30 p

[redacted]

[redacted]

NOT FOR USE IN NASA INFORMATION SYSTEM

— WRITTEN VERSION —

NASA TMX 51641

N65-35263 (ACCESSION NUMBER)	(THRU) 1
30 (PAGES)	(CODE) 02
TMX-51641 (NASA CR OR TMX OR AD NUMBER)	(CATEGORY)

FACILITY FORM 602

A STUDY OF HYPERSONIC AIRCRAFT

By Douglas E. Wall

GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 2.00

Microfiche (MF) .50

ff 653 July 65

For presentation at
Fourth National Airport Conference
San Francisco, Calif.
April 22-24, 1964

[redacted]

N65-35263

[redacted]

A STUDY OF HYPERSONIC AIRCRAFT

Douglas E. Wall
NASA Flight Research Center

Proposed for Presentation

at

Fourth National Airport Conference

Hotel Sheraton - Palace

San Francisco, Calif.

April 22-24, 1964

A STUDY OF HYPERSONIC AIRCRAFT

Unedited version - Not for use in NASA info system

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROPOSED PAPER

A STUDY OF HYPERSONIC AIRCRAFT

By Douglas E. Wall

ABSTRACT

35263 A

This paper presents the results of a study performed at the NASA Flight Research Center in which the characteristics of several potential hypersonic aircraft were compared. In this study, candidate fuels were assessed for their application to hypersonic aircraft, several modes of propulsion were considered as well as their flight regions of operation, and an assessment of various classes of hypersonic aircraft was made.

The study showed that long-range hypersonic cruise aircraft are sufficiently interesting to warrant more detailed studies. Interceptors employing hydrogen fuel are competitive with those employing hydrocarbon fuels at Mach numbers of 5 to 6. Finally, advancements in the state of the art would provide a more practical sized recoverable booster for takeoff from conventional runways.

This study also concluded that research programs should be aimed at providing technology advancements in propulsion, configuration aerodynamics, and high temperature light weight structures to meet the demands of future hypersonic aircraft.

Author

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

PROPOSED PAPER

A STUDY OF HYPERSONIC AIRCRAFT

By Douglas E. Wall

INTRODUCTION

A study was performed at the NASA Flight Research Center to determine the gross characteristics of future hypersonic aircraft. This study did not incorporate the refinement of configuration optimization. The characteristics defined by this study were to be used as a guide in assessing the need for future hypersonic flight research.

The purpose of this paper is to show some of the possibilities and characteristics of future hypersonic aircraft as envisioned by Flight Research Center engineers.

In this space age one might logically ask why we are still concerned with airplanes. The answer is that the aspects of aerodynamic lift and air-breathing propulsion available from the atmosphere appear to be potentially attractive for future applications. This is clearly evident for those systems requiring sustained cruise operation.

Figure 1 shows the history of aircraft speeds. The shaded areas indicate probable extensions in future years. The large slope of the rocket powered research airplanes indicates rapid advancements in technology. This trend could be reflected in military and commercial aircraft in the future resulting in flight at hypersonic speeds. However, this would be dependent upon engine development and the development of high temperature, light weight structures and materials.

Since hypersonic aircraft are so dependant upon the mode of propulsion, it is in order to review some of the proposed fuels and some candidate propulsion systems and their flight regions of operation. Following this, an assessment will be made of each class of hypersonic aircraft.

HYPERSONIC PROPULSION

Flight in the sensible atmosphere at hypersonic speeds will require at least two and possibly three or four modes of propulsion for some of the vehicle systems. Various tradeoffs also are possible, based on the selection of fuels and the flight region of operation. Figure 2 shows a performance comparison of the liquid H_2 air-breathing engines with the LH_2-LO_2 rocket motor. The ability of the air-breathing engines to produce significantly more thrust per pound of carried propellant shows their suitability for cruise applications.

Candidate Fuels for Hypersonic Cruise

The following table presents various characteristics of three fuels.

TABLE I - VARIOUS FUEL CHARACTERISTICS

FUEL	Lower Heating Value BTU/lb fuel	Apparent Heat Sink BTU/lb fuel	Density lbs/ft^3	Actual Heat Release *BTU/ft^3 air	Available Heat Sink *BTU/ft^3 air	Volumetric Fuel Requirements ft^3 tank fuel / *ft^3 air
Liquid Hydrogen	51,600	5,100	4.4	115	12.9	.09
Liquid Methane	20,000	1,200	26.5	89	4.9	.03
Hydrocarbon	18,700	500	49.9	100	4.3	.02

* per cubic foot of inlet air for stoichiometric combustion

The first three columns of the chart show the familiar values associated with fuels. The last three columns assess the fuels on the basis of each cubic foot of air entering the inlet for complete combustion. The last column shows the effect of change in tank volume for each cubic foot of inlet air. The LH_2 fuel gives the highest heat release for producing thrust. It is also clearly superior as a heat sink for operation at the higher flight speeds. The chief disadvantage is the large volume requirement for fuel storage, and in the smaller aircraft, this results in high drag which offsets the increased heat release. At first glance, the liquid methane appears to be attractive. However, the last three columns indicate that the small increase in available heat sink over the hydrocarbons would not warrant the loss in performance or the increase in tank volume.

Modes of Propulsion

Both turbojet engines and rocket motors were used extensively in this study. Since both are familiar propulsion systems, it is not felt that further discussion of these systems is warranted. In contrast, ramjets are not quite so familiar and therefore warrant some discussion.

Subsonic Combustion Ramjet

At hypersonic speeds, the subsonic combustion ramjet engine is clearly superior to the turbojet. However, flight speeds greater than a Mach number of 1 are usually required for ramjet acceleration of large vehicles. Therefore, the aircraft must be accelerated to this speed with rocket or turbojet power. The upper portion of Figure 3 shows the schematic of this engine. The inlet air is compressed and slowed down resulting in a terminal shock. The flow behind the terminal shock where combustion is taking place is subsonic. At the higher hypersonic speeds, the internal static pressure and temperature become extremely high. With present state of the art materials, this engine and portions of the inlet must be regeneratively cooled by the fuel. At extremely high speeds the fuel required to cool the engine and inlet exceeds the fuel flow required to cruise the aircraft. At speeds above this, cruise efficiency drops rapidly.

Supersonic Combustion Ramjet

At the high hypersonic flight speeds the supersonic combustion ramjet may be superior to the subsonic combustion ramjet. The supersonic combustion ramjet is shown in the lower schematic of Figure 3. The inlet air is not compressed nor slowed down as much as the air in the subsonic combustion engine; consequently, the flow remains supersonic throughout the combustion and expansion processes. The internal static pressures and temperatures are also less than those found in the subsonic engine. The proportionately smaller cowl also allows more radiation cooling on the inlet and exhaust nozzle surfaces. The chief disadvantage of this engine is that it becomes extremely large as will be shown later. It also requires some other propulsion scheme to boost it to these high hypersonic speeds.

