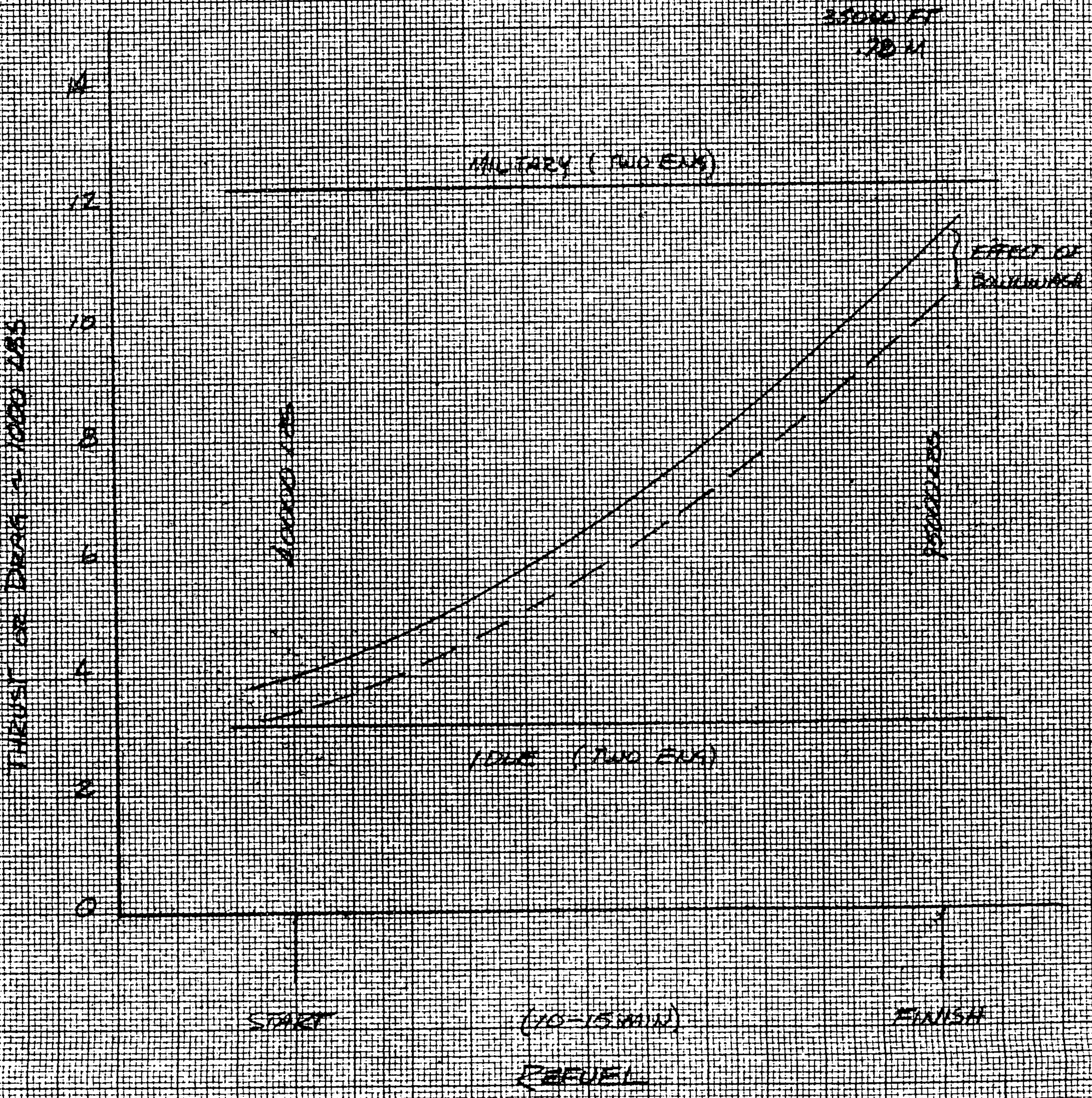
FIGURE 7

ESTIMATED

THRUST & DRAG

DURING

REFUELING



REFUELING (cont.)

course after breaking off contact. In actual practice, this distance traveled during refueling can often be utilized for increasing the approach leg of the mission.

[redacted]

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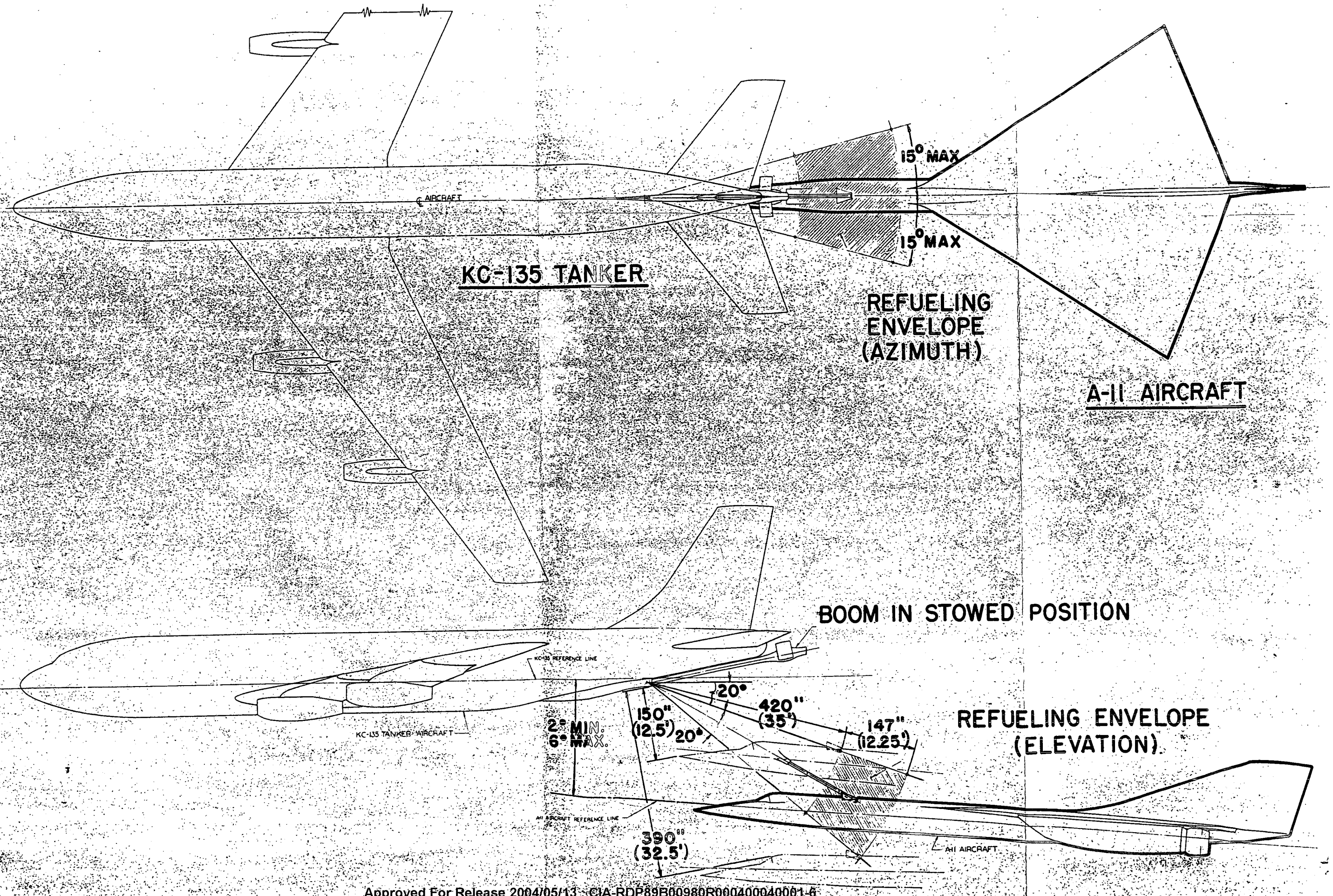
Fig. 8 shows the relative positions of the A-11 and the KC-135 tanker during fuel transfer.



AIR REFUELING ENVELOPE

A-11 DESCRIPTION

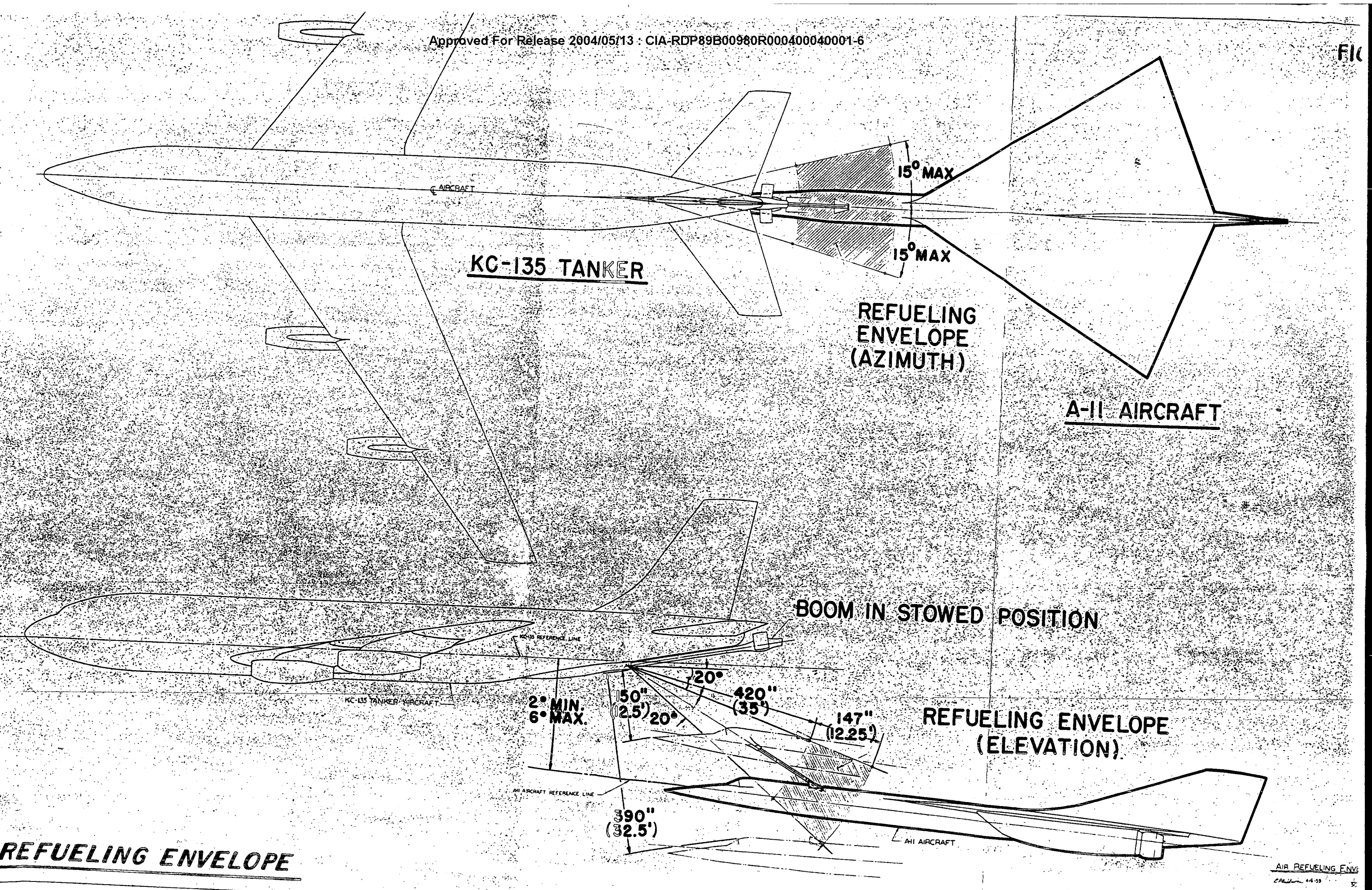
For the missions considered in this analysis, the A-11 airplane is identical to that described in the basic SP-114 report, except for the following modifications:

