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RESEARCH MEMORANDUM

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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ANALYSIS OF LOW-TEMPERATURE NUCLEAR-POWERED RAM-JET MISSILE FOR HIGH ALTITUDES[1]

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SUMMARY

The gross weight and uranium investment of nuclear-powered, direct-air, shieldless, ram-jet missiles are calculated for altitudes of 50,000 to 80,000 feet and flight Mach numbers of 2.5 and 3.0. The reactor effective wall temperature for most of the study was taken as 1800° R, which gives peak wall temperatures of about 2200° R.

For a pay load of 10,000 pounds (including guidance and controls with shielding, and fixed equipment), flight above 70,000 feet was not feasible with a reactor effective wall temperature of 1800° R. In order to operate at 80,000 feet with a flight Mach number of 3.0, an effective wall temperature of about 2300° R was necessary.

At 70,000 feet and a flight Mach number of 3.0, a uranium investment of 81 pounds and a missile gross weight of 64,000 pounds were necessary.

The reactor operating conditions were varied to enable selection of values giving a good compromise between low uranium investment and low gross weight at each altitude and flight Mach number considered. The corresponding values of reactor and missile operating conditions

[1]The results of this study were presented to the Scientific Advisory Board at the March 23, 1955 meeting held at the Rand Corporation, Santa Monica, California by Mr. A. M. Rothrock of NACA Headquarters.

are presented in the report. The sensitivity of the missile gross weight and uranium investment to critical assumptions such as lift-drag ratio, structure-to-gross-weight ratio, pay load, and reactor effective wall temperature was determined for an altitude of 50,000 feet and flight Mach number of 2.5. The chief results of these calculations are that (1) lift-drag ratios as low as 3.5 could be tolerated, (2) structure-to-gross-weight ratio had relatively small effect on uranium investment and gross weight, (3) doubling the pay load doubled the gross weight but did not appreciably affect uranium investment, and (4) reactor effective wall temperatures below 1600° R gave excessive uranium investments and gross weights.

INTRODUCTION

A major problem in nuclear-powered flight is the heavy shield required for crew protection. Heavy shields require high-gross-weight airplanes with reactors of high power per unit volume. A shieldless reactor greatly reduces these problems. However, its use is restricted to remotely controlled aircraft such as guided missiles. The loss of fissionable material associated with the use of one-way guided missiles must be balanced against the complexity, cost, and difficult ground handling and maintenance of high-gross-weight, man-carrying, nuclear-powered aircraft.

The nuclear-powered, direct-air, ram-jet missile, which is considered in reference 1 and the present report, was first studied in reference 2. Reference 2 shows that a beryllium-oxide-moderated, direct-air, ram-jet missile was feasible with reactor surface temperatures of 3600° F; this result was based on a missile lift-to-drag ratio estimated at less than 1.5 from the best data available at that time. In the years that followed, the fund of aerodynamic and nuclear design data greatly increased so that better performance estimates could be made. Reference 1, with the use of this new data, shows that nuclear-powered ram-jet missiles are feasible with effective wall temperatures as low as 1800° R. This large reduction in reactor temperature was made possible chiefly because the missile lift-to-drag ratio was estimated at about 5.0 instead of less than 1.5 as in reference 2.

The present study represents an extension of reference 1 to determine the feasibility of the nuclear-powered shieldless ram jet as a high-altitude missile.

DESCRIPTION OF CYCLE

The high-altitude, nuclear-powered, shieldless, ram-jet missile investigated is shown in figure 1 and is identical to that reported in reference 1. The nuclear-powered ram jet combines the conventional diffuser and exhaust nozzle with a nuclear reactor in place of chemical fuel to supply heat. The diffuser decelerates the free-stream air before it enters the reactor passages. The air is heated in the reactor by contact with the hot walls and then discharged in a fully expanding nozzle to provide thrust. The engine, consisting of diffuser, reactor, and exhaust nozzle, makes up the fuselage to which the required wing and tail surfaces are attached.

The reactor is moderated by beryllium oxide. A number of 0.50-inch-inside-diameter smooth passages are provided through the moderator for direct-air cooling. The uranium can be assumed to be distributed through the beryllium-oxide moderator or concentrated near the surface of the air-flow passages. The length and number of passages are determined by the heat-transfer and air-flow requirements. The reactor has 3-inch beryllium-oxide end reflectors, no side reflectors, and no shielding inasmuch as the missile is unmanned.

PROCEDURE AND ASSUMPTIONS

Calculations were made to determine the best reactor and missile operating conditions for low-temperature, direct-air, shieldless, ram-jet missiles operating at altitudes of 50,000 to 80,000 feet and flight Mach numbers of 2.5 and 3.0. The reactor inlet-air Mach number and reactor free-flow ratio were systematically varied to include values giving the "best" combination of low gross weight and low uranium investment at each flight condition. The best values of gross weight and uranium investment and corresponding reactor and missile operating conditions were then plotted as functions of altitude and flight Mach number.

The best operating condition is difficult to establish. An expendable missile should be low in cost and use a minimum amount of uranium. As will be shown later in the section RESULTS AND DISCUSSION, the operating condition giving minimum uranium is not always that giving lowest gross weight and accordingly not the lowest in cost. Frequently, a slight increase in uranium investment might reduce the gross weight sufficiently to lower the over-all cost.

In this report the best operating condition was taken as the minimum uranium condition unless a slight increase in uranium investment gave substantial weight savings. In this case the best operating condition was selected quite arbitrarily by inspection of the results since a detailed cost analysis was beyond the scope of this report.

For these calculations the pay load (including guidance and controls with shielding, and fixed equipment) was assumed to be 10,000 pounds. In order to be conservative, the reactor effective wall temperature was assigned a value of 1800° R. The reactor effective wall temperature is defined as the constant wall temperature which gives the same air-temperature rise as the actual reactor variable wall temperature. Reference 1 shows that, by varying the free-flow ratio sinusoidally with a mean value of 0.35, the peak reactor wall temperature would be about 400° R higher than the effective value. The peak reactor temperature was therefore about 2200° R. This calculation assumed uniform uranium distribution. Further reduction in peak wall temperature can be expected by a more favorable distribution of uranium. The reactor outlet-air temperature was held constant at the choking value minus 90° R. Reference 1 indicates that the close-to-minimum uranium investment and low gross weight occurred at reactor outlet-air temperatures which were in the range of 30° to 90° R less than the value which caused choking. The value of 90° R was chosen for the present study in order to be conservative.

The uranium-investment calculations assumed that (1) only beryllium-oxide, uranium 235, and void are present in the reactor core; (2) the distribution of all materials and voids within the reactor is uniform; (3) the 3-inch-thick beryllium-oxide end reflectors have the same void fraction as the core; (4) the reactor mean temperature is 1800° R; and (5) no extra uranium is included for control or burn-up.

The detailed method of calculation is the same as that in appendix B of reference 1.

RESULTS AND DISCUSSION

The uranium investment, missile gross weight, and other operating parameters are presented in figures 2 to 5 and are tabulated in table I for the following range of operating conditions:

Flight Mach number	2.5	3.0
Altitude, ft	50,000, 60,000, 70,000	[a]60,000, 70,000
Reactor effective wall temperature, °R	1800	1800
Reactor outlet-air temperature, °R	Choke value minus 90°	Choke value minus 90°
Pay load, lb	10,000	10,000

[a]Calculations were also made for an altitude of 80,000 ft and flight Mach number of 3.0. In order to obtain a reasonable missile at these conditions, the effective wall temperature must be considerably greater than 1800° R; hence, results for this case are discussed but not presented in the figures.

Effect of Reactor Operating Conditions and Flight Conditions on Ram-Jet Performance

Effect of reactor free-flow ratio and inlet-air Mach number on uranium investment and gross weight. - The uranium investment and missile gross weight are plotted in figure 2 as functions of the reactor free-flow ratio (free-flow area divided by frontal area) and reactor inlet-air Mach number for each combination of altitude and flight Mach number. In general, with increasing free-flow ratio, the gross weight and reactor diameter decrease, giving a net decrease in uranium investment, until a point is reached where further reduction in reactor diameter causes an increase in uranium investment. The values of free-flow ratio and inlet-air Mach number which give the best combination of low gross weight and low uranium investment for each flight condition are indicated on the figure.