Region of Operation

The probable region of operation for the air-breathing engines is shown in Figure 4. Although there is considerable overlap for each of the propulsion systems, the figure shows the relative order of each. It is noted that flight at the higher speeds would require operation at very high skin temperatures. It is doubtful that aircraft would cruise at speeds high enough to require active cooling of major portions of the aircraft. It therefore, appears reasonable that a Mach number 8 to 10 cruise aircraft employing a supersonic combustion ramjet would be a logical choice. For the subsonic combustion ramjet engine it appears that a Mach number 5 to 6 cruise speed would be reasonable.

Hypersonic Aircraft

Long Range Cruise Aircraft

The probable ranges for long range cruise aircraft are as shown on Figure 5. Since the large aircraft must necessarily accelerate and decelerate at low rates, it is interesting to note that the ratio of cruise range to ascent plus descent range decreases from 5.0 for an SST to 1.8 for a Mach number 10 cruise aircraft capable of flight half-way around the world. At speeds significantly above Mach 10, the aircraft would probably be classed as an acceleration-boost aircraft rather than a cruise aircraft. Cruise above a Mach number of 4 will require extensive analyses of configuration tradeoffs, inlet-engine matching, and cooling requirements. It was beyond the scope of this study to determine whether these ranges could be met with practical airplanes. Therefore, they should be viewed as probable goals. A configuration for a Mach number 8 to 10 cruise aircraft employing supersonic combustion is currently under study and is shown on Figure 6. The engine inlet, cowl, and exhaust nozzle extend the full length of the vehicle. The inlet cowl closes at the lower speeds to prevent spill drag. Auxiliary inlets and exhausts outlets open on the ramps to provide propulsive thrust at the lower speeds. It is estimated that the vehicle would weigh approximately 600,000 lbs.

Short Range Accelerator - Cruise Aircraft

This category includes those aircraft which would accelerate rapidly to hypersonic speeds and also be capable of extended cruise with total ranges of approximately 3,000 nautical miles. This includes hypersonic interceptors and the hypersonic research airplane.

Figure 7 shows an outline drawing of a LH_2 fueled interceptor using turboramjet engines. It would have dash capability to a Mach number greater than 7, and would cruise at a Mach number of 6. Figure 8 shows an outline drawing of a JP-fueled interceptor using turboramjet engines. This vehicle would cruise at a Mach number of 6. For the Mach number 6 cruise case both vehicles had comparable ranges - in the order of 3,000 nautical miles. However, the interceptor using JP fuel was not designed for operation above a Mach number of 6.

Figure 9 shows an outline drawing of a LH_2-fueled turboramjet powered hypersonic research airplane. This vehicle would have acceleration capability greater than a Mach number of 7, and a total range of 2,800 nautical miles at a cruise speed of Mach number 6.

Figure 10 shows the estimated sonic boom overpressures for a typical boost trajectory of the hypersonic research airplane. Since flights of a vehicle of this type would be made over a sparsely populated area, the 3.0 lbs/ft^2 level was felt to be acceptable.

Acceleration - Boost Aircraft

In Figure 2 it was shown that the air-breathing engines are clearly superior to the rocket engines for cruise applications. If aircraft such as recoverable boosters will require periods of extended cruise for increased orbital offset capability, then the air-breathing engines are needed. However, if the recoverable boosters must only accelerate to some final or staging speed, it is not clear which propulsion system is superior. The rocket engine has a high thrust-to-weight ratio and a low specific impulse. The air-breathing engines have a high specific impulse and a low thrust-to-weight ratio. and the classical arguments will continue on through the years until sufficient technology is obtained through research to show the true merits of the air-breathing engines.

For this paper, a comparison was made between a subsonic combustion turboramjet-powered research vehicle and a rocket-powered vehicle. Both vehicles were the same external shape except for propellant tankage, engines, and inlets. Figure 11 shows the results of that study. The rocket powered airplane was weight limited at takeoff and weighed 100,000 lbs. At a Mach number of 7, both vehicles had about the same propellant (or fuel) reserves. The air-breathing vehicle weighed 20% less than the rocket airplane at takeoff and took much longer to accelerate to the terminal speed. It is realized that two entirely different aircraft would result if each vehicle were optimized for it's propulsion system; however, the trends would remain the same. It also indicates that hybrid propulsion systems such as the air-augmented rocket may also be competitive for booster applications.

Although boost-aircraft have been considered for many applications in the past, the following studies were focused on an earth-to-orbit transportation system. This system would transport men and supplies to a hypothetical space station.

Single Stage to Orbit

A study was performed assuming that air-breathing engines would be utilized to their maximum capacity and then final propulsion would be supplied by LO_2-LH_2 rockets. Figure 12 shows the requirements to achieve single stage to orbit capability. The ordinate is the velocity of transition from air-breathing to rocket engines plotted versus the overall mass ratio for three rocket specific impulse curves. These curves represent the existing LO_2-LH_2 rocket, an advanced chemical rocket, and a nuclear rocket, respectively. As an example of the joint requirements, if air-breathing engines were advanced from 3,000 ft/sec to 7,000 ft/sec and the rocket was improved to a specific impulse of 500, it would require a mass ratio of about 3.8. With current structural efficiences, it does not appear to be possible to build an airplane with this overall mass ratio. The nuclear rocket would require a mass ratio of 2.25. Again, with the high shielding weights it is doubtful that an overall mass ratio of this magnitude could be built. Therefore, it did not appear feasible to consider a single stage to orbit transportation system in the near future.

Two Stage to Orbit

Since the requirements for a two-stage vehicle are less stringent than those of the single-stage vehicle, a study was performed to investigate this type of vehicle. A parametric study was performed to determine second-stage launch weight requirements. Figure 13 shows the effect of rocket motor specific impulse on the second-stage launch weight as a function of staging velocity. The curves show that high staging velocities are required to reduce the second stage launch weight to a reasonable size. For a second stage launch weight of 400,000 lbs. the takeoff gross weight would probably exceed 1,000,000 lbs. Figure 14 shows the effect of inert weight fraction. For the values selected, the effects of inert weight fraction had a larger effect than the specific impulse effect. It indicates that significant improvements may be offered by lighter and stronger high-temperature structures. Figure 15 shows the combined effect of specific impulse and inert weight fraction. Assuming that the second-stage launch weight is 40% of the total vehicle takeoff gross weight, a staging velocity of 6,600 ft/sec would require a 1,000,000 lb takeoff gross weight for present state-of-the-art. Improvements in the state-of-the-art or in the staging velocity would significantly reduce the weight and improve the second-stage payload weight fraction.