1. In-flight refueling provisions added.
2. HEF fuel provisions deleted.
3. Improved navigation system added.
4. Air conditioning and cooling systems modified to account for the longer flight duration.

The refueling boom slipway is installed well aft of the cockpit, as shown in Fig. 9. This position minimizes the danger of the boom damaging the canopy and keeps the boom free from the pilot's view of the tanker's position signal lights. The boom receptacle is located in the forward fuselage fuel tank bay, which simplifies the fuel transfer system.

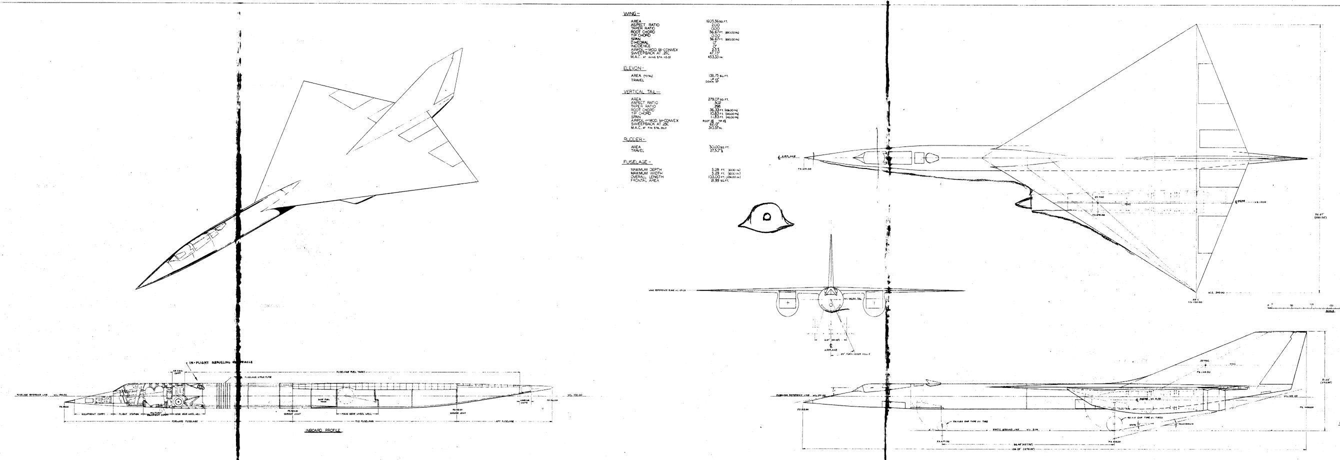
For the reasons discussed in the Fuel Comparison section, the provisions for use of HEF fuel have been deleted. The weight saved more than compensates for the weight added by the in-flight refueling equipment.

To provide the greatest possible speed and reliability in making refueling contacts, a stellar-inertial navigation system replaces the gyro-inertial



AIR REFUELING ENVELOPE

FIGURE 9



WING -

AREA	1605.56 SQ. FT.
ASPECT RATIO	2.00
TAPER RATIO	0.00
ROOT CHORD	56.67 FT. (680.00 IN.)
TIP CHORD	0.00
SPAN	56.67 FT. (680.00 IN.)
DIHEDRAL	0°
INCIDENCE	0°
AIRFOIL — MOD. BI-CONVEX	2.5%
SWEEPBACK AT .25C	47.73°
M.A.C. AT WING STA. 113.33	453.33 IN.

ELEVON -

AREA (TOTAL)	138.75 SQ. FT.
TRAVEL	UP 23° DOWN 18°

VERTICAL TAIL -

AREA	279.07 SQ. FT.
ASPECT RATIO	.502
TAPER RATIO	.298
ROOT CHORD	36.33 FT. (436.00 IN.)
TIP CHORD	10.83 FT. (130.00 IN.)
SPAN	11.83 FT. (142.00 IN.)
AIRFOIL — MOD. BI-CONVEX	ROOT 3% TIP 2%
SWEEPBACK AT .25C	62.13°
M.A.C. AT FIN STA. 38.21	310.57 IN.

RUDDER -

AREA	30.00 SQ. FT.
TRAVEL	27.50° ±

FUSELAGE -

MAXIMUM DEPTH	5.29 FT. (63.50 IN.)
MAXIMUM WIDTH	5.29 FT. (63.50 IN.)
OVERALL LENGTH	103.00 FT. (1236.00 IN.)
FRONTAL AREA	21.99 SQ. FT.

GENERAL ARRANGEMENT — A11

3-12-59
3-16-59
1/50 SCALE

A-11 DESCRIPTION (cont.)

system previously used. This change is fully discussed in the Navigation section.

The quantities of expendable items which are not replenished by refueling (oil, oxygen, nitrogen and water) have been increased in accordance with the longer flight duration.

A-11 DESCRIPTION (cont.)

WEIGHT AND BALANCE

The weight changes to the basic A-11 are due to the removal of HEF provisions and the addition of a refueling system, with the associated increase in the service systems due to the longer mission time. The air conditioning system in the basic airplane weighs 750 pounds; this includes 250 pounds of water and liquid nitrogen used during the mission, 100 pounds of containers, and 400 pounds of insulation, water boiler, etc. For each refueling, an additional 250 pounds of coolant and 100 pounds of containers must be added to the above weight. This and the other weight changes in the airplane for the mission with two refuelings are summarized below.

A-11 Weight Empty	35,815
Remove HEF Provisions on Engine	-360
Remove HEF Fuel System	-200
Remove Air Conditioning - Total	-750
Add Refueling Probe-Retractable	120
Add Refueling System	230
Add Astro Correction to Nav. System	130
Add Air Conditioning - Fixed	700
Weight Empty	35,685

A-11 DESCRIPTION (cont.)

WEIGHT AND BALANCE (cont.)

Weight Empty	35,685
Non-Expendable Useful Load:	
Unusable Oil	20
Unusable Fuel	100
Pilot	285
Payload	500
Basic Weight	36,590
Oil	60
Oxygen	40
Air Conditioning Coolant (Expendable)	750
Zero Fuel Weight	37,440
Fuel	57,150
Take-Off Weight	94,590

The airplane balance during the refueling operation is held within the normal flight center of gravity limits by scheduling the fuel in the following manner:

1. Fill sump tank.
2. Fill forward wing tanks.

A-11 DESCRIPTION (cont.)

WEIGHT AND BALANCE (cont.)

3. Fill aft forebody tank.
4. Fill aft wing tanks.
5. Fill forward forebody and aftbody tanks.

A-11 DESCRIPTION (cont.)