Effect of altitude and flight Mach number on uranium investment and gross weight. - The uranium investment and missile gross weight are plotted in figure 3 as functions of altitude and flight Mach number using the best-operating-point values of reactor free-flow ratio and reactor inlet-air Mach number (from fig. 2) at each flight condition. For a flight Mach number of 2.5, the uranium investment increases from 30 pounds to 222 pounds and the gross weight increases from 32,000 to 82,000 pounds as the altitude is increased from 50,000 to 70,000 feet. At a flight Mach number of 3.0, the uranium investment increases from 35 to 81 pounds and the gross weight increases from 38,000 to 64,000 pounds as the altitude is increased from 60,000 to 70,000 feet.

For an altitude of 80,000 feet, it was impossible to obtain a reasonable missile with a reactor effective wall temperature of 1800° R. Because of the decreasing air density with increasing altitude, the weight of the reactor per pound of air flow increases. In order to keep the missile gross weight reasonable, the reactor weight per unit of air flow must be reduced. This can be done by increasing the free-flow ratio or by increasing the air density. Increasing the free-flow ratio to values necessary for reasonable gross weight gives excessive uranium investments. The air density can be increased by increasing the flight Mach number. Unfortunately, increasing the flight speed decreases the thrust per unit air flow sufficiently to cause excessive increases in gross weight. The only way to obtain a reasonable ram-jet missile at 80,000 feet is to increase the reactor effective wall temperature. Calculations indicate that an effective wall temperature of about 2300° R is required for operation at an altitude of 80,000 feet with a flight Mach number of 3.0; the uranium investment and gross weight at this condition are 161 pounds and 76,000 pounds, respectively.

Effect of altitude and flight Mach number on reactor and missile parameters. - The best values of reactor free-flow ratio, reactor diameter, reactor length, thrust per pound of air, thrust minus body drag per pound of air, thrust minus body drag per pound of reactor, air flow, reactor heat release, structure (wing, tail, and body shell) to gross weight ratio, and missile lift-to-drag ratio are plotted in figure 4 as functions of altitude and flight Mach number. For convenience, best values of these parameters, as well as others, are also given in table I for the range of flight conditions studied.

Effect of altitude and flight Mach number on missile-weight breakdown. - The missile-weight breakdown as a function of altitude and flight Mach number is shown in figure 5. The component weights considered are (1) reactor, (2) missile body shell, (3) wing and tail surfaces, and (4) pay load (including guidance and controls with shielding, and fixed equipment). The assigned pay load was 10,000 pounds. The actual component weights are given in table I for all the flight conditions considered.

Effect of Assumptions on Ram-Jet Performance

Additional calculations were made to show the effects of airplane lift-to-drag ratio, structure-to-gross-weight ratio, pay load, and reactor effective wall temperature on uranium investment and missile gross weight. These parameters were independently varied over a range of values for an altitude of 50,000 feet and a flight Mach number of 2.5 (reference flight condition). The results are presented in figures 6 to 9. The reference value of the particular parameter being considered is indicated on the corresponding figure.

Effect of airplane lift-to-drag ratio on gross weight and uranium investment. - Uranium investment and missile gross weight are plotted in figure 6 as a function of airplane lift-to-drag ratio for the reference flight condition. A reduction in lift-to-drag ratio from the reference value of 5.21 to a value of 4.0 gives no appreciable change in uranium investment but increases the gross weight from 32,000 to 65,000 pounds. If the lift-to-drag ratio were as low as 3.5, the gross weight would be about 190,000 pounds and the uranium investment about 75 pounds. The increase in uranium investment at the larger values of lift-to-drag ratio results from the reactor diameter decreasing below the value giving minimum uranium investment.

Effect of structure-to-gross-weight ratio on gross weight and uranium investment. - Uranium investment and gross weight are plotted in figure 7 as a function of structure-to-gross-weight ratio for the reference flight condition. The structure weight is the sum of the wing- and tail-surface weights and the missile body-shell weight. The reference value is 0.135 at the reference flight condition (fig. 4).

A 50-percent increase in structure-to-gross-weight ratio to about 0.20 gives no appreciable change in uranium investment and an increase in gross weight from 32,000 to 40,000 pounds.

Effect of pay load on gross weight and uranium investment. - Uranium investment and gross weight are plotted in figure 8 as a function of pay load. The reference pay load (including guidance and controls with shielding, and fixed equipment) is 10,000 pounds (fig. 5). The curve shows that gross weight is, for all practical purposes, directly proportional to pay load; increasing the pay load from 10,000 to 20,000 pounds (fig. 8) increases the gross weight from about 32,000 to 63,000 pounds. At a pay load of 10,000 pounds, the reactor diameter is slightly less than that giving minimum uranium investment. Hence, an increase in pay load (which increases reactor diameter) causes a slight reduction in uranium investment, while a decrease in pay load (from 10,000 lb) causes an increase in uranium investment.

Effect of reactor average wall temperature on gross weight and uranium investment. - Uranium investment and gross weight are plotted in figure 9 as a function of reactor effective wall temperature for the reference flight condition. The reference value of effective wall temperature is 1800° R, where a reactor free-flow ratio of 0.45 and reactor inlet-air Mach number of 0.30 gave the best combination of low gross weight and low uranium investment (fig. 2(a)). Similarly, the values of reactor free-flow ratio and inlet-air Mach number used at other values of effective wall temperature (tabulated in fig. 9) are neither for minimum uranium or minimum gross weight, but a good combination of both. Consequently, either curve in figure 9 could be shifted to show an improvement, but at the expense of the other. Figure 9 shows that a decrease in reactor effective wall temperature from 1800° to 1600° R results in an increase in gross weight from 32,000 pounds to 80,000 pounds with corresponding increase in uranium investment from 33 to 57 pounds. A further reduction in wall temperature gives prohibitive increases in gross weight and uranium investment.

Effect of stainless steel in reactor, side reflection, and nonuniform power distribution. - These effects, considered in detail in reference 1, are briefly summarized.

In the event that stainless-steel tubes, with an inside diameter of 0.50 inch and a wall thickness up to 0.010 inch, are inserted in the beryllium-oxide moderator to contain the fissionable materials, an increase in uranium investment is required. At the reference flight condition, the uranium investment would increase from 30 pounds (fig. 3) with no stainless steel in the reactor to 160 pounds with 0.010-inch-wall stainless-steel tubes in the reactor.

Reactor side reflection is not considered for the present application. Actually, reference 1 shows that the addition of side reflector (in the case of a fixed-size missile with reactor-plus-reflector diameter, air flow, and reactor inlet-air Mach number and hence over-all free-flow ratio held constant) results in a net increase in uranium investment. That is, the increase in free-flow ratio of the core alone, as side reflector is added, tends to increase the uranium investment while reflector savings tend to decrease the investment. The net result is that uranium investment increases about 20 percent by the addition of a 3-inch side reflector.

The effect of nonuniform power distribution is to increase the difference between the reactor effective wall temperature and the allowable peak temperature in the center of the reactor. This temperature difference may be reduced by a suitable radial variation of free-flow ratio (heat-transfer surface area). For example, in reference 1 it is shown that for a given reactor configuration and average wall temperature of 2200° R, the peak temperature of the center tube was 4100° R with uniform free-flow variation. By using a sinusoidal free-flow variation (with an average value of 0.35 and with a maximum value of 0.65 at center of reactor), the peak temperature for the same over-all free-flow ratio was reduced to 2600° R. This 400° difference between peak temperature and reactor effective wall temperature would roughly limit the latter to a value of 2000° R (fig. 9) if stainless steel were required in the reactor. The peak wall temperature could also be reduced by using a more favorable uranium distribution at the expense of greater uranium investment; this calculation was beyond the scope of the present report.