CONCLUSIONS

The following conclusions can be formed from the studies completed to date:

1. The long-range hypersonic cruise aircraft is sufficiently interesting to warrant more detailed studies.
2. Interceptors flying at low hypersonic speeds could use JP or H_2 fuel. If dash capability to the higher speeds is required, then LH_2 appears to be the best fuel.
3. First stage recoverable boosters must stage at reasonably high velocities to reduce the takeoff gross weight. Advancements in the state-of-the-art would provide a more practical size for takeoff from conventional runways.

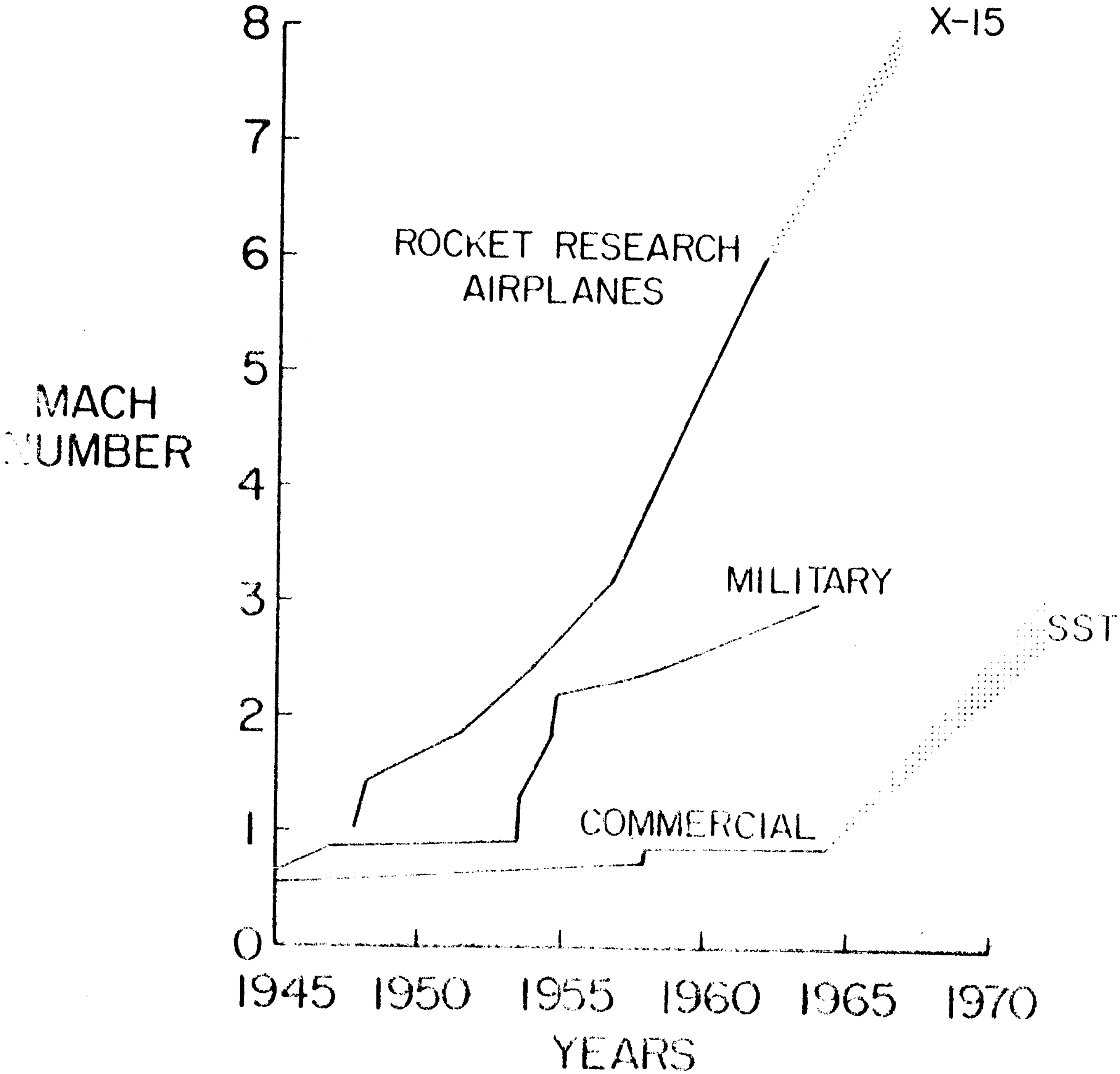
4. Research programs should be aimed at providing advancements in technology in the fields of propulsion, configuration aerodynamics, and high temperature light weight structures to meet the demands of future hypersonic aircraft.

SYMBOLS AND ABBREVIATIONS

BTU	Quantity of heat required to raise a one pound mass of water 1F°
Isp	$\frac{\text{lbs thrust (for rocket)}}{\text{lb/sec flow rate of propellant}} = \frac{\text{lbs thrust (for air-breather)}}{\text{lb/sec flow rate of fuel}}$
JP	Hydrocarbon jet fuel
LO_2	Liquid oxygen
LH_2	Liquid hydrogen
R cruise	Range for cruise portion of flight, nautical miles
R(ascent and descent)	Range for ascent and descent portion of mission, nautical miles
SST	Supersonic transport
V_i	Ideal velocity - velocity one would have achieved without drag and gravity losses, FPS
W_{TO}	Weight of single stage at takeoff, lb
W_{BO}	Weight of single stage at burnout, lb
W_{TO}/W_{BO}	Overall mass ratio
W_i	Inert weight = $W_o - W_p - W_{pl}$, lb
W_o	Weight of 2nd stage at time of launch, lb
W_{pl}	Weight of payload in 2nd stage, lb
$\frac{W_i}{W_o}_{II}$	Inert weight fraction of 2nd stage
$\frac{W_{pl}}{W_o}_{II}$	Payload in percent of 2nd stage launch weight

[redacted]

