HYPERSONICS AND REENTRY

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HYPERSONIC AND REENTRY

You are now at the site of the Continuous Flow Hypersonic Tunnel. The subjects to be discussed here are vehicles for reentry and hypersonic flight and some of the new NASA high-speed facilities, including this one. First let us consider the conditions under which various types of reentry and hypersonic vehicles operate in the atmosphere. On this slide are shown the altitudes and Mach numbers for typical reentry and hypersonic vehicles. Now, in general, the upper limit of the entry corridors is associated with the vehicle lifting capability in the rarefied atmosphere while the lower limit is determined by maximum heating rates and maximum aerodynamic loads. The vehicle environment encompass wide variations of altitude and Mach number, consequently, there is a considerable variation of the conditions to which the vehicles are subjected.

We can divide these vehicles into classes dependent upon their hypersonic aerodynamic efficiency parameter, the ratio of lift to drag. These classes are: the ballistic or semiballistic with zero or low L/D, the lifting bodies with medium L/D, and the winged vehicles with high L/D. These classes actually reflect the ranging capability of the vehicle within the atmosphere, the higher the L/D the longer the range.

Now many advanced hypersonic vehicles are under study at NASA and cover these ranges of L/D and today we will discuss the research associated with only two types; first, an example of lifting-body reentry vehicles, and second, the high L/D hypersonic cruise airplane.

For the manned lifting-body reentry vehicles, let us consider how increasing the hypersonic L/D affects a few of its features. At the top are sketches of representative configurations throughout the range of L/D's to be considered. In the neighborhood of $L/D = 1$ we find the lifting-body class of vehicle that combines features of the low L/D and the higher L/D vehicles. Some of the reasons for the special interest in this class will be summarized.

Characteristically, the weight of a reentry vehicle increases with L/D. In the case of a 12-man vehicle, as considered here, the lifting vehicle weight in reference to the nonlifter weight undergoes only a small increase through an L/D of about one. Secondly, for vehicles with $L/D \approx 1$ the shape can be tailored to achieve conventional, horizontal landing without the use of auxiliary aids such as parachutes, paragliders, etc. Thirdly, the ablation heat-protection schemes that are relatively free of temperature restraints, are generally applicable. Finally, as mentioned previously, increasing L/D increases atmospheric ranging capability. Shown in this figure are the extremes in range available during entry from a typical near-earth orbit for vehicles of various L/D's. We see that with $L/D = 1$ the landing sites available encompass an area comparable to about 1/2 of that of the U.S. This capability makes available a variety of landing sites in the U.S. from <u>any</u> near-earth orbit, including polar orbits, at least once a day even with an allowance for reasonable maneuver errors in flight.

For these and other reasons, we concluded that the technology for the vehicle with $L/D = 1$ should be established. In-house and contractural studies cover a variety of areas, some of which are listed in slide 3. Included are analytic, aerodynamic, structural, and dynamic studies. In the course of some of these studies two representative lifting-body configurations have evolved. These configurations are being used as focal points in the identification of problem areas and of their solutions. You saw a full-scale version of this vehicle at your first stop. On this display panel are photographs that illustrate some of the static-aerodynamic tests and heat-transfer tests, using three techniques, in the Langley ground facilities. This model was used in the analysis of booster-entry-vehicle compatibility, and this model was used to measure detailed aerodynamic heating rates.

A coordinated subsonic flight investigation that involves three NASA research centers has been initiated. One-man, 22-foot versions of these two vehicles will be air-launched from a B-52 at the Flight Research Center. Pilot-handling problems will be defined and solutions investigated during equilibrium and maneuvering subsonic glides and during approach and landing.

Let us turn now from this first type, the lifting-body reentry vehicle, to the high L/D hypersonic-cruise vehicle.

The problem areas associated with a typical airbreathing hypersonic vehicle are shown in the 4th slide. Because of the high speeds at which these vehicles will operate, high heating will occur over the vehicle's surface and edges and the resulting heating rates will have to be accurately predicted. In order to reduce local heating, the nose and leading edges of the wings, control surfaces, and inlet will have to be blunt. The configuration will have to be stable and controllable. Because of the huge quantities of air required, the air inlets will be much larger than present-day inlets and will occupy a large part of the vehicle. In fact, the resulting configuration may actually be a "flying inlet."