The calculated uranium investments are for the clean hot core. If a reactor life of 6 hours is assumed, an initial excess reactivity of 0.014 must be built into the reactor to counteract the poison build-up and fuel burn-up in this period. This requires an increase in uranium concentration of about 8 percent. Therefore, the uranium investments shown in the figures herein should be increased by about 8 to 10 percent to account for poisoning, fuel burn-up, and control.

SUMMARY OF RESULTS

Uranium investment, gross weight, and corresponding reactor operating conditions are calculated for a high-altitude, low-temperature, nuclear-powered, ram-jet missile. Studies are made for altitudes of 50,000 to 80,000 feet, flight Mach numbers of 2.5 and 3.0, a reactor effective wall temperature of 1800° R, and an assigned pay load of 10,000 pounds.

Calculations to determine the effect of reactor operating conditions and flight conditions on ram-jet performance indicate that

(1) The reactor operating conditions giving the "best" combination of low gross weight and low uranium investment at various flight conditions are as follows:

Altitude, ft	Flight Mach number	Gross weight, lb	Uranium investment (hot clean core), lb	Reactor free-flow ratio	Reactor inlet-air Mach number
50,000	2.5	32,100	29.9	0.45	0.30
60,000		45,400	46.2	.52	.28
70,000		82,400	222.0	.57	.30
60,000	3.0	37,500	34.6	0.50	0.28
70,000		63,700	81.3	.59	.28

(2) For an altitude of 80,000 feet and a flight Mach number of 3.0, the reactor effective wall temperature must be increased to at least 2300° R to obtain a missile with reasonable gross weight and uranium investment.

Calculations to determine the sensitivity of performance to basic assumptions for an altitude of 50,000 feet and a flight Mach number of 2.5 indicate that

(1) A decrease in lift-to-drag ratio from 5.21 to 4.0 had little effect on uranium investment; the corresponding gross weight increased from 32,000 to 65,000 pounds. The lowest tolerable value of lift-to-drag ratio was about 3.5.

(2) An increase in structure-to-gross-weight ratio of 50 percent had no appreciable effect on uranium investment and increased the gross weight from 32,000 to 40,000 pounds.

(3) An increase in pay load from 10,000 to 20,000 pounds had a negligible effect on uranium investment. The gross weight, which was approximately proportional to pay load, increased from 32,000 to 63,000 pounds.

(4) Lowering the reactor effective wall temperature from 1800° to 1600° R increased the uranium investment by about 75 percent and the gross weight by 150 percent. A further reduction in wall temperature gave a prohibitive increase in uranium investment and gross weight.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, July 22, 1955

REFERENCES

1. Rom, Frank E.: Analysis of a Nuclear-Powered Ram-Jet Missile. NACA RM E54E07, 1954.

2. Starr, Bollay, Rice, and Waite: Feasibility of Nuclear Powered Rockets and Ram-Jets. NA-47-15, North Am. Aviation, Inc., 1947.

TABLE I. - REACTOR AND MISSILE OPERATING CONDITIONS GIVEN "BEST" COMBINATION OF LOW GROSS WEIGHT AND LOW URANIUM INVESTMENT AT EACH ALTITUDE AND FLIGHT MACH NUMBER

Assumptions: Reactor effective wall temperature, 1800° R
Reactor outlet-air temperature, choke value minus 90° R
Pay load, 10,000 lb
Diffuser pressure recovery, 0.825 (at flight Mach number = 2.5)
Diffuser pressure recovery, 0.675 (at flight Mach number = 3.0)
Nozzle velocity coefficient, 0.97
Beryllium-oxide moderator
No stainless steel in reactor core

Flight Mach number	2.5	2.5	2.5	3.0	3.0
Altitude, ft	50,000	60,000	70,000	60,000	70,000
Reactor free-flow ratio	.45	.52	.57	.50	.59
Reactor effective wall temperature, °R	1800	1800	1800	1800	1800
Reactor inlet-air temperature, °R	883	883	883	1097	1097
Reactor outlet-air temperature, °R	1467	1527	1467	1625	1625
Reactor inlet-air Mach number	.30	.28	.30	.28	.28
Reactor outlet-air Mach number	.565	.543	.565	.470	.470
Reactor pressure ratio	.763	.746	.759	.766	.766
Length-diameter ratio (diffuser)	2.78	2.53	1.99	1.65	1.04
Length-diameter ratio (body center section)	2.00	2.00	2.00	2.00	2.00
Length-diameter ratio (nozzle)	1.29	.92	.30	.01	.78
Thrust/lb air	14.9	16.4	14.9	12.1	12.1
Thrust minus body drag/lb air	8.98	11.6	11.5	9.14	9.34
Length-diameter ratio (tubes)	104	100	79	117	106
Thrust minus body drag/lb reactor	.199	.198	.187	.203	.192
Gross weight, lb	32,100	45,400	82,400	37,500	63,700
Air flow, lb/sec	397	474	877	529	899
Wing surface area, sq ft	165	411	1200	258	720
Wing span (including body), ft	25.7	38.9	65.7	31.4	51.4
Body total length, ft	37.1	44.3	55.8	25.5	40.6
Reactor heat release, Btu/sec	59,000	77,900	130,000	72,600	124,000
Lift-drag ratio (over-all)	5.21	5.83	6.32	5.84	5.83
Structure (wing plus body shell) to gross weight ratio	.131	.171	.223	.101	.157
Reactor diameter, ft	6.11	8.12	13.0	6.97	10.6
Reactor length, ft	4.31	4.17	3.29	4.87	4.43
Uranium investment, lb	29.9	46.2	222	34.6	81.3
Weight breakdown:					
Wing and tail, lb	1280	3180	9060	1500	4460
Body shell, lb	2910	4610	9300	2280	5540
Reactor, lb	17,910	27,610	54,040	23,720	43,700
Pay load, lb	10,000	10,000	10,000	10,000	10,000

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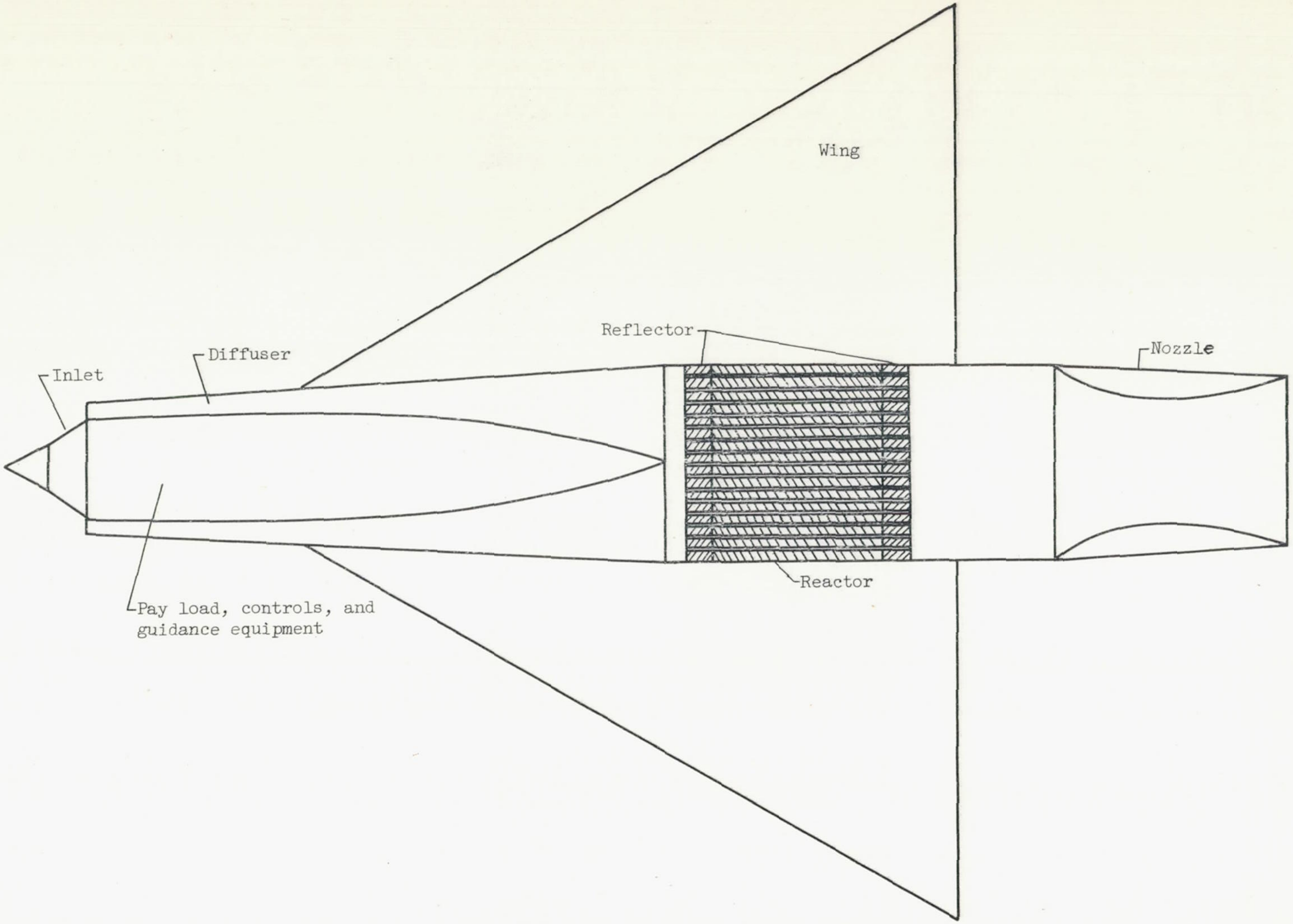