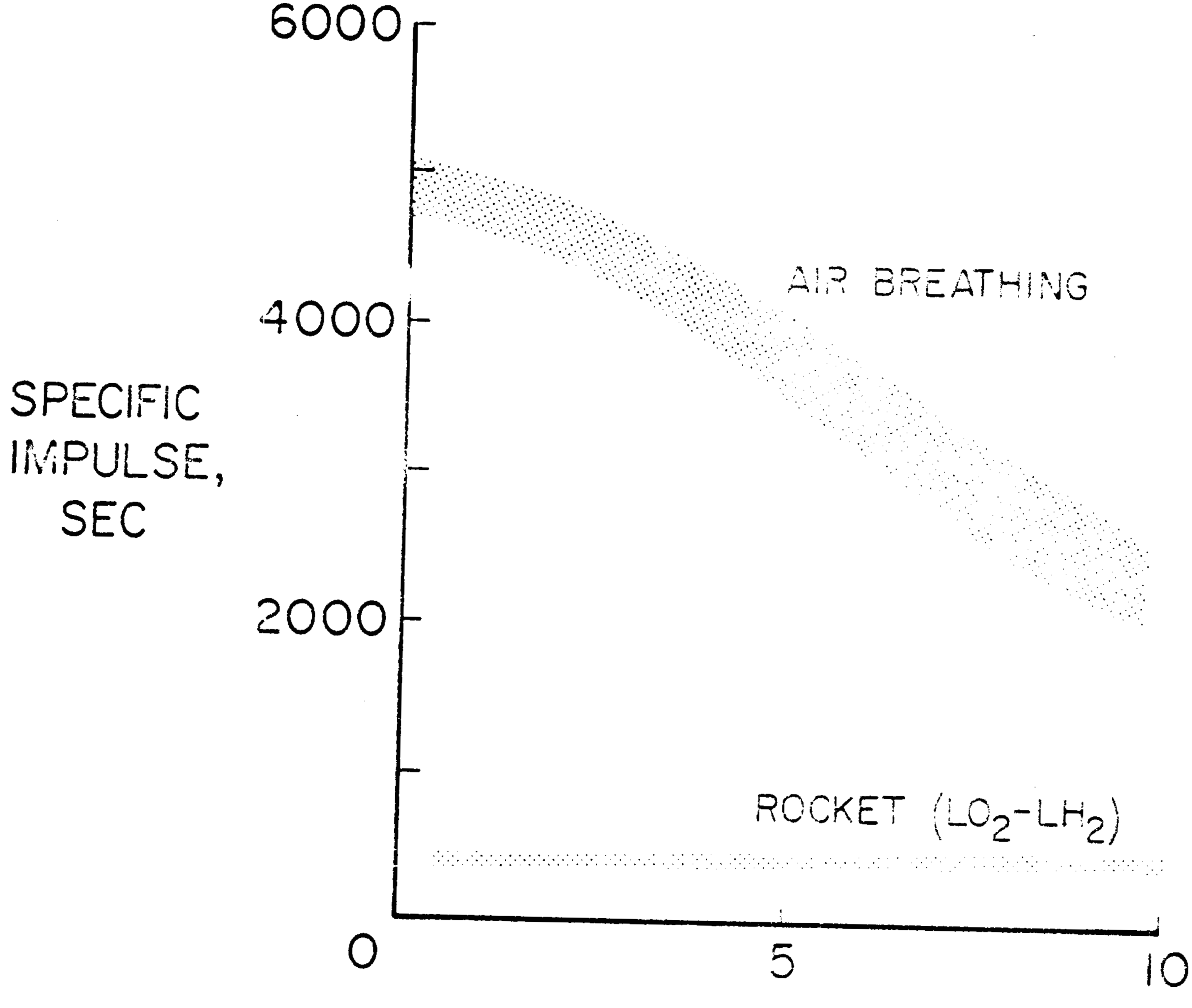
HISTORY OF AIRCRAFT SPEEDS



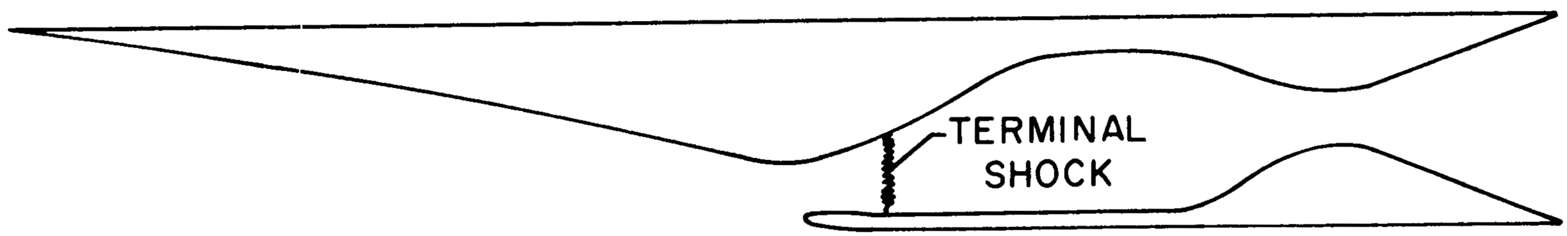
[redacted]