Now the final resolution of all these problem areas must result in a configuration which is still aerodynamically efficient, or in other words, it must be capable of developing a high lift-to-drag ratio to improve its range capability. Unfortunately, as the lift-drag ratio increases, the structural weight also increases; this tends to reduce range. In the final vehicle design, then, a compromise between lift-drag ratio and structural weight would be required. Before this compromise can be made, however, we must know how configuration geometry affects the maximum lift-drag-ratio characteristics. We are finding these effects by means of the simple models shown here. These models on the left are used to investigate the effects of cone angle, wing leading-edge sweep, and bluntness, while these on the right are used to study the effects of fuselage shape, wing position, and adding canard surfaces. These changes can significantly change the maximum lift-drag-ratio characteristics of these models.

Now these models are great simplifications of a final vehicle design. As the models become more complex we will encounter penalties in this maximum lift-to-drag ratio. The nature of some of these penalties is shown in the 5th slide. The lift-to-drag ratio, against which these figures are plotted, is decreased by increasing wing leading-edge bluntness required to alleviate aerodynamic heating. The L/D of the untrimmed directionally unstable vehicle is reduced as shown here by providing trim and is still further reduced by also providing directional stability. Similarly, the addition of air inlets reduces the L/D.

The purpose of our future work will be to determine how to integrate these features with minimum loss in maximum lift-to-drag ratio. Two large recoverable boosters on top of the panel are shown as examples of models used to study complete configurations.

The design of the inlet itself poses additional problems. Present-day engine cycles in which combustion occurs at subsonic velocities inside the engine are usable up to the lower hypersonic speeds. At higher hypersonic speeds, however, these cycles cannot be used because of the extreme temperatures occurring in the combustion chamber. For these speeds, then, combustion must occur at supersonic velocities inside the engine and studies of inlets for supersonic burning ramjets are underway.

The 6th slide shows a diagrammatic cross section of a supersonic inlet-engine combination and the problem areas. The flow enters here, is compressed by the shocks and mixed with fuel and burned at supersonic velocities. The boundary layer, which is low energy air, poses one problem. At hypersonic speeds, it thickens rapidly and may fill the entire inlet throat, thereby reducing the efficiency of the engine. Bleeds to siphon off the boundary layer may introduce serious heating problems. Leading edges, which have to be blunt to alleviate heating, will also introduce low energy air.

An inlet model being used to study these problems is shown here. Here are the inlet ramp, the cowl lip, and the nozzle expansion surfaces. The flow enters here, is compressed by the shocks from these small compression surfaces to a temperature of about 3,000° F, mixed with fuel and burned in this region at a temperature of about 5,200° F and exhausted here.

Up to now we have been concerned with types of vehicles on which research is focused. Let's consider next what ground facilities are available for furnishing answers in connection with these and other research studies.

The 7th slide serves to define one of the types of simulation we are demanding of ground facilities. This slide illustrates the regions in flight where Air Chemistry Effects occur. The altitude scale on the left extends from 0 to 400,000 feet; as we move toward the right the higher velocities and correspondingly higher temperatures behind the nose shock on a reentry vehicle cause various chemical reactions in the air. This is indicated by the color scheme.

As the velocity and temperature increase, the two atoms composing an oxygen molecule in the air first vibrate with respect to each other, and finally break apart. The separation of the molecules into two atoms is called dissociation and the chemical formula is given at the top. At higher speeds the nitrogen molecules dissociate and finally the air becomes ionized. Dissociation and ionization cause the air to have new properties and in many cases these effects on the aerodynamics and heat transfer are not completely understood.

A typical reentry vehicle might follow the path shown by this gray line and such a vehicle will, in succession, pass through the different regions where each labeled chemical reaction is dominant in its flow field.

In order to accomplish research on air chemistry effects in ground facilities the velocity and the stagnation temperature must be high enough to produce the chemical reactions specified on this slide.

No one facility can simultaneously duplicate all flight conditions in the higher velocity range on this slide for prolonged running times so we have resorted to partial simulation techniques wherein several different types of facilities which are chosen in accordance with the research problem under study. For example, the proper flight temperature and velocity might be simulated when studying air chemistry effects, but not necessarily the correct Mach number. Conversely, in order to study fluid dynamic problems, the Mach number and air density might be simulated but not necessarily the proper temperature or velocity. The results from the various facilities are then considered and with a heavy dependence on analytical techniques, it has been possible to obtain, in many cases, the answers to engineering problems.