Figure 1. - Schematic sketch of shieldless nuclear-powered ram-jet missile.

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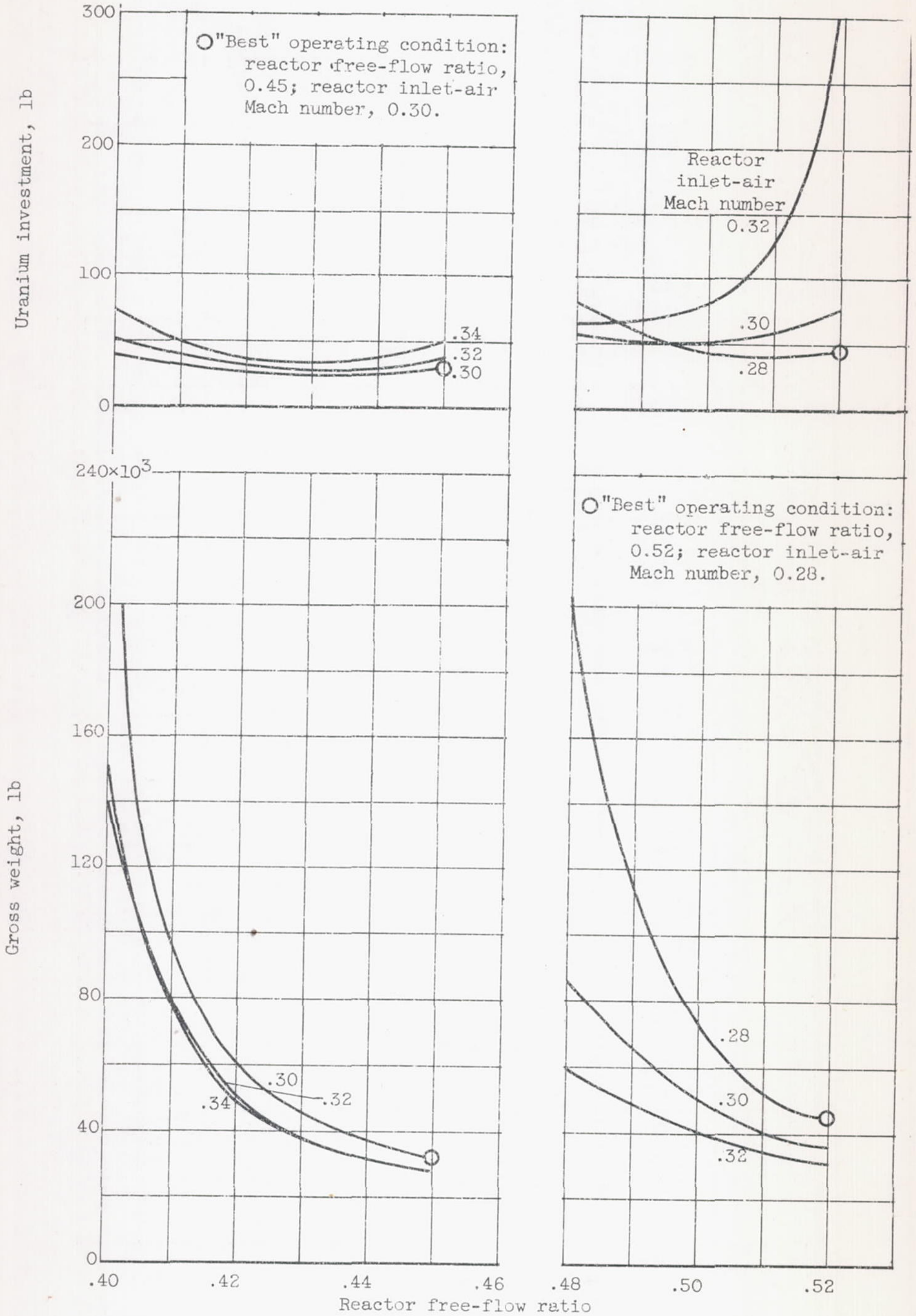
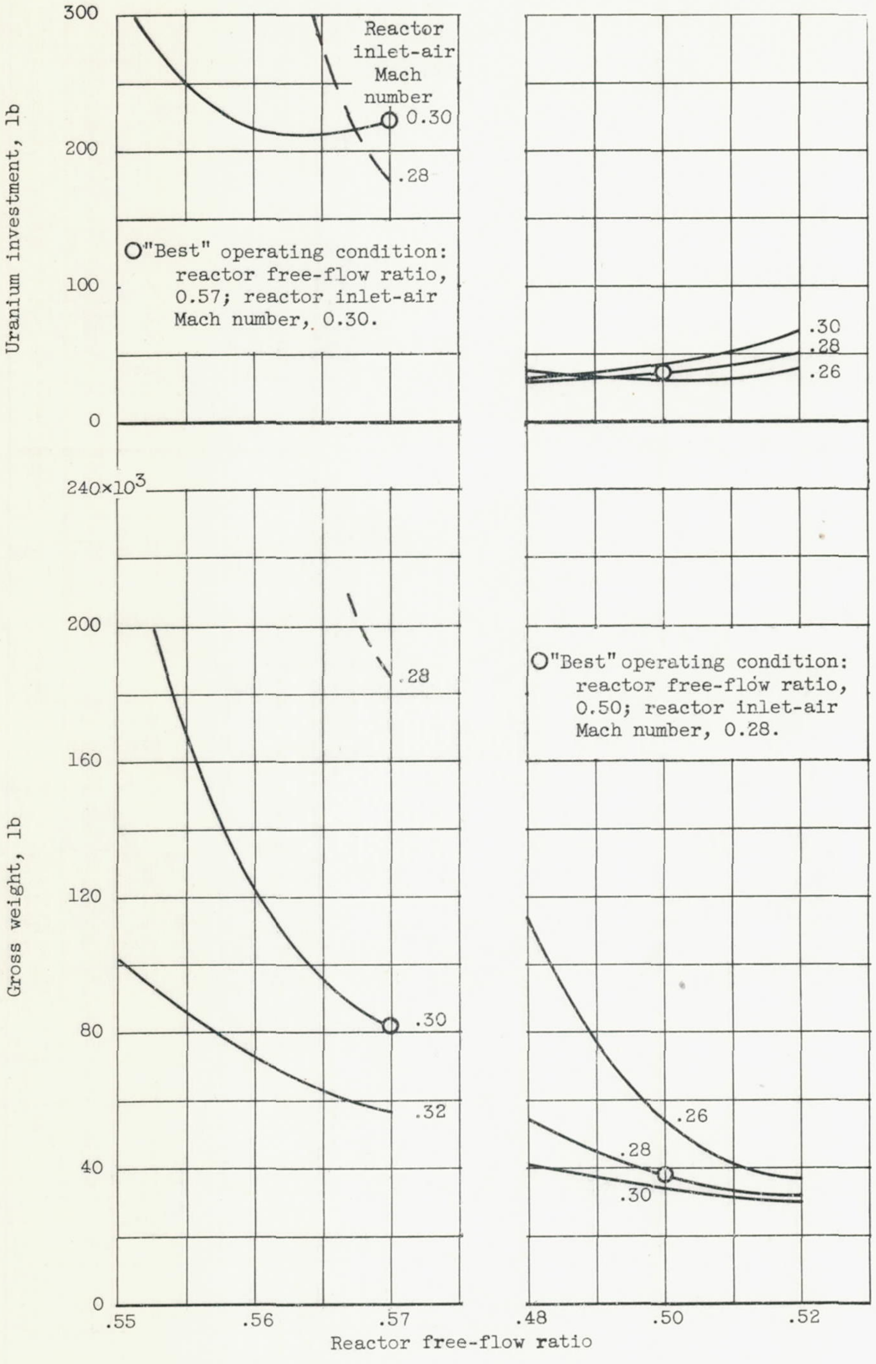