ENGINE-PERFORMANCE COMPARISON

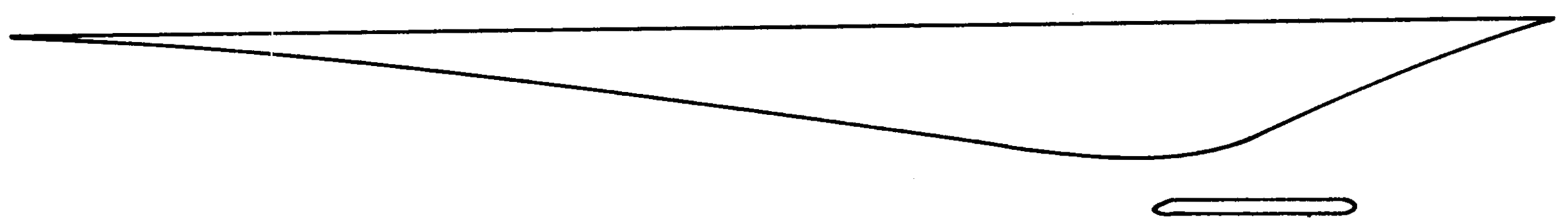
H_2 FUEL



HYPERSONIC AIR-BREATHING PROPULSION SYSTEMS

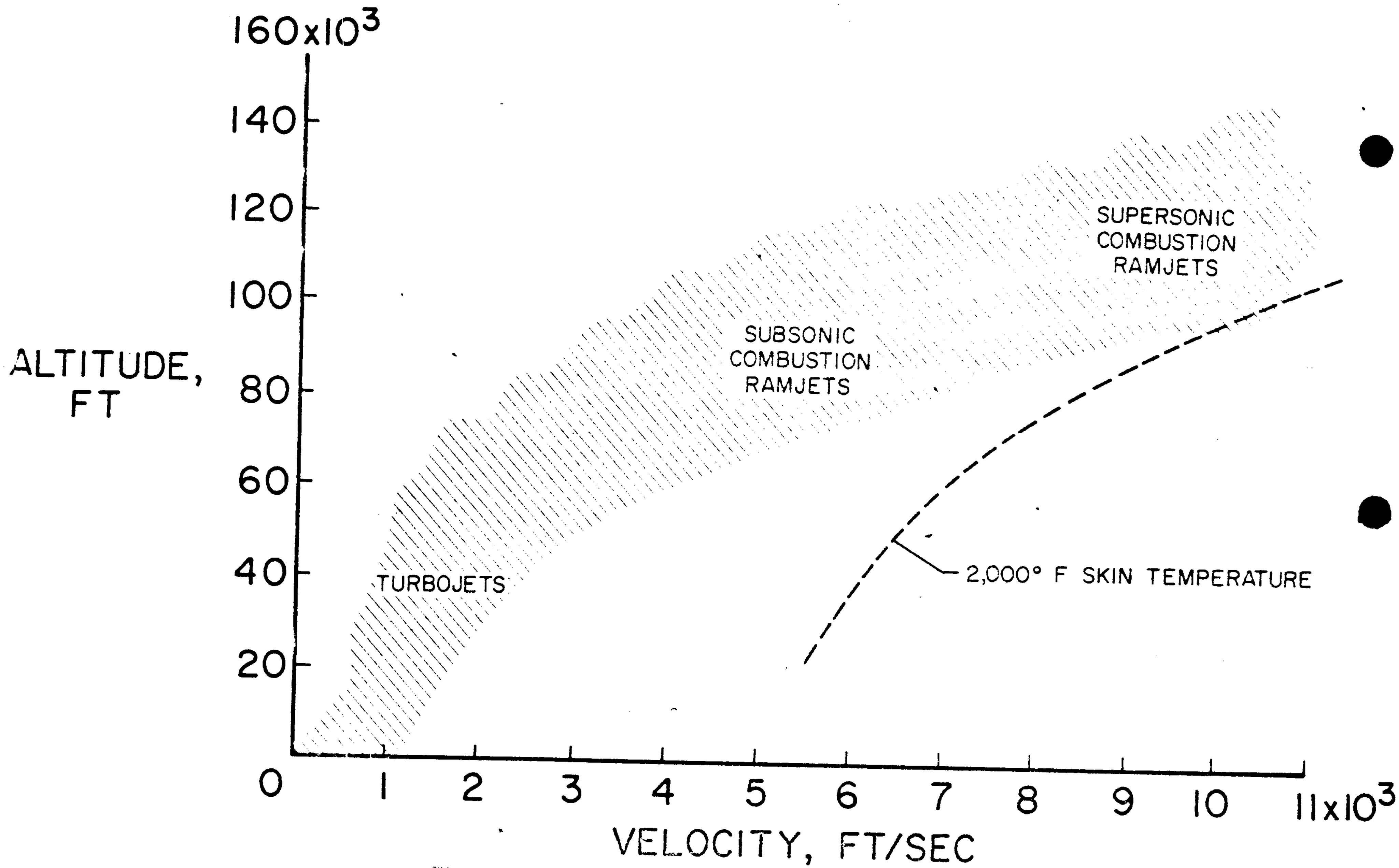


SUBSONIC COMBUSTION RAMJET



SUPERSONIC COMBUSTION RAMJET

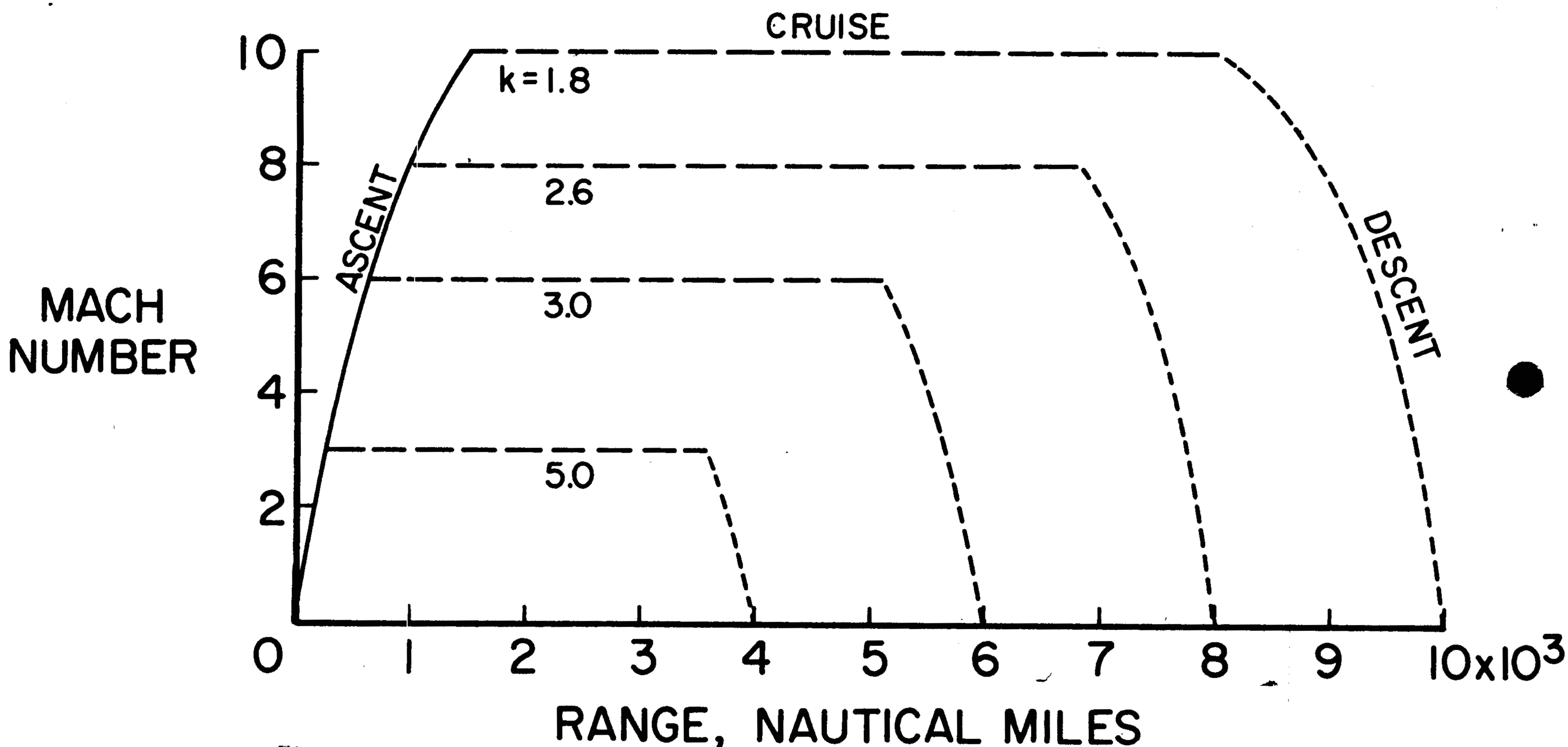