PERFORMANCE

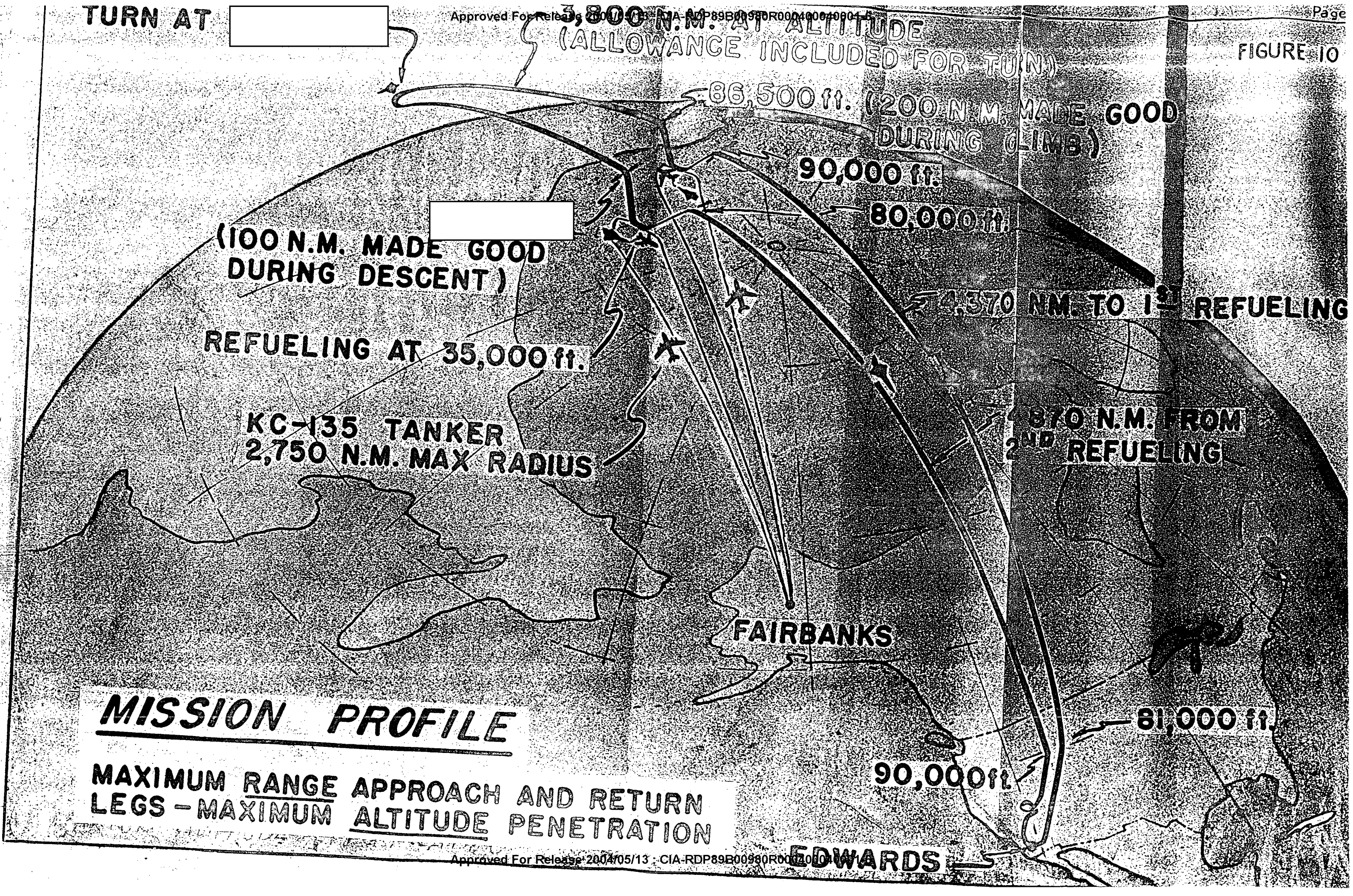
The performance of the A-11 airplane is illustrated in Fig. 10 for a twice refueled mission. This performance is based on the use of JP-150 fuel and the allowances and assumptions enumerated in the following paragraphs.

The take-off allowance is for start, warm-up, taxi, take-off, and acceleration of the airplane to climb speed. This amount of fuel is equivalent to one minute at full afterburner or to ten minutes idle plus one-half minute on full afterburner. One-half minute of full afterburner is sufficient to accelerate the airplane from zero to 400 knots at take-off gross weight.

Climb is made on full afterburner at 400 knots equivalent airspeed to 74,000 feet altitude. At 74,000 feet, Mach 3.2 is obtained, which is thereafter maintained constant. The climb is corrected continuously for the fuel consumed and for kinetic energy.

The cruise is made in all cases at Mach 3.2. On the approach and return legs over neutral territory, the cruise is made at part throttle for the best range performance. Penetration cruise is made at full throttle to

FIGURE 10



MISSION PROFILE

MAXIMUM RANGE APPROACH AND RETURN LEGS – MAXIMUM ALTITUDE PENETRATION

PERFORMANCE (cont.)

obtain the maximum possible altitudes -- 86,500 feet initial and [redacted] feet final. The penetration range can be increased at the sacrifice of altitude. For example, if the penetration is made at the maximum range conditions of the approach and return legs, the penetration range at altitude increases from [redacted] nautical miles, an increase of [redacted] nautical miles. The corresponding reduction in initial altitude is 6,500 feet, and 8,800 feet in final altitude.

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The penetration range has been corrected to account for the effects of geometry and load factor for a 180° turn at the midpoint. The net effect is a loss of 180 nautical miles of range.

The descent allowance for range is 100 nautical miles at cruise fuel consumption. Subsequent to descent, in every case there are 3,600 pounds of fuel on board, which is sufficient to fly one hour at 35,000 feet altitude. One-half of this is allowed to locate and establish refueling position with the tanker. The tanker makes good this fuel and the fuel burned during refueling, leaving the A-11 with full tanks.

A-11 DESCRIPTION (cont.)

PERFORMANCE (cont.)

Because of the differing geographic and mission circumstances, as discussed in the Refueling section, 100 nautical miles range credit for the distance travelled during refueling is applied to the return leg, but not to the approach leg of the mission.

Tables I and II summarize the A-11 performance for a maximum altitude penetration mission with maximum range approach and return legs.

A-11
PERFORMANCE SUMMARY

TABLE I

REFUELED MISSION

MAXIMUM RANGE APPROACH & RETURN
MAXIMUM ALTITUDE PENETRATION

Approach (Base to 1st refueling)

Distance	[redacted] n. mi.	STAT
Cruise Alt.	81,000 to 90,000 ft.	
Speed	Mach 3.2	
Time	2.60 hr.	
Search & Reserve at Refueling Point	1.0 hr.	

Penetration (1st refueling to 2nd refueling)

Total Distance	[redacted] n. mi.	STAT
Distance at Altitude	[redacted] n. mi.	
Cruise Alt.	86,500 to [redacted]	STAT
Speed	Mach 3.2	
Time	2.40 hr.	
Search & Reserve at Refueling Point	1.0 hr.	

Return (2nd refueling to base)

Distance	[redacted] n. mi.	STAT
Cruise Alt.	80,000 to 90,000 ft.	
Speed	Mach 3.2	
Time	3.00 hr.	
Loiter & Reserve at Base	1.0 hr.	

Total

Distance	[redacted] n. mi.	STAT
Time (Search, Loiter & Reserve not Included)	8.0 hr.	

Airport Performance

Take-off Ground Run	
Two Engines	2,900 ft.
One Engine	8,400 ft.
Landing Ground Run Without Chute	3,000 ft.

Lockheed AIRCRAFT CORPORATION

CALIFORNIA DIVISION

TABLE II

A-11

REFUELED MISSION

MAXIMUM RANGE APPROACH & RETURN

MAXIMUM ALTITUDE PENETRATION

JP-150

	Weight Lbs.	Fuel Used Lbs.	Dist. N. Mi.	
Approach				
T.O.G.W.*	94,590	1,930✓	[redacted]	STAT
Climb to 81,000 ft.	92,660	11,720✓		
Cruise at 81,000 to 90,000 ft. at M = 3.2	80,940	39,200		
Descend to 35,000 ft.	41,440	700		[redacted] STAT
Refuel at 35,000 ft.				
Search 1/2 hr.	40,740	1,800	0	57000 55350 1650
Refuel (with 1/2 hr. reserve - 1,800 lbs.)	38,940	(55,350)	0	
Penetration				
Climb 35,000 to 86,500 ft.	94,290	8,450	[redacted]	STAT
Cruise at 86,500 to [redacted] STAT at M = 3.2	85,840	44,320		
Descend to 35,000 ft.	41,230	700		[redacted] STAT
Refuel at 35,000 ft.				
Search 1/2 hr.	40,530	1,800	0	
Refuel (with 1/2 hr. reserve - 1,800 lbs.)	38,730	65,270 (55,350)	[redacted]	STAT

*Includes 850 lbs. of expendable weight items other than fuel (oil, oxygen, nitrogen and water) which are consumed in the course of the mission.

A-11

TABLE II (cont.)

REFUELED MISSION (cont.)

MAXIMUM RANGE APPROACH & RETURN
MAXIMUM ALTITUDE PENETRATION

	Weight Lbs.	Fuel Used Lbs.	Dist. N. Mi.
Return			
Climb 35,000 to 80,000 ft.	94,080	7,900	[redacted]
Cruise at 80,000 to 90,000 ft. at M = 3.2	86,180	44,950	[redacted]
Descend to 35,000 ft.	40,890	700	[redacted]
Reserves			
Loiter 1/2 hr. at 35,000 ft.	40,190	1,800	[redacted]
Land with 1/2 hr. reserve	38,390	1,800	[redacted]
ZFW	36,590		[redacted]

STAT

[redacted] STAT

A-11 DESCRIPTION (cont.)

SINGLE ENGINE CAPABILITY

In the event of an engine failure, there are alternate courses of action available; the A-11 can make good the planned mission range at subsonic speed at about 50,000 feet, or the airplane can maintain Mach 3.2 at about 70,000 feet with a reduction in range capability. Since the approach and return legs are entirely over neutral territory, the reduction in speed and altitude presents no problem. However, on the penetration leg, security requires the maintenance of the highest possible speed and altitude. Since there is a range loss involved, it is desirable to evaluate the conditions under which the A-11 can make a supersonic exit from unfriendly territory, or must accept the risks of lower speed and altitude.

Figure 10.1 shows graphically the distance obtainable on one engine at Mach 3.2 as a function of the distance already covered on two engines. At the beginning of the penetration, the A-11 can retrace its course supersonically on one engine and make an exit provided no more than [redacted] miles STAT of the mission have been covered. Refueling can then be accomplished and the airplane flown subsonically to its home base. Beyond [redacted] miles, STAT the A-11 can continue on course and schedule to the refueling rendezvous. STAT Between the [redacted] mile points, the planned course must be altered to suit the applicable geography in order to make a supersonic exit to a

STAT

A-11 DESCRIPTION (cont.)

SINGLE ENGINE CAPABILITY (cont.)

new tanker rendezvous or alternate friendly base. The irregular dotted curve shows the distance to the nearest exits from a typical penetration course. In the illustrated case there is an exit within the supersonic single engine range capability of the airplane. Further analysis of the geography involved indicates that there are no target areas which do not provide an alternate exit if the mission is properly planned.

It has bean shown, therefore, that the A-11 is not only safe and reliable, but also secure in the event of an engine failure over unfriendly territory.