(a) Altitude, 50,000 feet; flight Mach number, 2.5.

(b) Altitude, 60,000 feet; flight Mach number, 2.5.

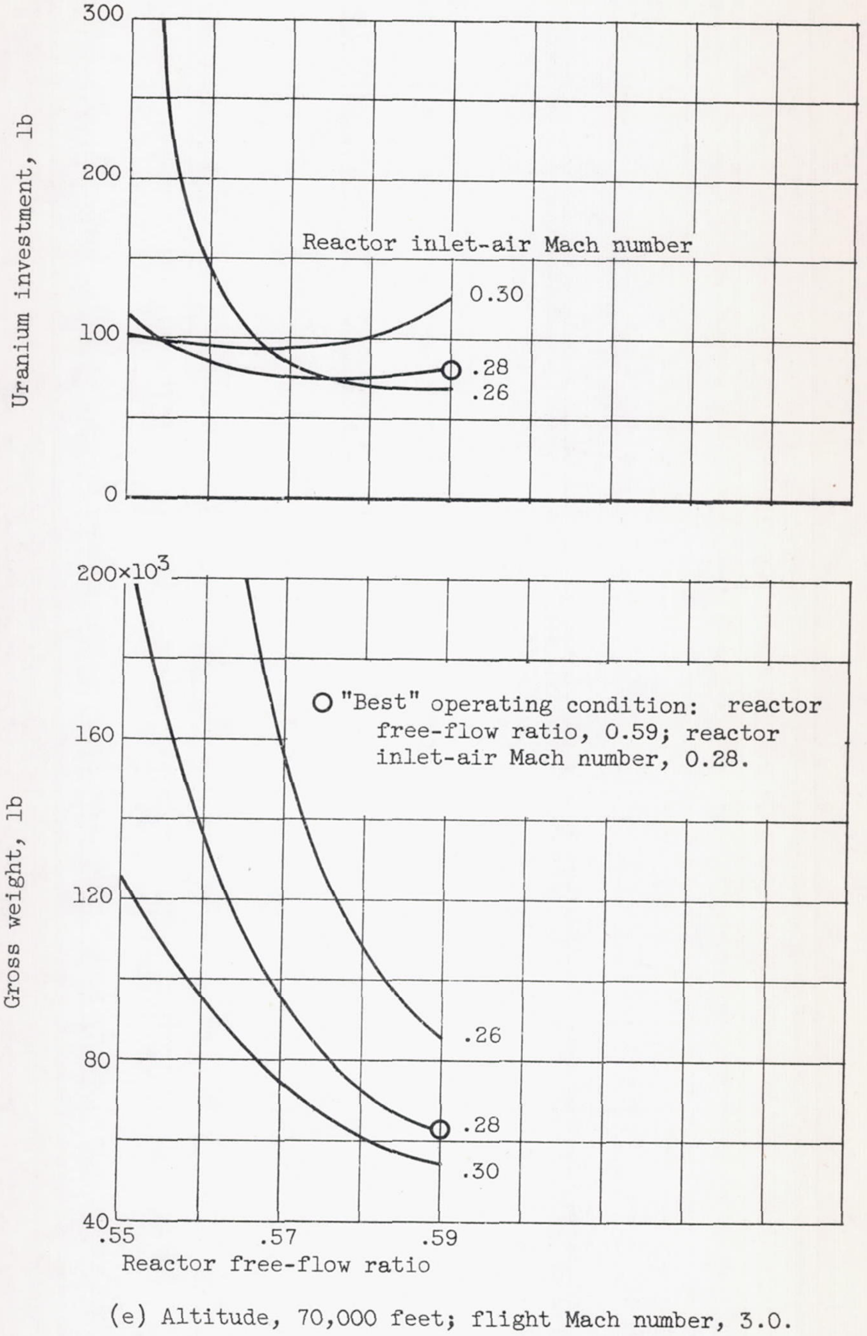
Figure 2. - Uranium investment and missile gross weight as function of reactor free-flow ratio and reactor inlet-air Mach number. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.



(c) Altitude, 70,000 feet; flight Mach number, 2.5.

(d) Altitude, 60,000 feet; flight Mach number, 3.0.

Figure 2. - Continued. Uranium investment and missile gross weight as function of reactor free-flow ratio and reactor inlet-air Mach number. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.



(e) Altitude, 70,000 feet; flight Mach number, 3.0.

Figure 2. - Concluded. Uranium investment and missile gross weight as function of reactor free-flow ratio and reactor inlet-air Mach number. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.