ENVELOPE OF PROBABLE OPERATION FOR AIR-BREATHING ENGINES



Figure

PROBABLE RANGES FOR FUTURE CRUISE AIRCRAFT

$$k = \frac{R_{CRUISE}}{R_{(ASCENT + DESCENT)}}$$



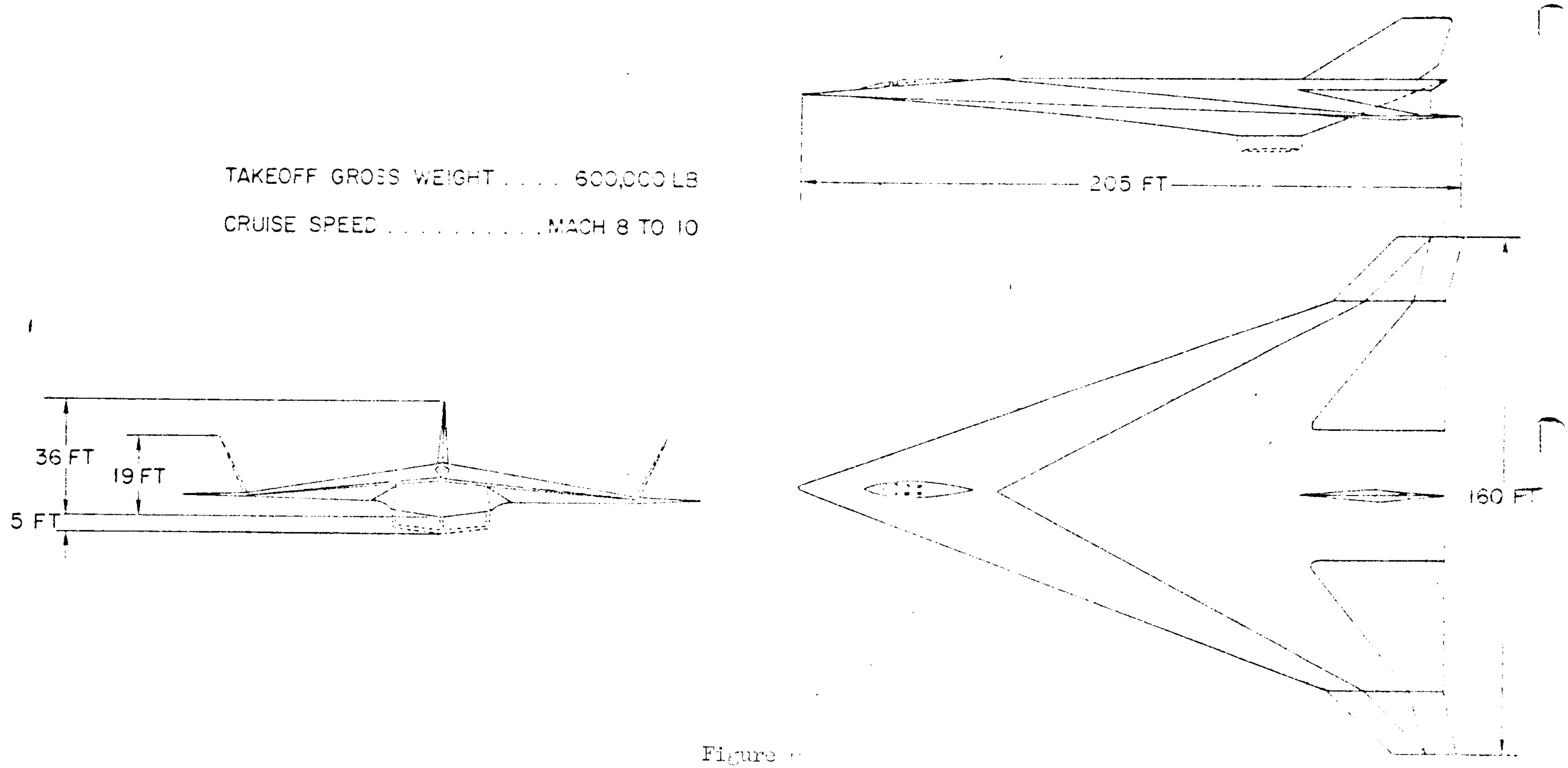
Figure

HYPERSONIC CRUISE AIRCRAFT