Sometimes the only available technique for obtaining all desired conditions simultaneously is flight experiments. An example was the recent Project FIRE shot from Cape Kennedy. This is a small model of the Project FIRE payload on top of an Atlas booster and as part of your tour there is a display in another building connected with Project FIRE. This project consisted of firing an instrumented payload back into the atmosphere at a velocity of 37,900 feet per second. The information obtained in a flight experiment for a particular set of conditions can then be used to assess the partial simulation techniques in ground facilities and serve as a basis for extending them to other conditions.

The Mach number and altitude at which various types of reentry vehicles fly is illustrated in the 8th slide. This figure was presented previously but we are showing it again in order to define the needed Mach number and altitude simulation capabilities of our ground facilities. On the 9th slide we show an overlay in blue that indicates the Mach number and altitude range of each facility. This is the Helium Tunnel and this is the 17-Inch Nitrogen Tunnel. Although the gas temperature in the Nitrogen Tunnel is 4,000° F, this is still considered cool in terms of simulating the flight temperature at this Mach number.

The 31-Inch-CFHT, which you see in front of you, is representative of this class of facility and the complexity of its engineering problems warrants some mention. It has a total of 25,000-horsepower rotating compressors that drive the test air through a small 1-inch throat section. The air is then expanded to a number of 10 in the 31-inch test section in which you see a model of the lifting-body vehicle previously discussed.

Although these facilities, because of their relatively low temperature, cannot work on air chemistry effects, they are of great importance in the study of what we call Fluid Dynamic problems. A typical fluid dynamic problem is caused by the fact that air has viscosity. At hypersonic speeds the viscosity of air causes a thick boundary layer to form around the flight vehicle that changes the effective shape of a vehicle and the aerodynamic and heat-transfer characteristics vary with this effective shape. This can radically alter the design of a vehicle.

The 10th slide shows the altitude and velocity simulation capabilities of some of the hotter types of facilities compared again to the typical flight reentry corridors. The Expansion Tube shown in this figure is still in the design and construction stage. However, studies made with a small pilot model of this facility indicate that it can perform radiation studies in the high-velocity region shown in this figure. It completely simulates the Mach number, altitude, velocity, and temperature in the region shown. The facility is currently limited primarily to radiation studies, because of the short test time (5/1,000,000 sec). A black and white picture of a model being tested at an angle of attack in this facility at a velocity of about 36,000 ft/sec is shown on your right. Also shown is a short listing and photographs of some of the newer Langley hypersonic facilities.

The ballistic range, such as in operation at the Ames Research Center, can also simulate flight in this high-velocity range. The Ballistic Range and the Expansion Tube complement each other in that different instrumentation is available for each type of facility and they can work on different research problems.

Now, facilities such as the electric arc-heated hypersonic tunnels, which the various Research Centers have under development and in limited operation, can undertake other types of research problems because of their longer running times. However, as this chart shows, they cannot yet attain the extreme velocities of the short-duration facilities but the long running time permits the investigation of a wide variety of research areas.