NAVIGATION

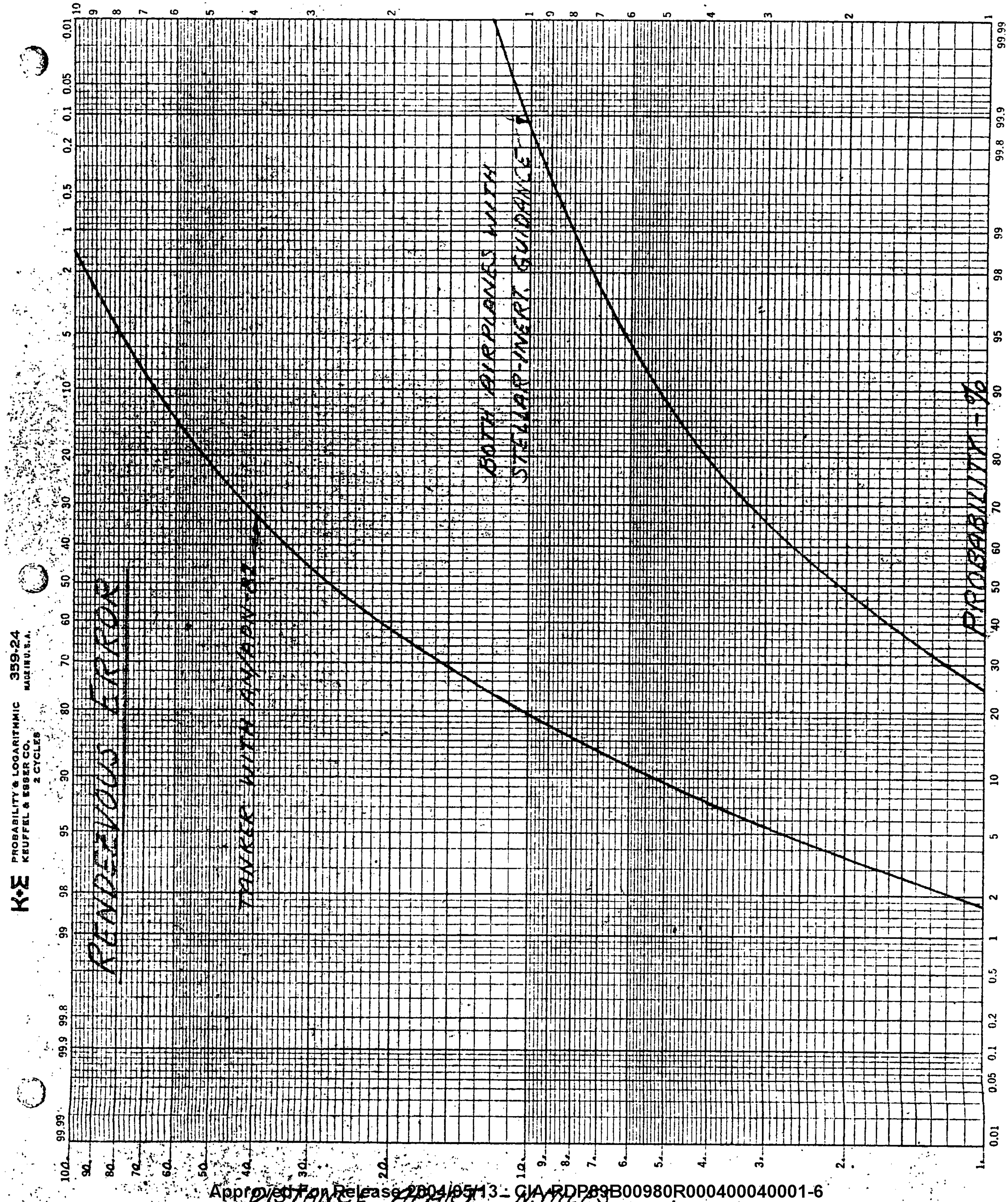
For the A-11 refueled mission, a study has been made of the navigational requirements to guarantee rendezvous of the A-11 and the KC-135 tankers.

The basic navigation system of the KC-135 is the AN/APN-82 Doppler radar set. Considering the northern latitudes and open sea and ice covered terrain, it is believed that a reasonable or even optimistic estimate of the C. E. P. at the rendezvous point is 1% of the distance covered. In the present case of tankers staged out of Fairbanks, the tanker distance is about 2700 nautical miles. It follows that in 50% of the cases the tanker's rendezvous error is more than 27.0 nautical miles.

The A-11, at the second refueling point, has accumulated a C. E. P. of 5 nautical miles, with the uncorrected inertial guidance system previously proposed.

Combining these two C. E. P.'s, we find a C. E. P. for the distance between the two airplanes of 27.5 nautical miles. The upper curve in Fig. 11 shows the probability of the two aircraft being a given distance apart. It can be readily seen that in 10% of the cases, for example, the airplanes find themselves 67 or more nautical miles apart. Because of the crucial

FIGURE 11


RENDEZVOUS ERROR
TANKER WITH AN/APN-81
BOTH AIRPLANES WITH STELLAR-INERT. GUIDANCE
PROBABILITY - %
DISTANCE APART - N. MILES
K+E PROBABILITY & LOGARITHMIC KEUFFEL & ESSER CO. 2 CYCLES 359-24 MADE IN U.S.A.
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
100
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1

NAVIGATION (cont.)

nature of the refueling contact, and the undesirability of using search radar so close to a hostile coast, this precision is totally inadequate.

We propose, therefore, the installation of the same type navigation equipment in both aircraft -- namely, the stellar-corrected inertial guidance system, as described in Lockheed Aircraft Corporation report SP-114. The use of this equipment will give a C.E.P. of the distance between the airplanes of only 2.1 nautical miles. The lower curve in Fig. 11 shows the improved distribution so obtained. Now, for example, in 90% of the cases the two aircraft are within 5.2 nautical miles of each other, as contrasted to 67 miles before.

It is believed that this improvement will permit visual contact in most cases, and essentially eliminate the problem of missed contacts. The vastly improved precision more than justifies the increased cost of the refined system.

FUEL COMPARISON

SUMMARY

A comparison of the potential performance gains available from use of High Energy Fuels instead of JP-150 shows that they are not sufficiently important for this mission to jeopardize the time schedule and operational utility of the proposed refueled A-11 reconnaissance system.

The following considerations, discussed in this section, lead to this conclusion:

1. The 12% specific fuel consumption improvement shown by current afterburner tests will undoubtedly deteriorate when the boron fuel has suffered hydrogen evolution from aerodynamic heating effects.

2. The A-11 airplane is not volume limited and no gain can be shown through the fact that High Energy Fuel requires less volume than JP-150.

3. Empty weight of the A-11 is increased 1,215 pounds by the fuel system modifications required.

4. The tank vent system must be capable of safely disposing of large quantities of hydrogen gas as it evolves during aerodynamic heating.

FUEL COMPARISON (cont.)

SUMMARY (cont.)

5. Boric oxide deposits on the engine's variable area nozzle and deposits on tank walls and fuel system components due to fuel decomposition are potential sources of malfunction.

6. A wash and purge system must be incorporated to remove and jettison the residue which is deposited on tank walls due to fuel breakdown with temperature.

7. In-flight refueling will be considerably complicated, both in the tanker and the A-11, by the need to transfer and sequence two different fuels.

8. Vapor and smoke trails from High Energy Fuel may occur at all altitudes. These effects, if present, will greatly increase the probability of detection and identification.

Several other drawbacks associated with use of boron fuels, such as toxicity, cost, handling hazards, and the attendant complicated handling procedures, may not directly affect the A-11's reliability or performance but degrade the effectiveness of the over-all system operation.

FUEL COMPARISON (cont.)

A cursory comparison of the heating values of H. E. F. -3 and JP-150 fuel (25,800 BTU/lb. vs. 19,100 BTU/lb.) indicates that approximately a 30% increase in airplane performance might be expected by the use of H. E. F. -3. This impressive number has been bandied about in literature for the past few years, but unfortunately there are many reasons why this is not valid.

The actual improvement in specific fuel consumption of H. E. F. over JP-150 as measured by Pratt & Whitney when burning H. E. F. in the afterburner only was 12%. Some of the expected but unobtained gain may be accounted for by the heat required to vaporize the boric oxide (product of combustion). Possible dissociation of the molecules in the jet (frozen equilibrium), due to high temperature, moderate pressure and high Mach number, absorbs energy and unless the components recombine into the product of combustion within the nozzle some of the heating value of the fuel is not realized.

The specific gross thrust obtained by a jet of hot gases is an inverse function of the square root of the molecular weights of the products of combustion. In the case of boron fuel, the molecular weights are higher than those of hydro-carbon fuels. This results in an additional loss of thrust.

In order to obtain the 12% reduction of specific fuel consumption by use of

FUEL COMPARISON (cont.)

H. E. F. in the engine and afterburner, it is necessary to make modifications to the engine and airplane fuel systems. In both cases, these involve weight increases and complications.

Boron fuels have the following characteristics which complicate their use:

1. They hydrolyze with water, evolving hydrogen gas, and form a precipitant in the fuel which coats and clogs the fuel system components.

2. They deteriorate when heated, evolving hydrogen gas which changes the structure of the fuel and results in lowered heating value and increased viscosity, and eventually causes a precipitant.

3. Some of the boron fuels are pyrophoric and must be kept under an inert gas. Even H E. F. -3, which is not supposed to be pyrophoric, always contains a few percent H. E. F. -2, which is pyrophoric.

4. Many of the materials commonly used in fuel systems are not compatible with boron fuels and substitutes must be found.

The increase in airplane weight to use boron fuel in the afterburner breaks

FUEL COMPARISON (cont.)

down as follows:

Item	Weight Increase Over JP-150 System	Comments
Engines	360 lbs.	From Pratt & Whitney
Fuel Tank	80 lbs.	Extra sump tank
Purge gas	230 lbs.	Liquid nitrogen and system for 2 in-flight refuelings
H. E. F. fuel system	200 lbs.	H. E. F. pump, plumbing, etc.
Tank wash	220 lbs.	To wash residue from walls in flight
Refueling provisions	125 lbs.	Three-way valve & plumbing
Total	1,215 lbs.	