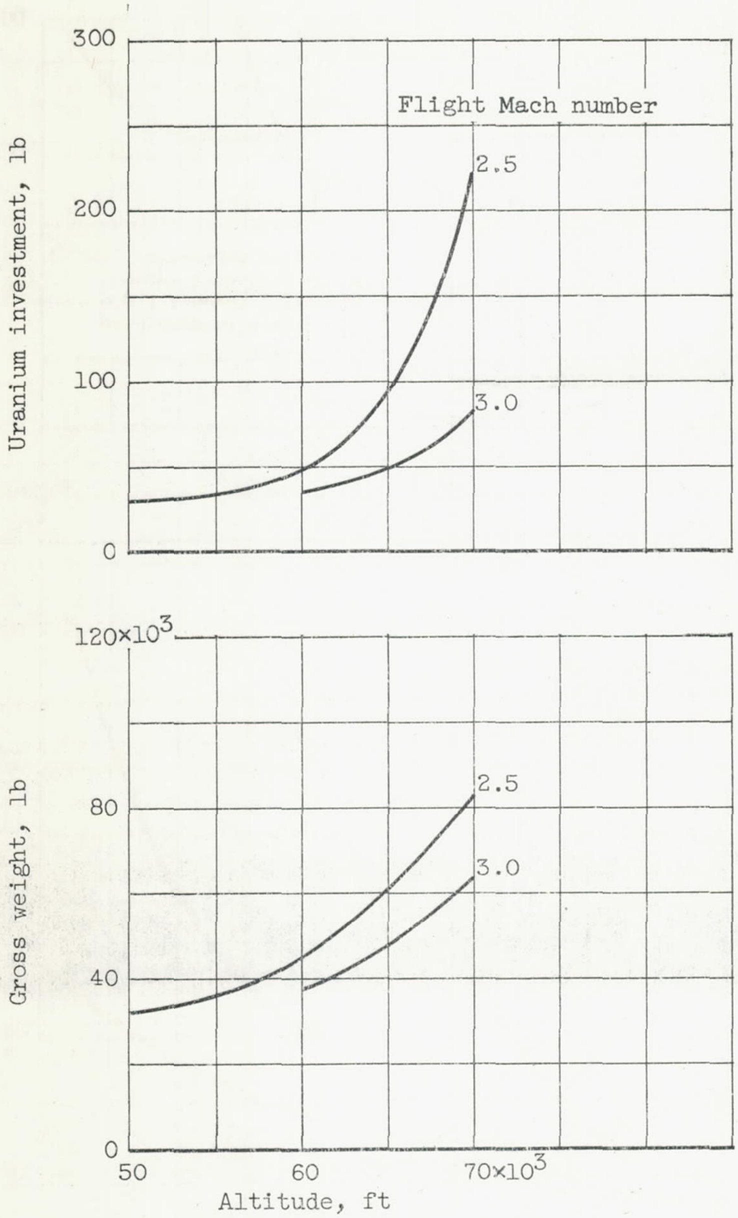


Figure 3. - Uranium investment and missile gross weight as function of altitude and flight Mach number for values of reactor free-flow ratio and reactor inlet-air Mach number giving "best" combination of low gross weight and low uranium investment. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.

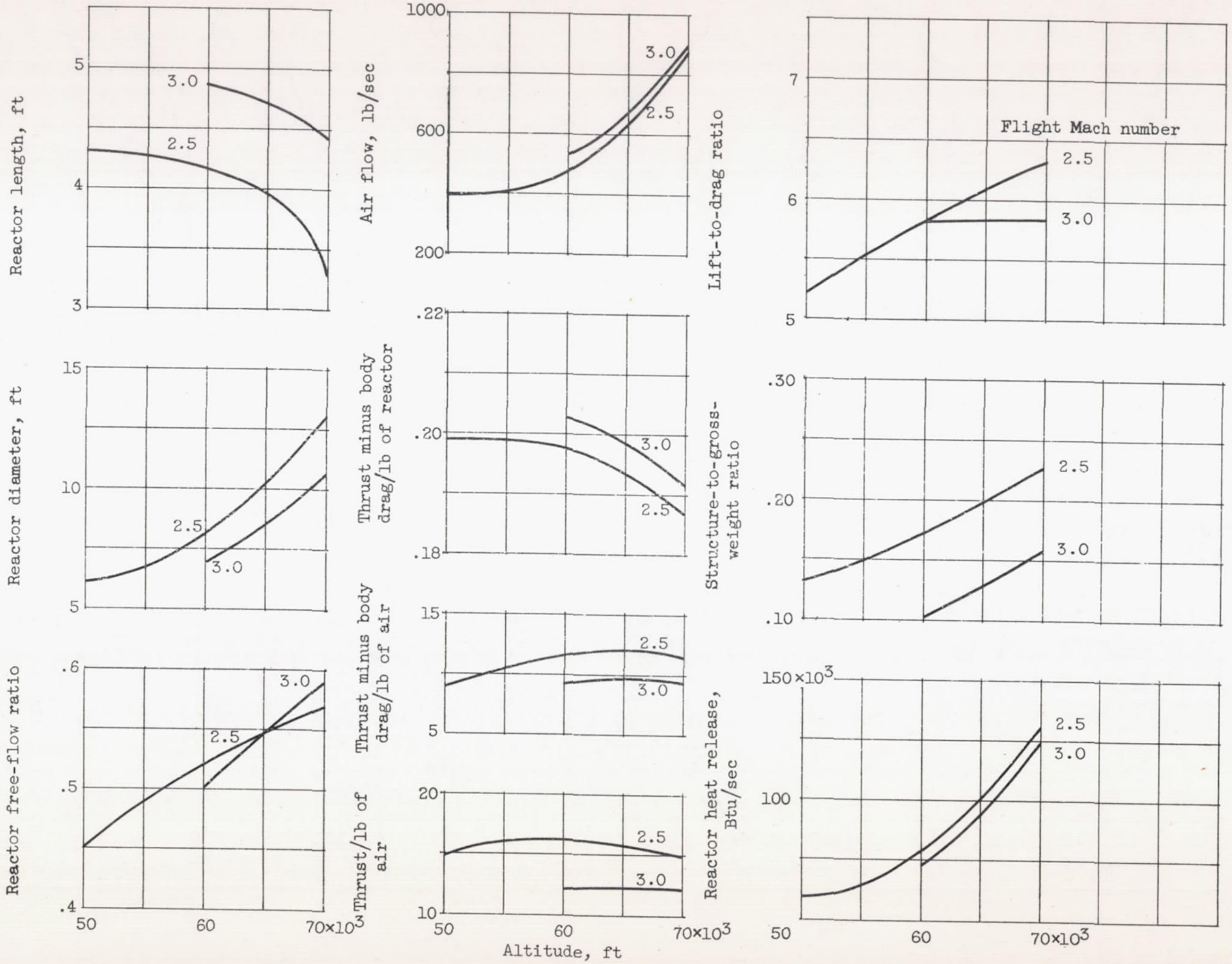
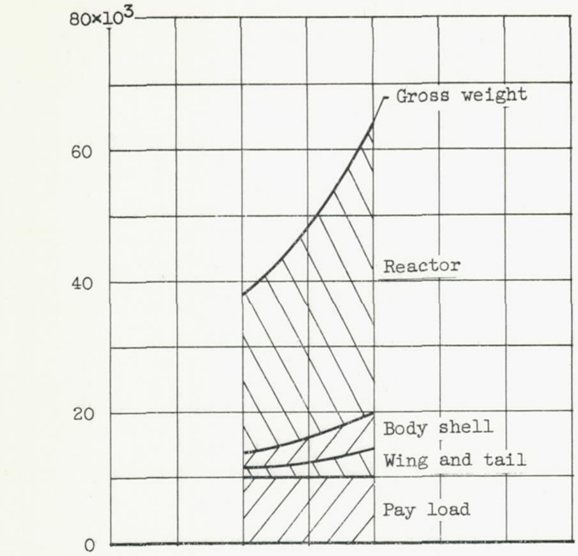
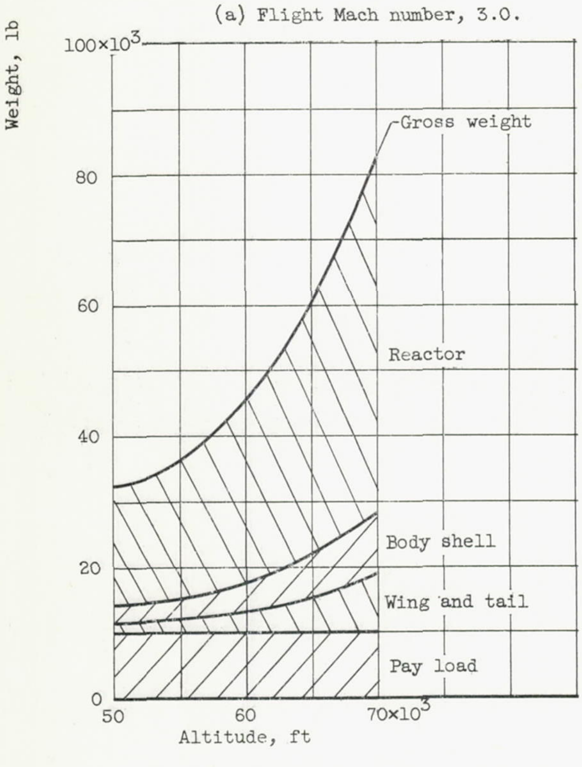


Figure 4. - Ram-jet missile operating conditions as function of altitude and flight Mach number for values of reactor free-flow ratio and reactor inlet-air Mach number giving "best" combination of low gross weight and low uranium investment. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.



(a) Flight Mach number, 3.0.



(b) Flight Mach number, 2.5.