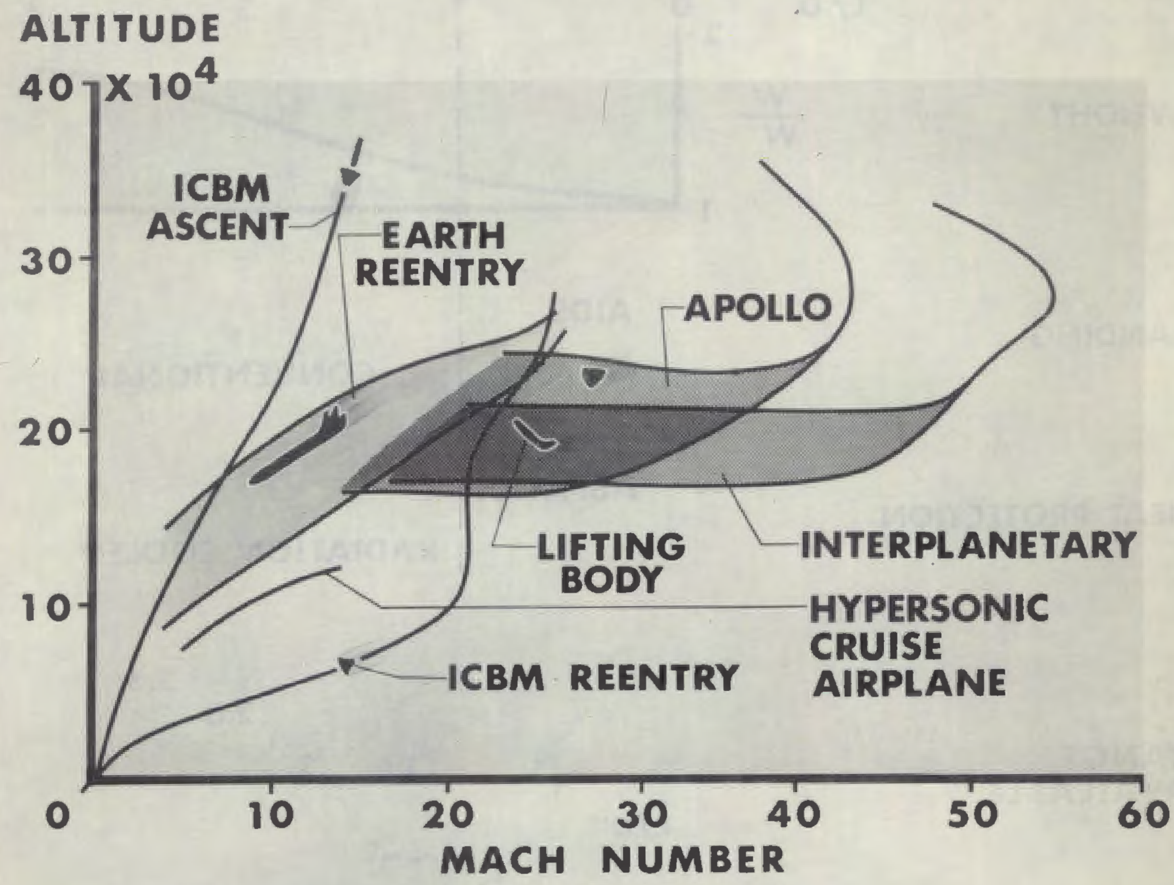
As a final topic we will show you a movie of a model being tested in an electric arc-heated tunnel which has a 1-foot test section. The test Mach number is 12 and the stagnation temperature of the air is about $6{,}500^\circ$ F.

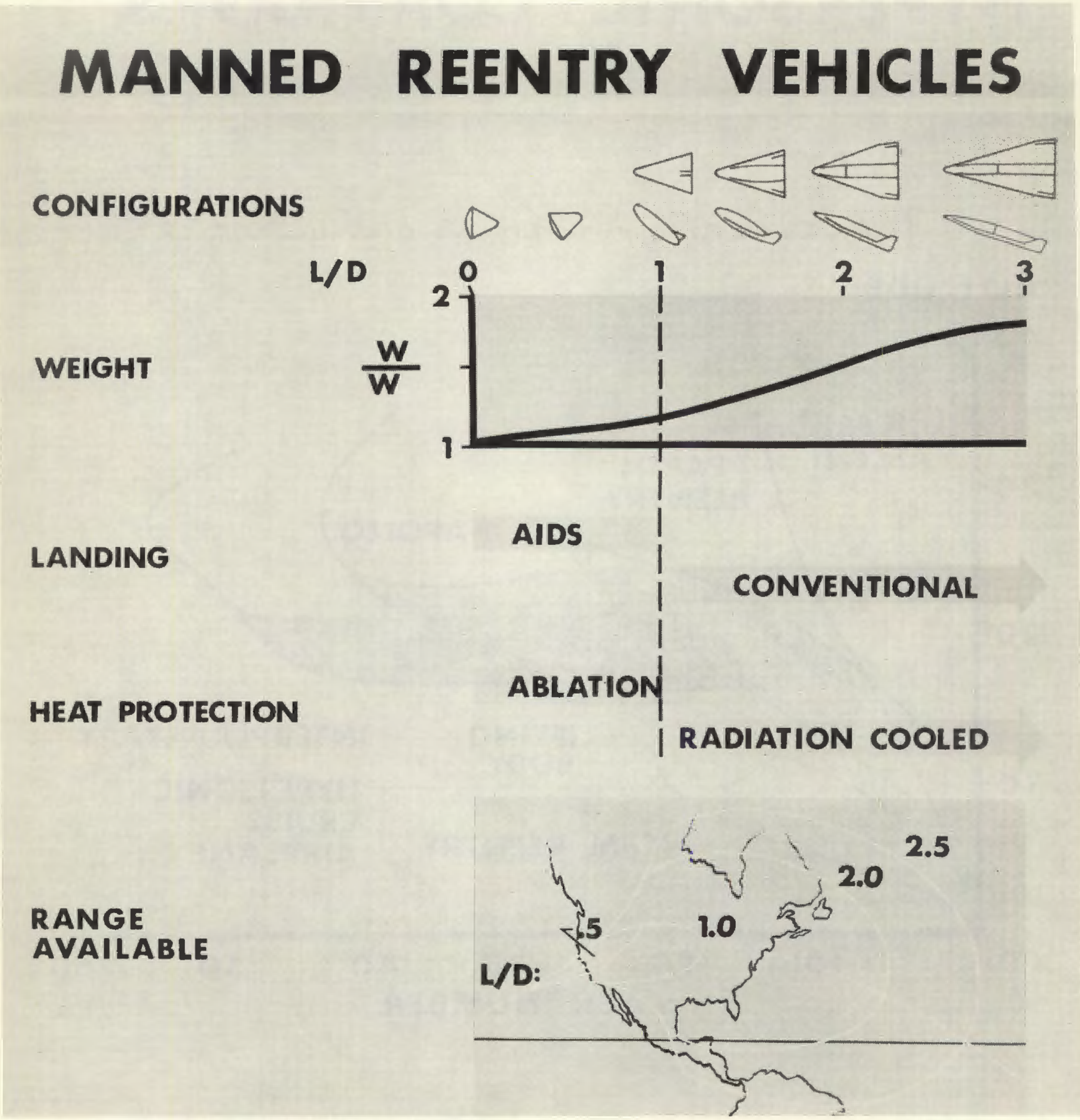
These first scenes in the movie show the model rotating at a constant angle of attack in the tunnel before the tunnel is started. After the tunnel starts the rotation will continue and the screen will be much darker because the only luminosity is coming from the flow itself.