The deposits formed in the tank by the decomposition of the fuel with temperature should be removed before it bakes to a hard cake. This should be done by washing the walls of the tank with water-free hydrocarbon fuel. To do this in flight requires additional tanks, lines, valves, etc., with a weight increase of at least 200 pounds. The following questions always arise:

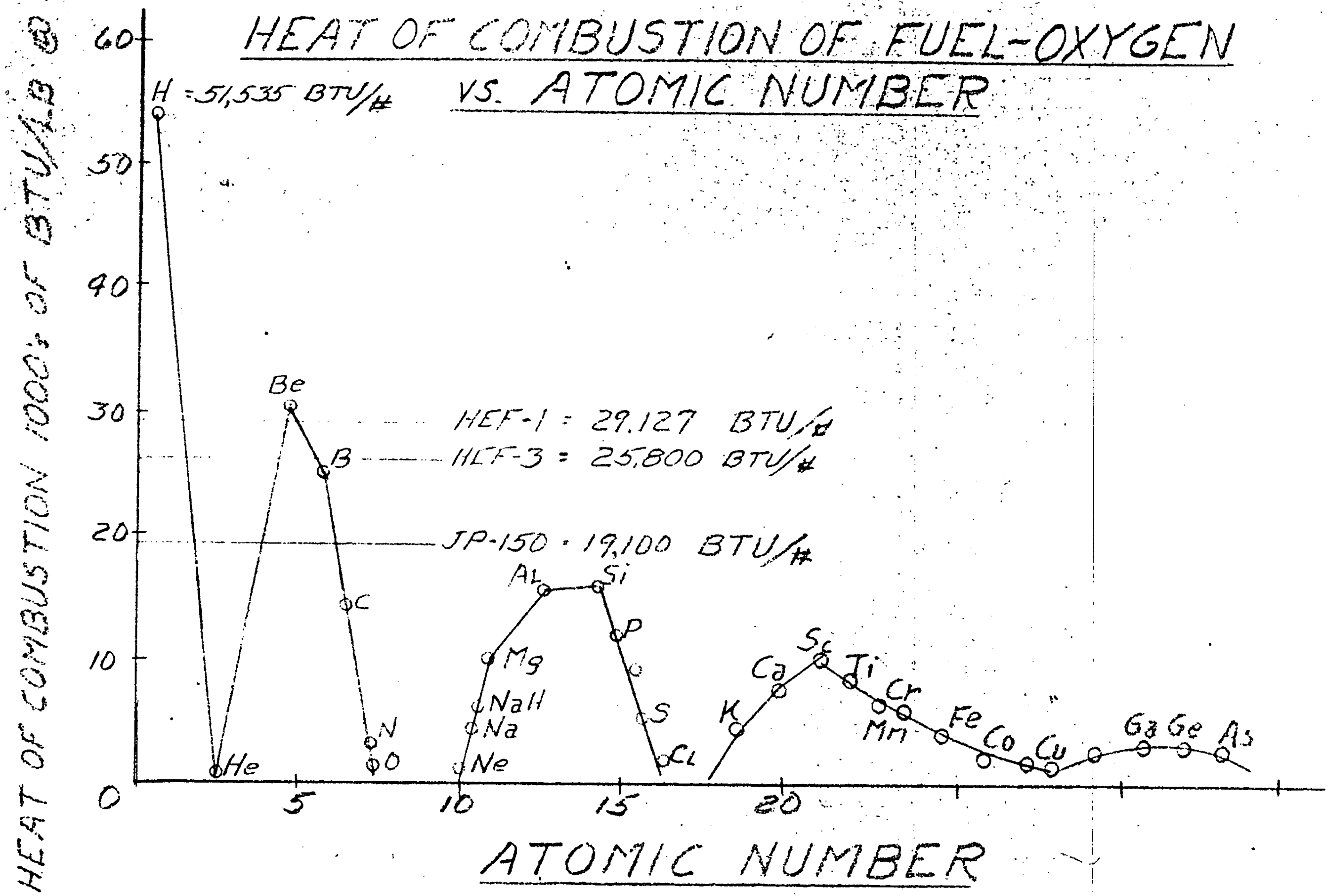
Why do this in flight?

Why not let it cake up and clean it on the ground?

FUEL COMPARISON (cont.)

To do this is an extremely dangerous and slow operation. As the H. E. F. is heated beyond a certain temperature, it evolves hydrogen gas; this changes the chemical structure of the remaining fuel to various complex structures. Some of these, when mixed with some of the common solvents, form shock sensitive explosives. Olin Mathieson Chemical Corporation has had several casualties during cleaning of apparatus which has been caked with H. E. F. residue. Lists of acceptable solvents have been compiled which can be used, but Olin Mathieson argues against allowing H. E. F. to cake up on an aircraft fuel system and cleaning on the ground, since any safe way of doing so would be extremely time-consuming and the results would be questionable, unless a complete inspection of all components were made -- an intolerable procedure for an operational airplane. Some of the personnel at Olin Mathieson were under the impression that the B-70 would wash the tanks with JP fuel during flight. If the tanks were insulated so the H. E. F. does not reach the temperature where it decomposes, the problems created by residue deposit would be eliminated, but the weight increases would be prohibitive.

Fig.12 (heat of combustion of fuel - oxygen system vs. atomic number) shows that elemental boron has less heating value than the boron fuels, the principle reason for the high heating value of H. E. F.-3 ($C_2H_5B_{10}H_{13}$)



HEAT OF COMBUSTION OF FUEL-OXYGEN VS. ATOMIC NUMBER

FIGURE 12

FUEL COMPARISON (cont.)

being due to the hydrogen, not the boron. When we heat H. E. F. -3 to a point where it decomposes and hydrogen is evolved (and wasted), we are robbing it of its high energy potential. There are no known data available which show the heating value of H. E. F. -3 at various stages of decomposition, but it is certain that the results will show a decrease in heating value proportionate to the amount of hydrogen lost.

Figs. 13 and 14 show the pressure developed by Hi Cal-3 after heating to different temperatures and times. It is apparent that the evolution of hydrogen cannot be stopped by any pressures which could be tolerated in an aircraft fuel tank. No such curves are available for H. E. F. -3, but it is similar to Hi Cal-3.

Most of the metals used in an aircraft fuel system are compatible with the boron fuels; however, most of the non-metallic compounds commonly used in fuel systems are not compatible, notably tank sealants. To date, no sealant has been found which is resistant to both the fuel and the high temperatures which will be experienced in a near empty fuel tank of a high Mach number aircraft, where the skin temperatures will be in the order of 450°F.

FIGURE 13

THERMAL STABILITY OF HiCAL-3

PRESSURE RISE VERSUS TEMPERATURE FOR 5 MINUTE HEATING PERIOD

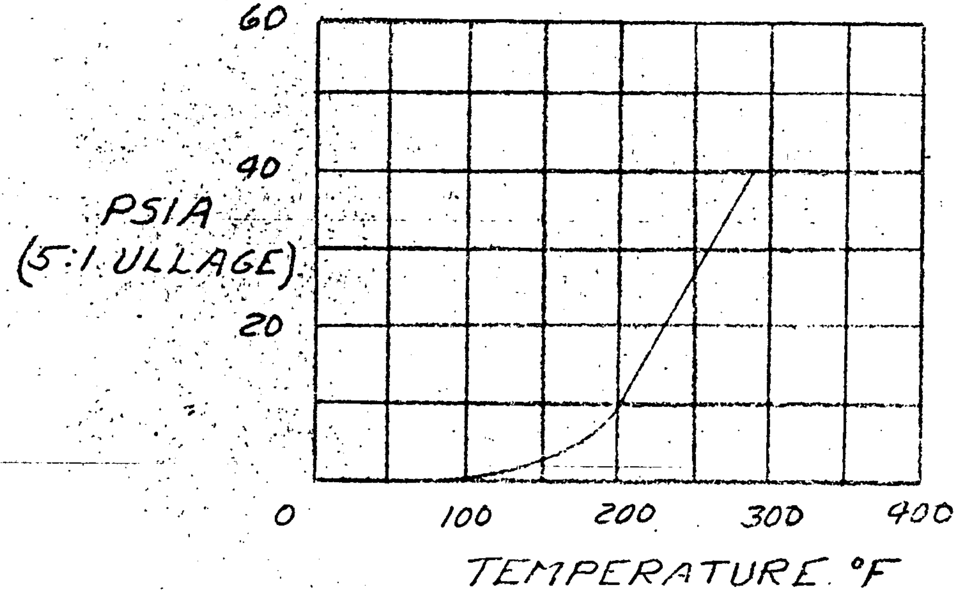
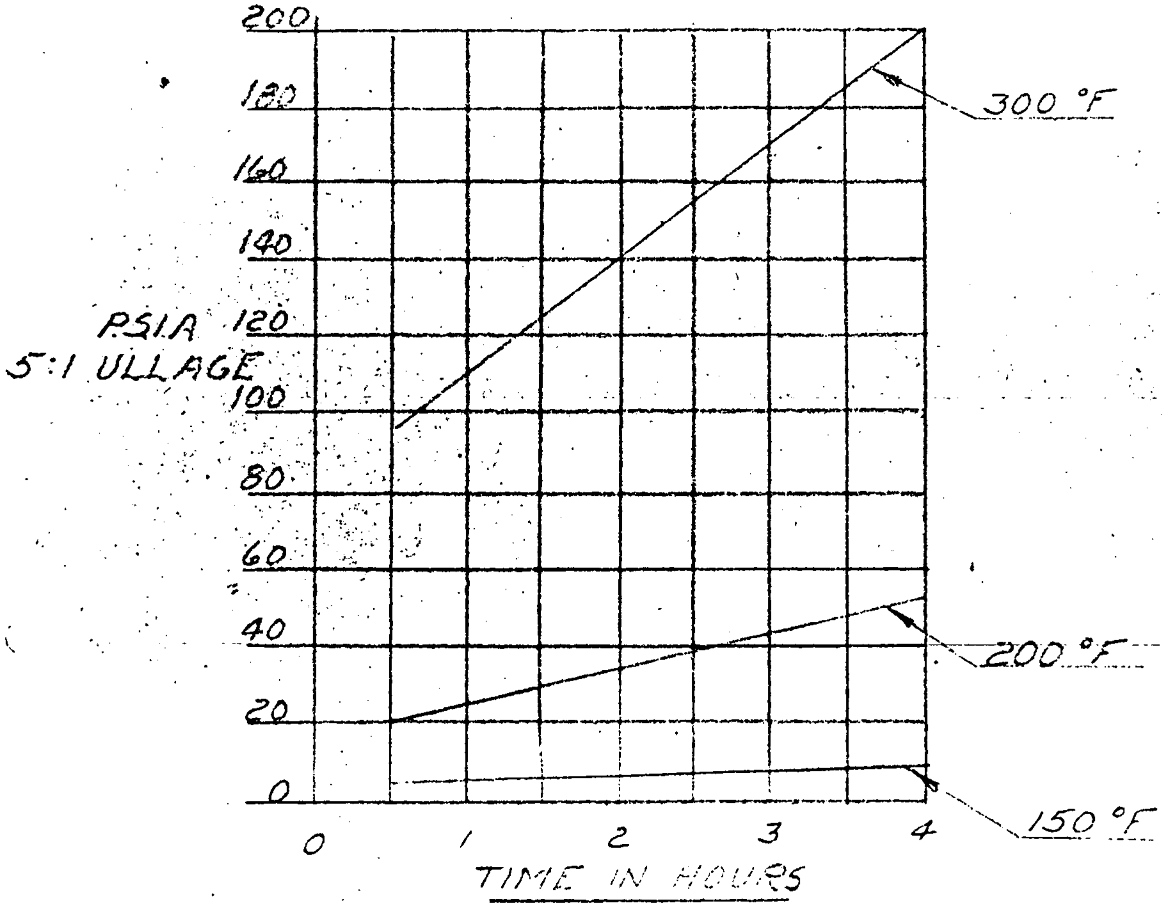