LIQUID–HYDROGEN FUEL

TAKEOFF GROSS WEIGHT . . . . 600,000 LB

CRUISE SPEED . . . . MACH 8 TO 10



Figure

GROUND-LEVEL SONIC BOOM

TYPICAL HYPERSONIC RESEARCH AIRCRAFT BOOST TRAJECTORY

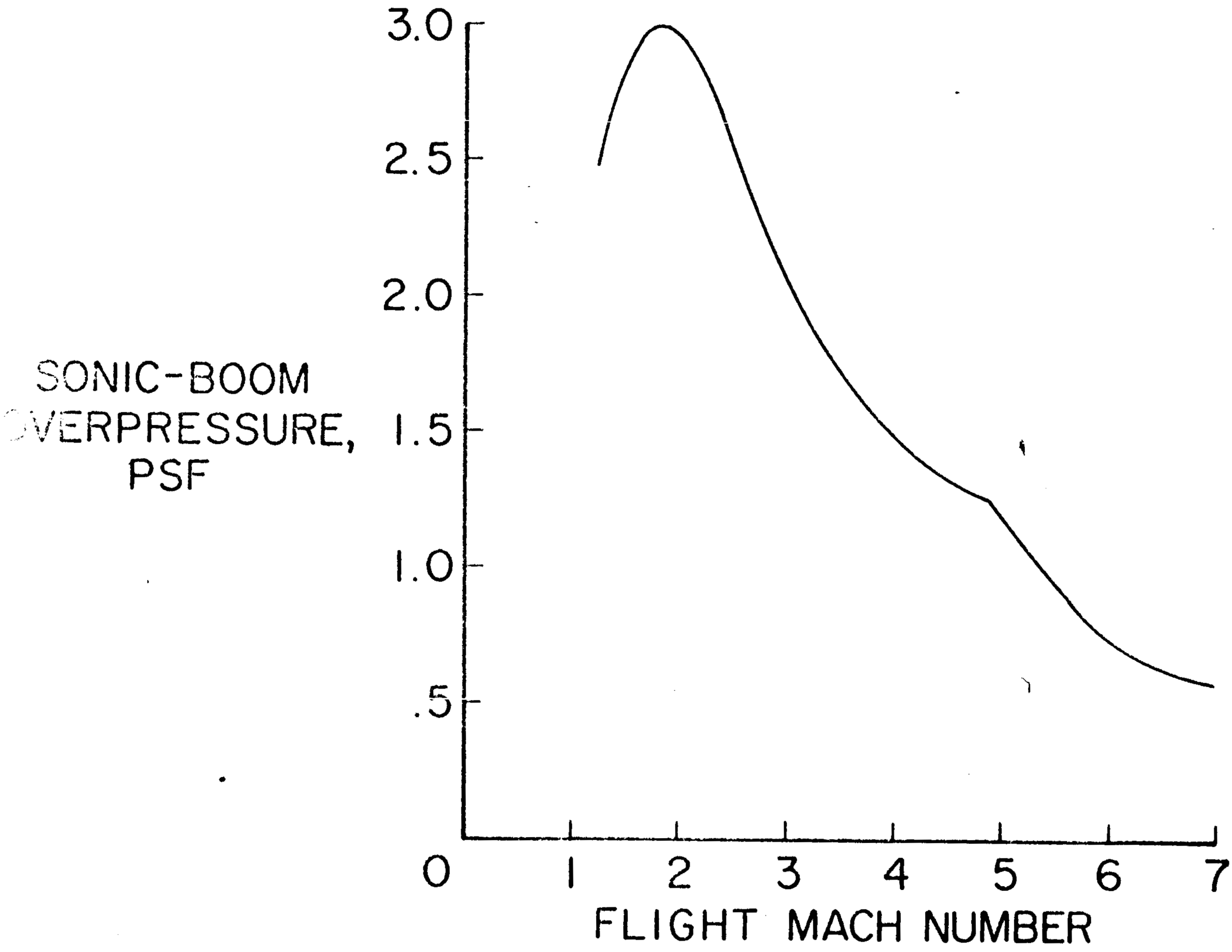
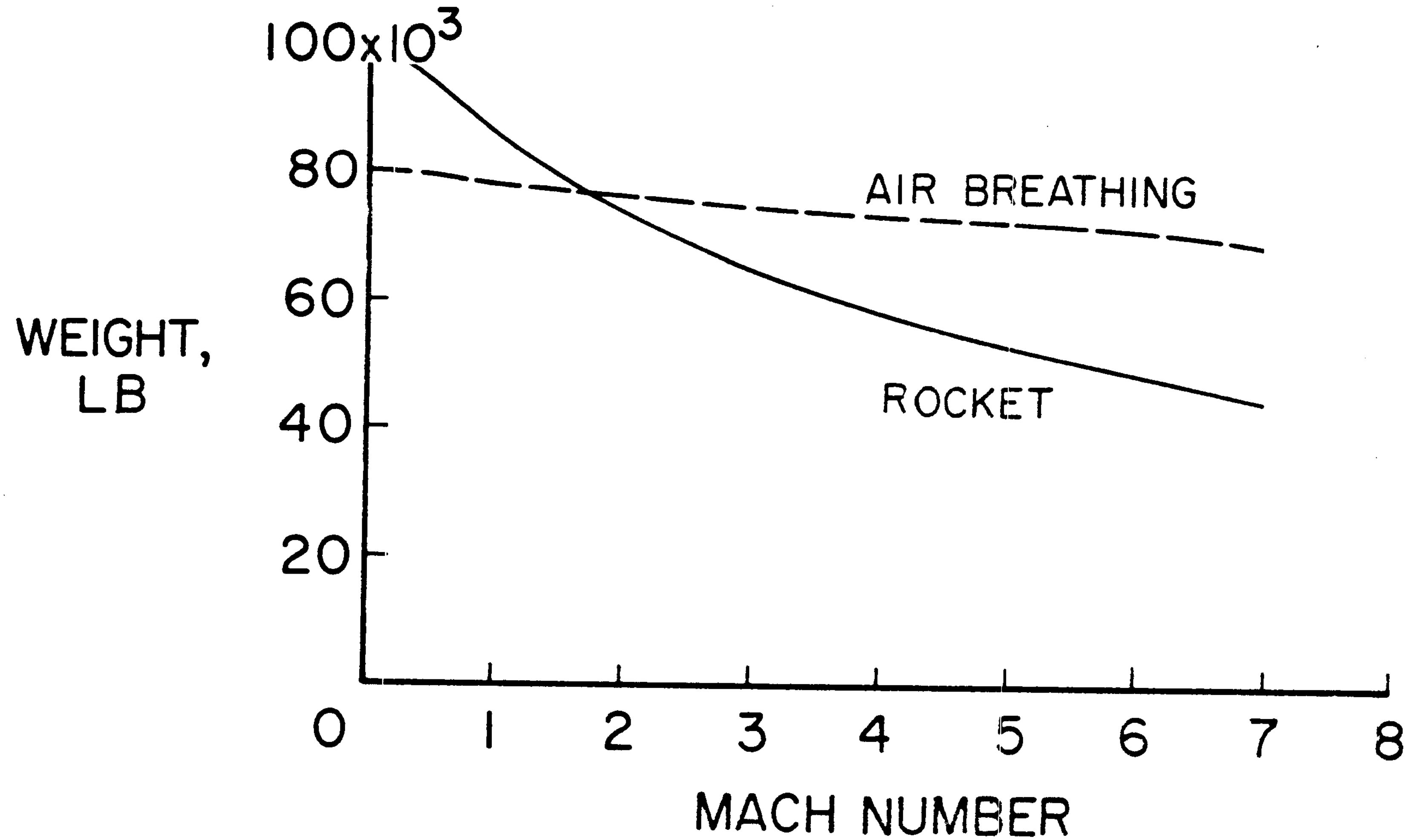