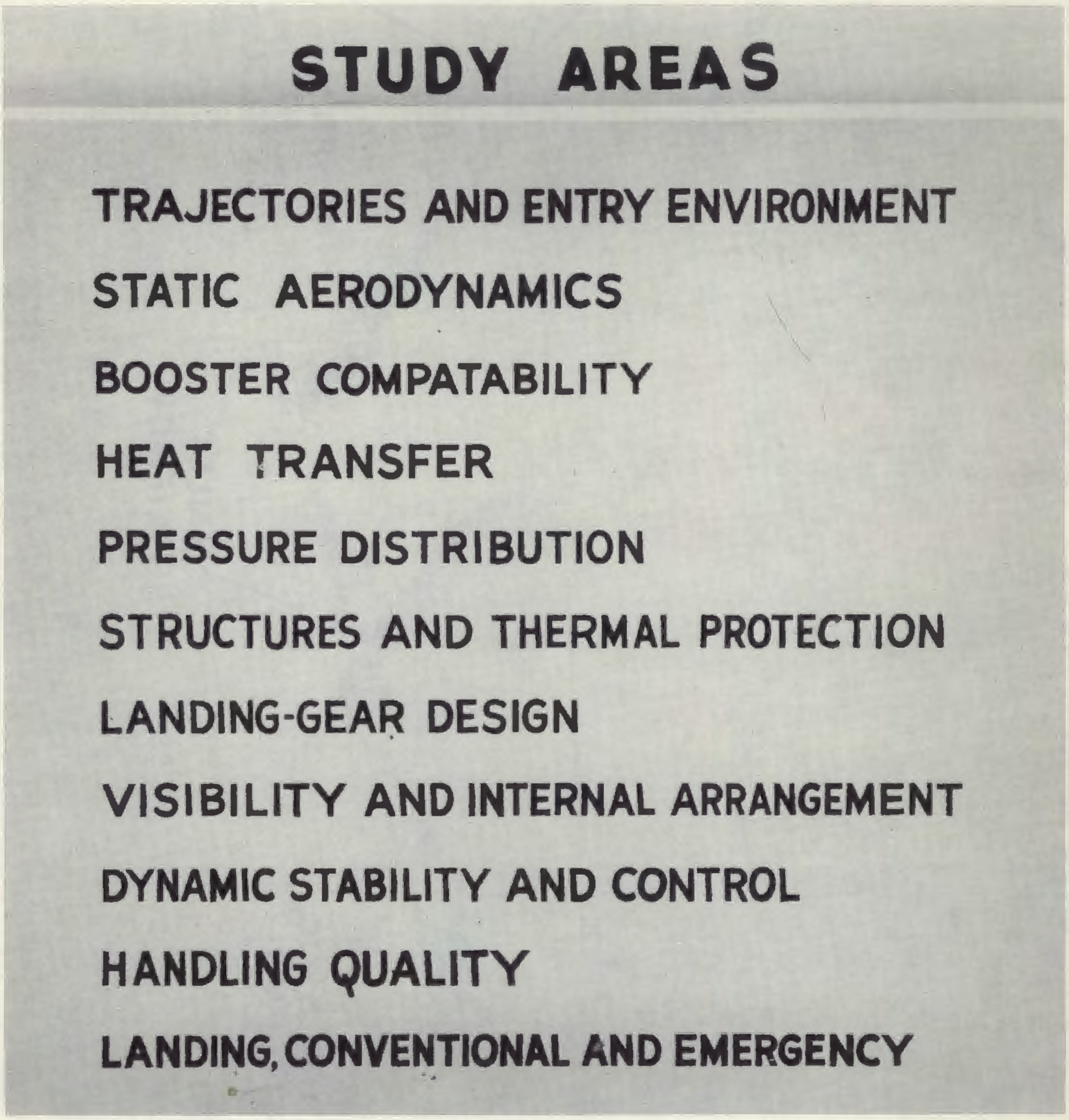
The model is the lifting-body reentry vehicle discussed earlier.