FIGURE 14

THERMAL STABILITY OF HI CAL-3

PRESSURE RISE VERSUS TIME AT 150, 200, & 300 °F



FUEL COMPARISON (cont.)

The most promising materials for high temperature fuel resistant sealants are the fluorinated elastomers. Of the many compounds tested, only a few had the right characteristics for a sealant suitable for aircraft use. The one that appeared to have the necessary qualifications was Viton "A". Wyandotte Chemical Company was awarded an Air Force contract to study sealants, and their experience with Viton "A" in the presence of H. E. F. -2 and H. E. F. -3 may be summarized as follows:

1. No reaction occurred when the polymer, Viton"A", was submerged in H. E. F. -3 for several hours at 400°F.

2. An increase in the temperature of the sealant to 475°F after soaking in an H. E. F. -3 bath resulted in an exothermic reaction which caused the temperature of the polymer to jump to 1500°F in about five minutes. There was no fire or explosion, but the polymer completely disintegrated and the fuel decomposed.

3. At some temperature less than 475°F, Viton "A" will react in H. E. F. -2 in a similar manner.

4. The reaction described above is dependent upon the rate at which the fuel is absorbed in the polymer, and the rate at which the fuel is heated.

FUEL COMPARISON (cont.)

The need for a sealant was discussed with both the Callery Chemical Company and Olin Mathieson, the manufacturers of Hi Cal-3 and H. E. F. -3, respectively. Neither had a possible solution to the problem, as they are contracted to produce boron fuels and do not have contracts to study compatibility other than what is necessary for their needs.

Beech Aircraft has a contract to study material compatibility with boron fuels, but as yet they have not found a suitable sealant.

The fact that a satisfactory sealant has not been found does not mean that there is not one or that one may not be developed, but to embark on the A-11 airplane program hoping, but not knowing, that a material or process is available is a risky assumption to make. The A-11 program's time span is based on firm technology and not wishful thinking or guesswork.

The inert atmosphere (nitrogen gas) which must blanket the boron fuel must be carried aboard either in high pressure cylinders, which are heavy, or as a liquid, which is lighter but more complicated.

The in-flight refueling of the A-11 airplane involving two types of fuel (JP-150 for main burners and H. E. F. -3 for afterburners) will indeed complicate the

FUEL COMPARISON (cont.)

fuel system, jeopardize reliability and add 125 pounds of weight to the refueling transfer system in the A-11. Extensive modifications to the tanker's equipment would be required, making it a special purpose aircraft, and reducing either its range or fuel transfer capability.

The condensation of B_2O_3 in the exhaust also presents a serious contrail problem. The boric oxide smoke is similar to the screening smokes used in chemical warfare. The problem is severe, since the smoke will persist for extensive periods of time and will be visible at extreme altitudes. The contrails generated by B_2O_3 differ from moisture contrails in that the smoke particles do not evaporate into the atmosphere. The dispersion is dependent principally on diffusion and gravity settling of the larger particles.

In addition, the enemy will probably be able to recognize that a fuel other than hydrocarbon fuel is being used, when the airplane produces a trail at altitudes where vapor trails would not be forecast to occur.

The toxicity of boric oxide exhaust on vegetation is currently being investigated. It appears that boron fuels will have to be restricted to altitudes above 10,000 feet to avoid this complication.

FUEL COMPARISON (cont.)

The security problem on the A-11 program will also be hampered, since the operational requirements demand approximately 50% of the proposed boron fuel production. The disappearance of this quantity of fuel from the program will give rise to numerous queries and investigation from outside sources.

MISCELLANEOUS

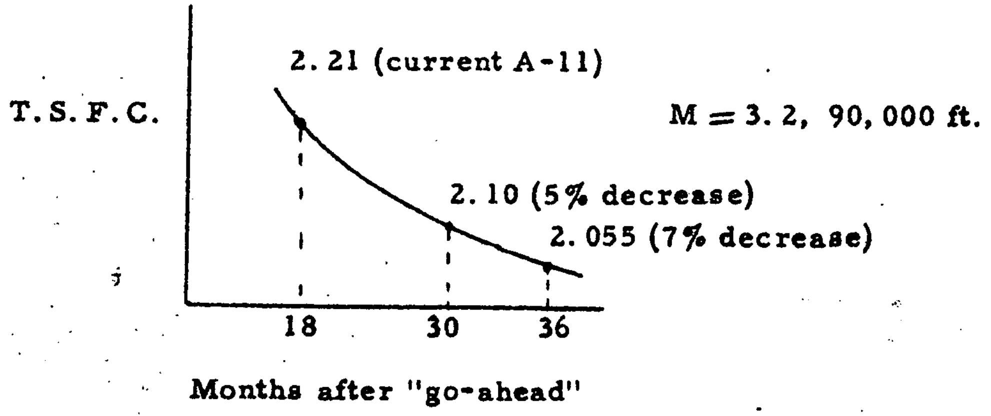
ENGINE GROWTH

To forecast the growth potential of the A-11 airplane, Pratt & Whitney was asked for the growth potential of the J-58 engine.

The results showed that within three years of a "go-ahead," significant gains in airplane performance could be achieved by increasing either turbine inlet temperature or afterburner temperature or both, as discussed below.

The data received show that increasing the turbine inlet temperature approximately 200°F will result in approximately 7% increase in range. The following curve shows the predicted gains due to increasing turbine inlet temperature.

A/B temp. increase

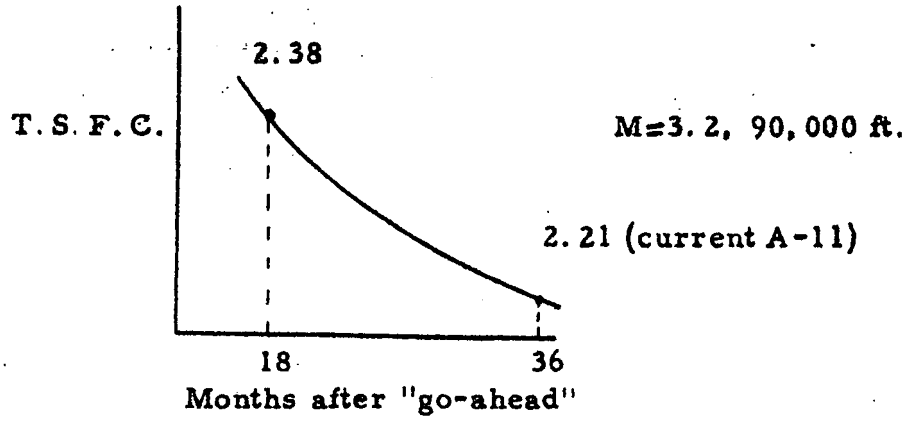


MISCELLANEOUS (CONT.)

ENGINE GROWTH (cont.)

Increasing the afterburner temperature 200°F will result in an 8% increase in net thrust at $M = 3.2$, 90,000 feet. This thrust increase is accompanied by a 7.5% increase in S.F.C. The 8% thrust increase would provide approximately 1,500 feet in altitude but with a range decrement corresponding to the S.F.C. increase. With time, however, the thrust increase can be achieved with no change in current S.F.C. as shown below.

A/B temp. increase

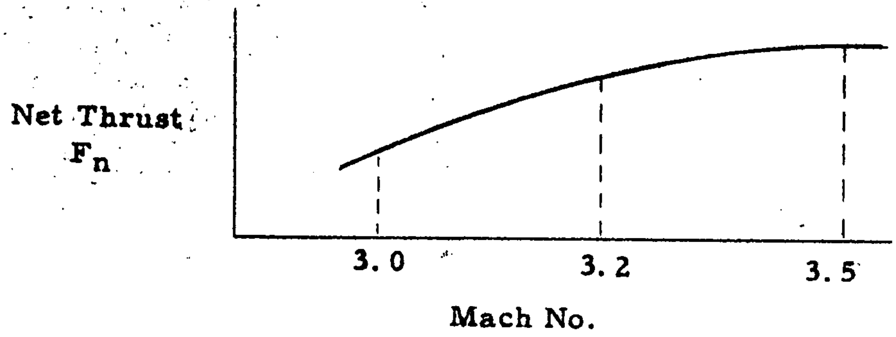


Since the structural material of A-11 is capable of $M = 3.5$ operation temperature-wise, the prospect of increasing cruise Mach number from $M = 3.2$ to 3.5 was also investigated. The results, using the current

MISCELLANEOUS (cont.)