Figure 5. - Ram-jet missile-weight breakdown as function of altitude and flight Mach number for values of reactor free-flow ratio and reactor inlet-air Mach number giving "best" combination of low gross weight and low uranium investment. Reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.

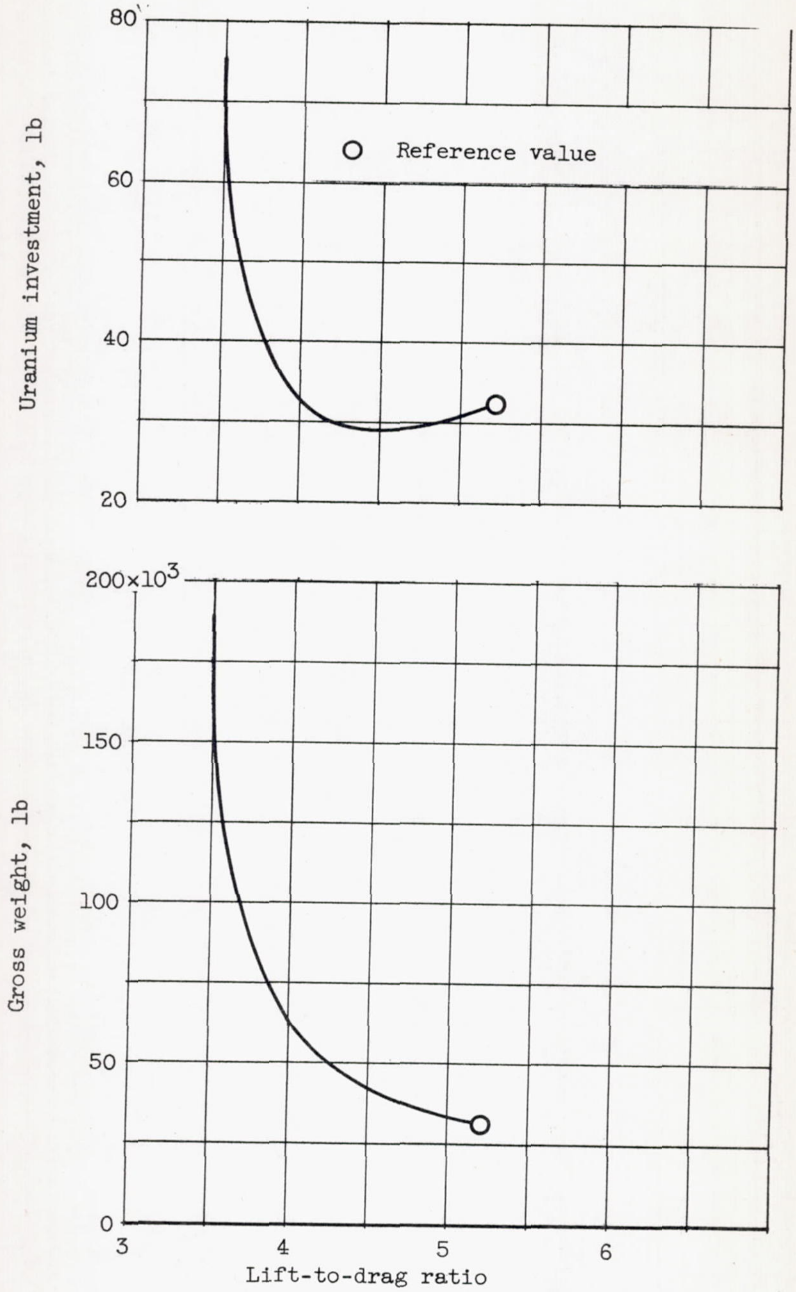


Figure 6. - Uranium investment and missile gross weight as function of airplane lift-to-drag ratio for an altitude of 50,000 feet and flight Mach number of 2.5. Reactor free-flow ratio, 0.45; reactor inlet-air Mach number, 0.30; reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.

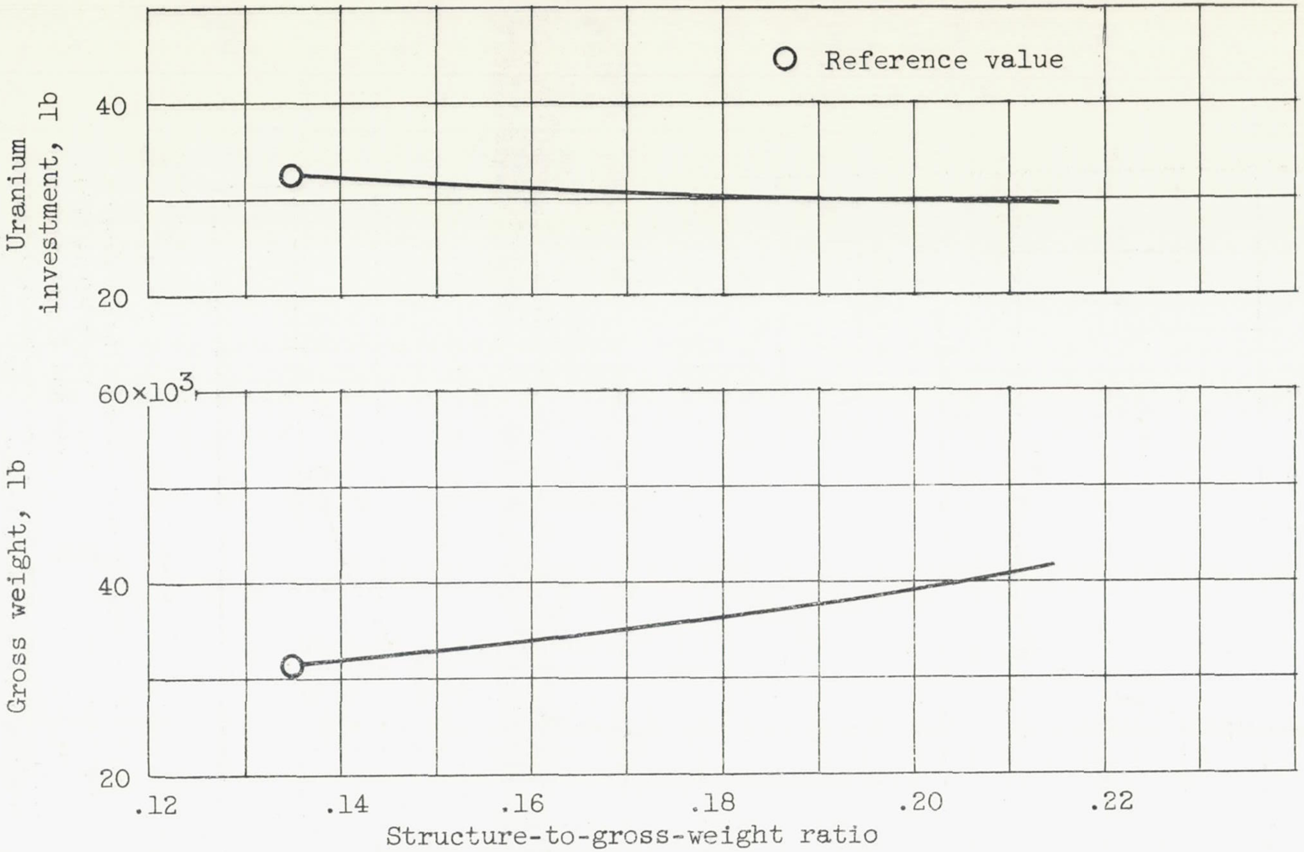


Figure 7. - Uranium investment and missile gross weight as function of structure-to-gross-weight ratio for an altitude of 50,000 feet and flight Mach number of 2.5. Reactor free-flow ratio, 0.45; reactor inlet-air Mach number, 0.30; reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; pay load, 10,000 pounds; no stainless steel in reactor.