Figure 10

COMPARISON OF AIR-BREATHING AND ROCKET-POWERED AIRPLANES

SAME BASIC HYPERSONIC RESEARCH AIRPLANES



SINGLE-STAGE-TO-ORBIT REQUIREMENTS

LH_2 FUEL, $V_i = 30{,}000$ FPS

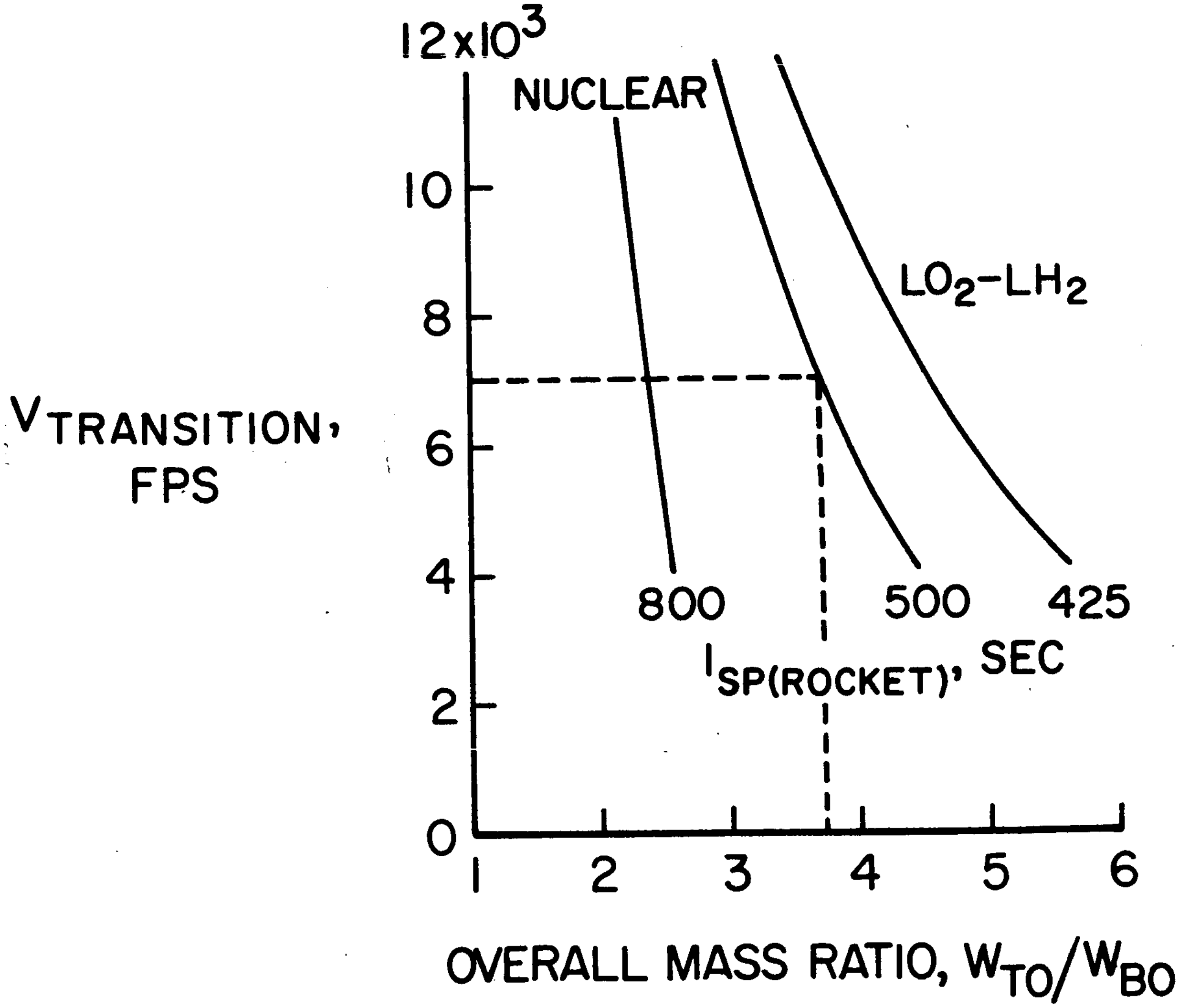


Figure 12

SPECIFIC-IMPULSE AND INERT-WEIGHT-FRACTION EFFECT

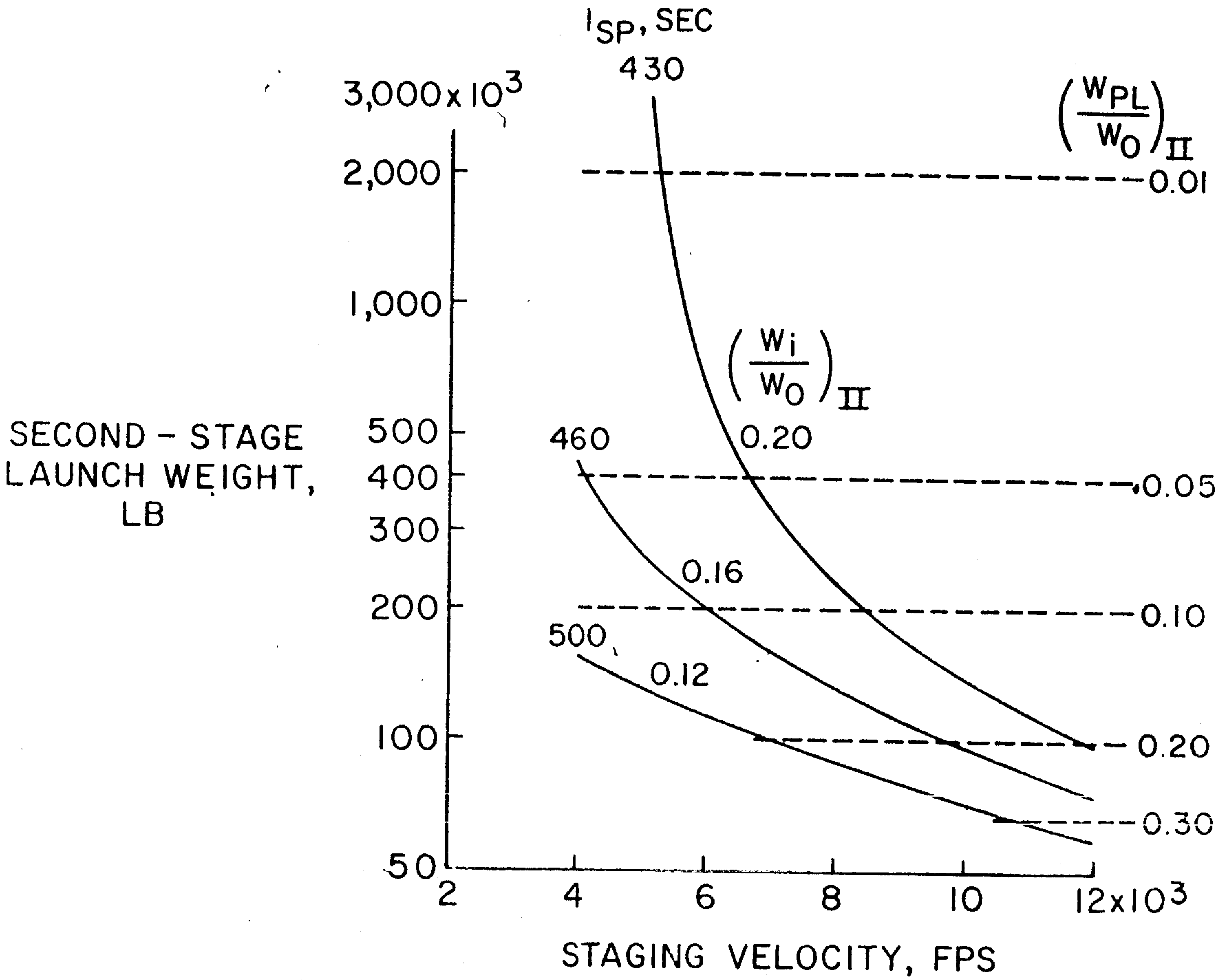


Figure 15