ENGINE GROWTH (cont.)

engine with material and design changes required for Mach 3.5 operation show only marginal gains, since the engine changes cost approximately 100 lbs. of weight per engine. The thrust gain with increasing Mach number is quite small above 3.2 as shown below.



The reason for the leveling off of thrust is that the ram temperature rise at M=3.5 approaches the allowable turbine inlet temperature, thereby limiting fuel addition. Additional thrust may be achieved by increasing engine airflow through use of higher engine RPM, but this will be limited and would require a major redesign and a weight increase of approximately 1000 pounds.

The engine manufacturer has, however, recently proposed another method of modifying the J-58 engine to achieve Mach 3.5 capability

MISCELLANEOUS (cont.)

ENGINE GROWTH (cont.)

which shows considerable promise. The method, which will require approximately three years for development, consists of converting the conventional turbojet to a bleed-bypass engine. The effect of the bleed-bypass engine on the A-11 performance is discussed in the Appendix of this report.

MISCELLANEOUS (CONT.)

CONTRAIL DETECTION

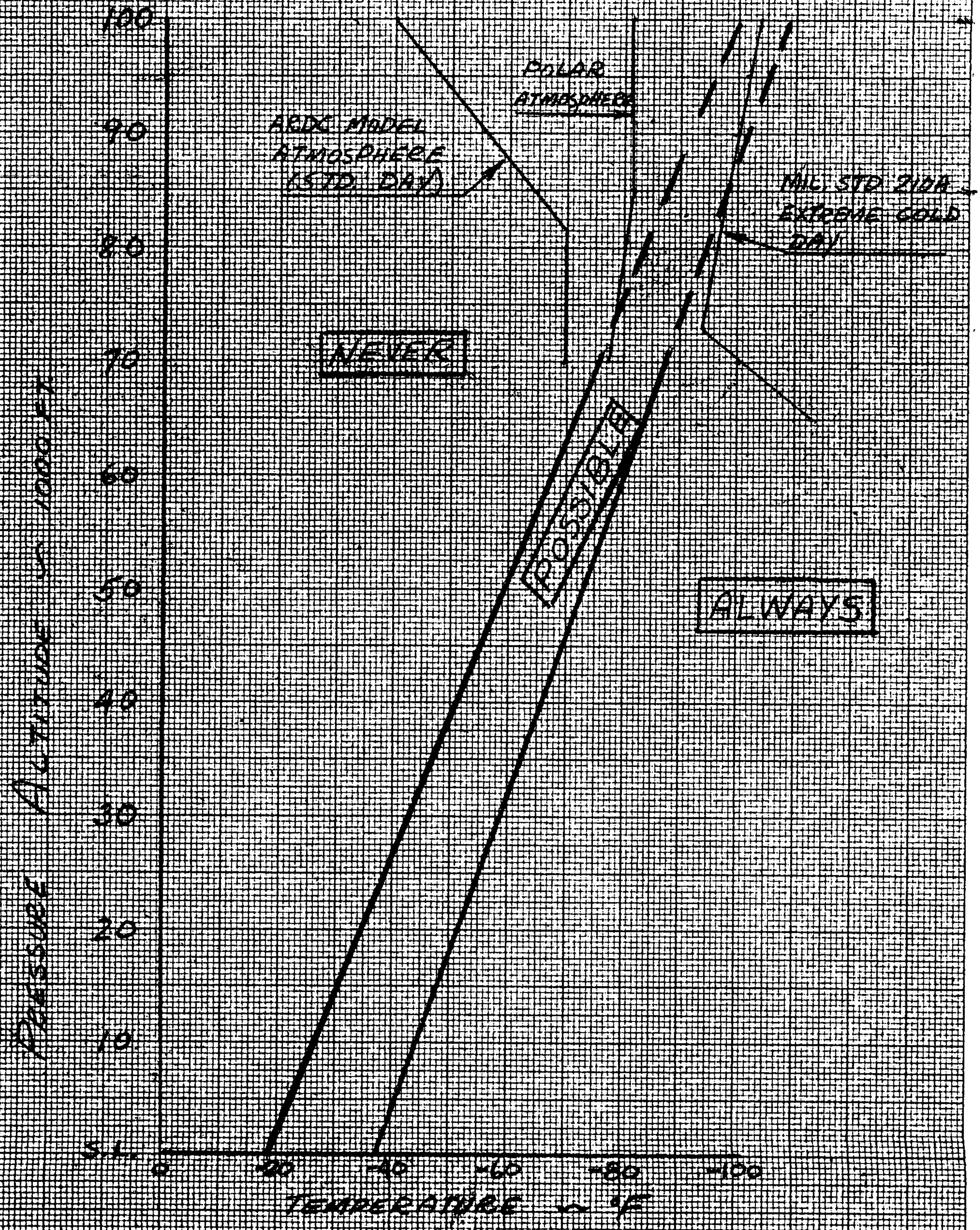
The vapor trails, called contrails, left by jets flying at high altitudes have been a very effective means of detecting airplanes in the sky. In order to see if A-11 airplanes would encounter the contrail problem, a study of the available data on contrail formation was made. It was assumed that only hydrocarbon fuels would be used.

Numerous investigations have been made on contrail formation. A fundamental study was made by the Cornell Aeronautical Laboratory (CAL) to find the temperatures and pressures at which liquid water could exist. Based on altitude chamber tests, CAL was able to set up a criterion of contrail detection as a function of temperature. The CAL results were correlated with Air Force flight data. These criterion are plotted in a slightly revised form and presented in Fig. 15

Fig. 15 shows a plot of altitude versus temperature with regions in which contrails will never form, always form, or may form, depending upon the amount of moisture in the ambient air. Also plotted for reference in Fig. 15 is the ARDC Model atmosphere -- the current standard

FIGURE 15

CONTRAIL DETECTION



MISCELLANEOUS (CONT.)

CONTRAIL DETECTION (cont.)

checked with flight data. The data correlated extremely well. The probability data on contrail formation is partially reproduced below from the above report for JP-4 fuel.

Probability of Contrail Formation

JP-4 Fuel Northern Hemisphere

Altitude/Latitude (^{o}N) (1000 ft.)	20	30	40	50	60	70	80
Percentage - January							
100	0	0	0	0	0	0	1
90	0	0	0	0	0	0	4
80	0	0	0	0	0	3	5
70	10	3	0	0	1	7	24
60	99	74	8	3	12	20	28
Percentage - April							
100	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0
70	3	1	0	0	0	0	0
60	99	65	4	0	0	0	0
Percentage - July							
100	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0
60	98	70	10	0	0	0	0
Percentage - October							
100	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0
70	2	1	0	0	0	0	0
60	98	90	30	8	3	1	2

MISCELLANEOUS (CONT.)

CONTRAIL DETECTION (cont.)

day, the polar atmosphere, and the Mil. Std. 210A extreme cold day, which supersedes the ANA 421 cold day. The tropical day was left off, since it falls in the region of the ARDC standard day at altitudes above 70,000 feet.

The data in Fig. 15 show that the A-11, flying between 86,500 to [redacted] STAT feet, will not have a contrail problem. The extreme cold day shows that contrail formation is possible; however, these conditions are not very probable.

Cornell findings also indicated that whereas contrails with a small content of water can be seen in bright sunlight with clear skies, under cloudy conditions only contrails with much greater water content can be detected.

A thorough study of contrail prediction and prevention was also made by ARDC. The results of this study are presented in Secret Report No. AFCRC-TN-58-451. This report deals with contrail problems at lower altitudes (30,000 to 50,000 feet) and the use of alternate fuels to minimize contrail formation. A method of contrail prediction was derived and was

MISCELLANEOUS (CONT.)

CONTRAIL DETECTION (cont.)

The table shows that at altitudes between 90,000 to [redacted] feet, the probability of contrail formation is zero, except at 80° N. latitude, where probability is between 1 to 4%, which is almost negligible. At altitudes of 60,000 feet and below, the probabilities become very large. STAT

MISCELLANEOUS (Cont.)

SHOCK-WAVE NOISE PROBLEM

The operation of a large number of supersonic airplanes over populated areas has brought considerable attention to the shock-wave noise problem inherent with supersonic aircraft - - the so-called sonic boom.

Since it was presumed that the shock-wave noise generated by the A-11 airplane would pose an airplane detection problem, a theoretical analysis was made and is discussed below. The preliminary results show that the low noise entensity level combined with the narrow lateral spread of the audible noise would make tracking from the ground extremely difficult. Tracking stations would have to include a method of discriminating and identifying noise characteristics and be located very nearly along the flight path in order to detect and vector the course.

Numerous theoretical methods of predicting the pressure amplitudes generated by supersonic aircraft are available. All of these theories, however, consider only a homogeneous atmosphere and thus neglect such atmospheric attenuation factors as: (1) factors which affect the variation in speed of sound in atmosphere (temperature, moisture content, dust content, cloud cover), (2) factors tending to disperse the disturbance (wind gradients, turbulence), (3) factors affecting energy dissipation (viscosity, molecular energy transfer), (4) factors directly affecting

MISCELLANEOUS (cont.)

SHOCK-WAVE NOISE PROBLEM (cont.)

the overpressure intensity (pressure gradient), and (5) the ground reflectivity factor, and type of terrain. Most of the above factors tend to make the theories conservative, and unfortunately very little flight test data are available for checking the results.

The best available theory on the shock-wave noise problem is the work developed by the British author, G. Whitham and extended by F. Walkden. The theory derives the pressure rise across the shock wave generated by the volume or shape contribution and the lift or wing contribution. The equations are quite involved and cannot be solved readily except for simple body and wing planforms. Numerous other theories are available but most of them neglect the lift contribution, which is particularly important at altitudes above 35,000 feet.

The best simplified equation is the one presented by Maglieri and Carlson of NASA, first presented at the NASA Conference on Aircraft Operational Problems in November, 1958, and later issued as NASA Memo 3-4-59L. This paper presents a theory which accounts only for the volume component for noise and assumes a shape factor to account for the area and lift distribution. It also includes a ground reflectivity constant not included

MISCELLANEOUS (cont.)