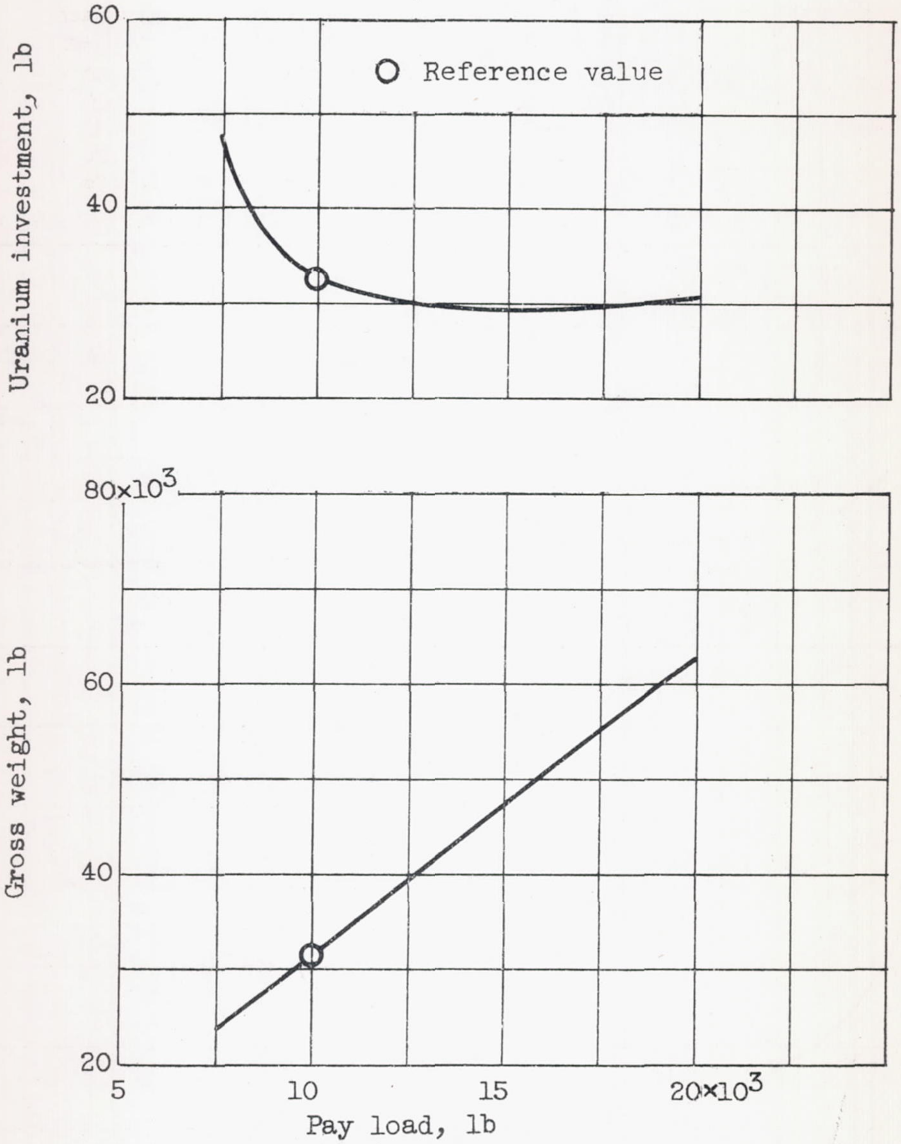
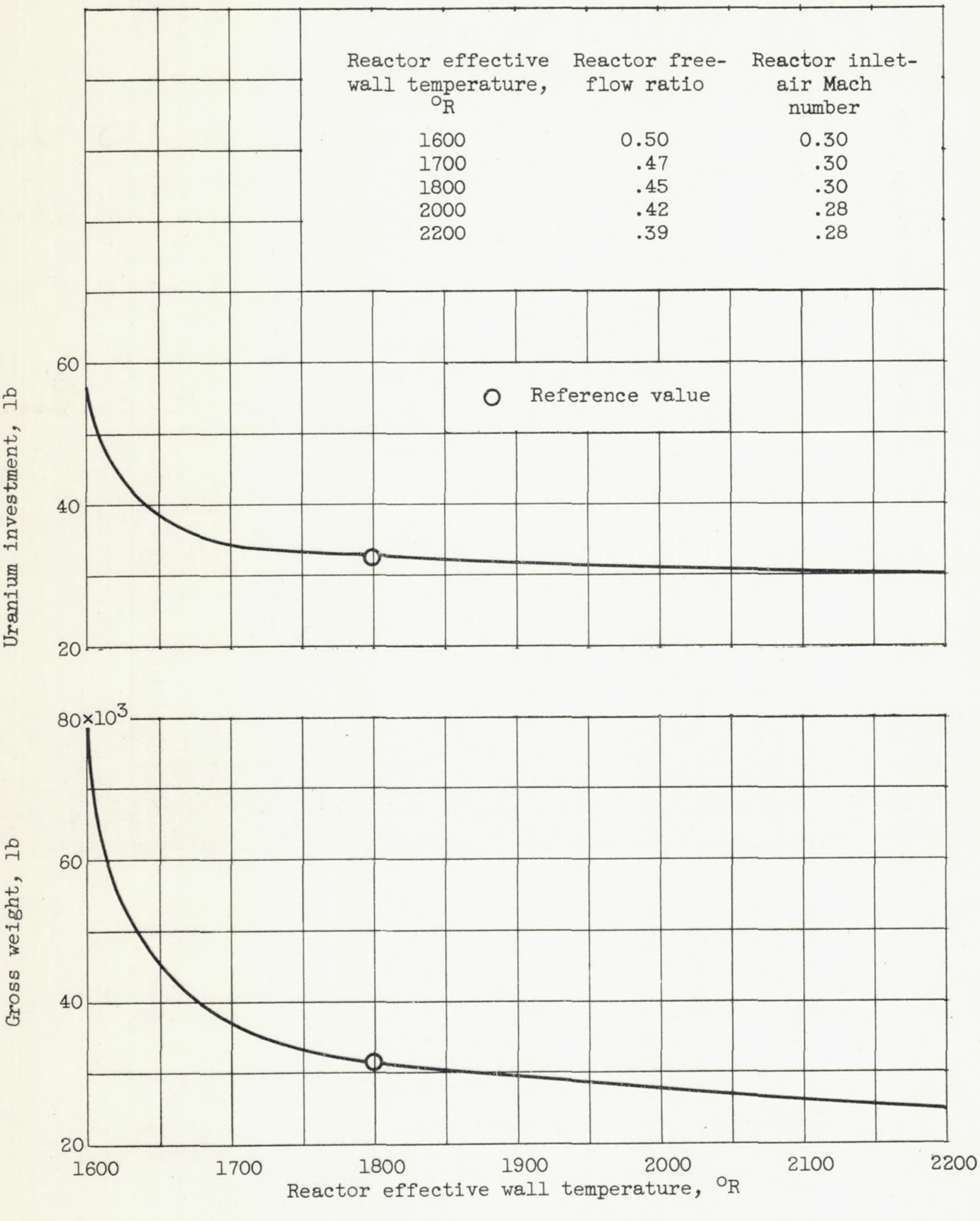


Figure 8. - Uranium investment and missile gross weight as function of pay load for an altitude of 50,000 feet and flight Mach number of 2.5. Reactor free-flow ratio, 0.45; reactor inlet-air Mach number, 0.30; reactor outlet-air temperature, choke value minus 90°; reactor effective wall temperature, 1800° R; no stainless steel in reactor.



Reactor effective wall temperature, °R	Reactor free-flow ratio	Reactor inlet-air Mach number
1600	0.50	0.30
1700	.47	.30
1800	.45	.30
2000	.42	.28
2200	.39	.28

Figure 9. - Uranium investment and missile gross weight as function of reactor effective wall temperature for an altitude of 50,000 feet and flight Mach number of 2.5. Reactor free-flow ratio and reactor inlet-air Mach number varied to give "best" combination of low uranium investment and low gross weight at each value of wall temperature; reactor outlet-air temperature, choke value minus 90°; pay load, 10,000 pounds; no stainless steel in reactor.

Unclassified when detached from rest of report

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