SHOCK-WAVE NOISE PROBLEM (cont.)

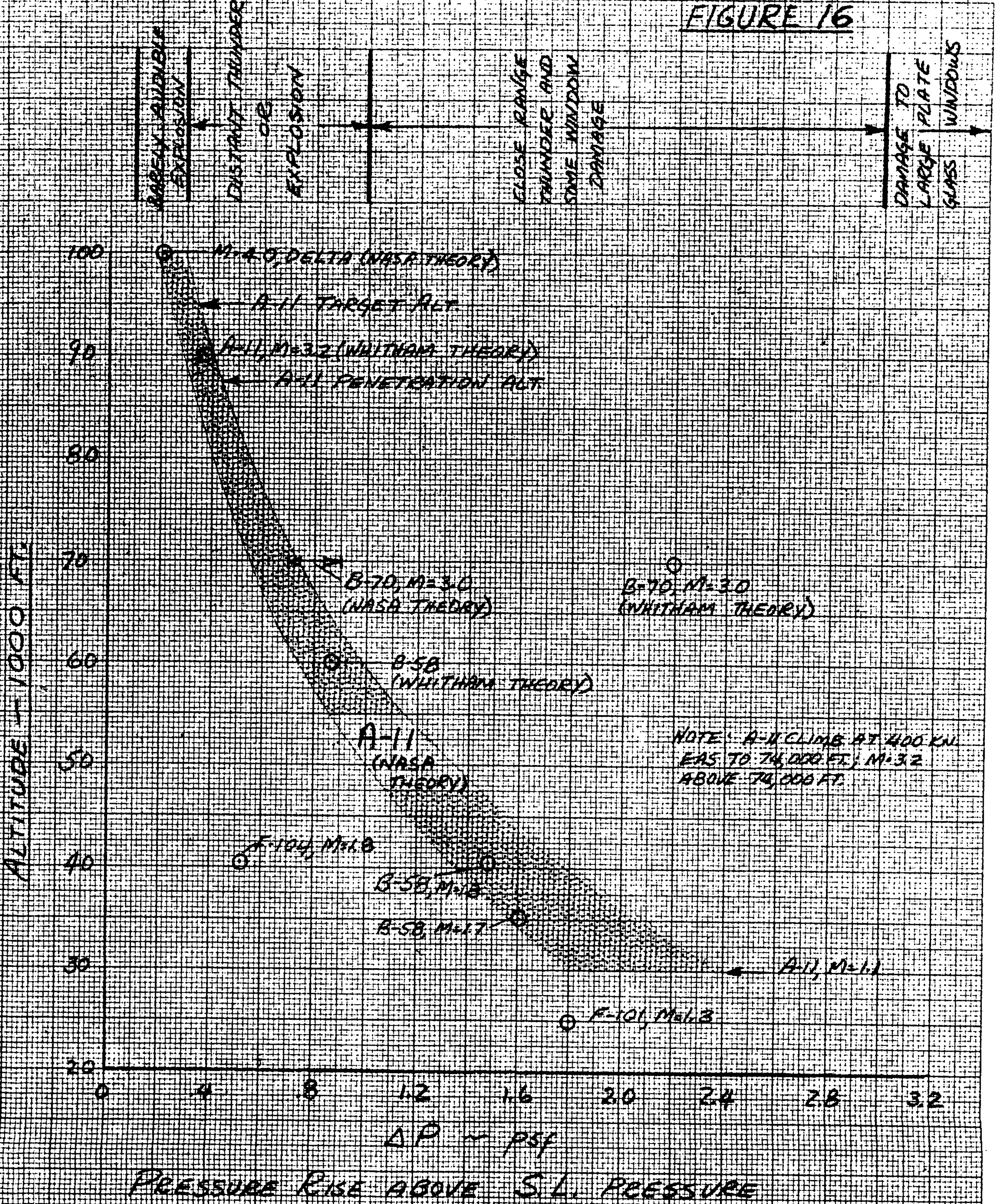
in the other theories. The paper also compares its theory with some flight test data and gives correlations with the subjective reactions of of observers and the physical damage associated with pressure amplitudes. The theory proved to be in fair agreement with the flight test data given.

The NASA theory shows that the principal variables on pressure amplitude (noise level) are altitude, Mach number, body fineness ratio, and body length. The overpressure is inversely proportional to altitude and fineness ratio and directly proportional to Mach number and length. The effect of Mach number is greatest between 1.0 and 1.3, with only a slight increase with Mach numbers above 1.3. The effect of size is secondary. At altitudes above 85,000 feet the noise generated is not objectionable to ground observers.

Using the NASA theory, the pressure amplitudes generated by the A-11 Airplane during climb and cruise were calculated and are presented in Fig. 16. The calculated data tend to be conservative since a homogeneous atmosphere, a maximum ground reflection factor of 2.0, and a minimum overall fineness ratio of 8.9 for the A-11 were assumed. The curve indicates that the A-11 will operate in a region of a barely audible explosion

SHOCKWAVE NOISE COMPARISON

FIGURE 16



MISCELLANEOUS (cont.)

SHOCK-WAVE NOISE PROBLEM (cont.)

throughout its cruise. A small M = 4.0 delta shaped airplane cruising at 100,000 feet is also plotted and falls in the same noise spectrum. These results would be typical for any supersonic airplane flying at 90,000 feet and above.

In order to check the NASA theory and reflect the lift contribution, the A-11 overpressure was calculated using the complex Witham theory. It was necessary to make two basic assumptions for the A-11 airplane in order to integrate complex equations: (a) the body is parabolic and, (b) the lift distribution is linear for the wing. Both of these assumptions are quite reasonable. The results of the calculation at 90,000 feet fall within the noise spectrum predicted by NASA theory as noted in Fig. 16.

Also plotted in Fig. 16 are flight test data for the F-101, F-104 and the B-58 airplanes, and a calculated spectrum for the B-70 airplane.

It is interesting to note that the F-101 test point is one in which a large plate glass window (128 in. x 90 in.) in the vicinity was cracked. The pressure amplitude of approximately 2 psf is equivalent to a 28 mph wind velocity. According to a glass manufacturer's catalogue this size glass panel should be able to withstand a steady loading of 8 times this pressure.

MISCELLANEOUS (cont.)

SHOCK-WAVE NOISE PROBLEM (cont.)

Therefore the glass cracking may have been due to stresses in the glass caused by improper installation or inadequate support. Similar windows in the area did not break. Much more information is required before conclusive correlation with damage can be made.

The discussion so far has been limited to a station directly in the flight path. The lateral spread however is of considerable interest. The only data available is that given in the NASA report. The latter presents flight test data for a F-101J airplane flying at 35,000 feet, M=1.3. This flight generated an overpressure of 1.6 psf along the flight path, which dissipated to half this value in a lateral distance of 10 miles and to zero in 15 miles. The sharp "cutoff" is attributed to refraction effects which are associated with temperature gradients in the atmosphere.

It should be noted that the higher overpressure values occurring at lower altitudes would not pose a problem with the A-11 airplane since these would occur only in the Edwards Air Force Base region under the proposed operating schedule.

APPENDIX

PERFORMANCE GAINS WITH THE J-58 BLEED-BYPASS ENGINE

Pratt & Whitney has recently supplied some advanced data on a bleed-bypass modification of the J-58 engine. The bleed-bypass engine will provide a Mach 3.5 cruise capability for the A-11 airplane and an average increase of 3,000 feet in cruise altitude, while keeping the mission range and takeoff weight essentially the same as that established for the airplane equipped with the standard J-58 engine.

The engine modification consists of ducting approximately 20% of the compressor airflow through the fourth stage bleed ports to a shrouded turbine. In this manner, turbine inlet temperature can be substantially raised with only a small increase in structural weight. The shroud provides the structural portion of the turbine and is cooled by the bleed flow. The design is achieved with no increase in engine frontal area.

The performance improvement of the bleed-bypass engine relative to the conventional J-58 turbojet at M=3.2 and 3.5 is given below for three (3) different altitudes:

Altitude (feet)	[redacted]		[redacted]		[redacted]	
Mach No.	3.2	3.5	3.2	3.5	3.2	3.5
Increase in Net Thrust, %	15	22.4	13.6	23.7	13.3	22.7
Decrease in SFC, %	0	0	1.3	0	1.3	0

STAT

APPENDIX (cont.)

When the bleed-bypass engine operating at M = 3.5 is compared to the current engine operating at M = 3.2, the net thrust increase ranges from 26 to 30 percent with an SFC increase of 4 percent.

The above gains achieved by the by-pass engine are accompanied by a weight increase of 200 lbs. over the M = 3.2 J-58 turbojet. Since the J-58 weight would have to be increased 100 lbs. to permit operation at M = 3.5, a net weight increase of only 100 lbs. is required for the bleed-bypass feature which increases inflow approximately 20 percent and reduces turbine inlet temperature. The engine manufacturer estimates that an approximate three-year period would be required for this development.

600#

A preliminary analysis of the limited engine data available shows that at constant airplane weight the fuel economy as defined by nautical miles per pound is increased by more than three percent at the higher Mach 3.5 cruise speed. The improved economy occurs despite the increased engine SFC's because of the higher cruise speed. The increased miles per pound decreases the fuel required for each cruise period by about 1,000 pounds. The zero fuel weight can therefore be increased by 1,000 pounds without increasing the initial weight.

APPENDIX (cont.)

The airframe weight increment necessary to provide a Mach 3.5 capability has not been well defined due to the limited time that the engine data has been available. The preliminary work does indicate that the 600 pounds remaining after increasing the engine weight by 200 pounds each will cover the major changes necessary.

It appears that the bleed-bypass modification to the J-58 engine will increase the A-11 performance capability by:

1. Increasing cruise Mach to 3.5.
2. Increasing cruise altitude to 90,000 feet at penetration and [redacted] feet at the end of cruise, an average of about 3,000 feet.

STAT

These gains accrue for the same mission radius and essentially the same takeoff weight.