The red glow is because the ablation material from which this model is constructed is charring as it ablates. The carbon char glows red when heated to its vaporization point. This type of test clearly defines the regions of most intense heating and illustrates one of the important uses of arc tunnels.

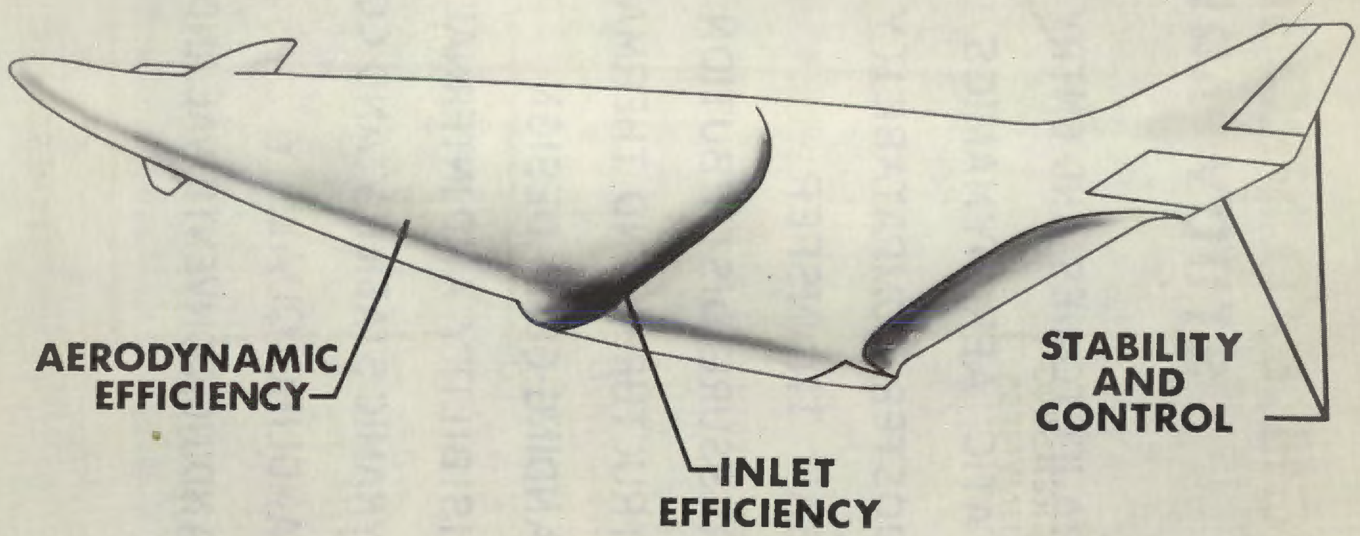
HYPERSONIC CORRIDORS



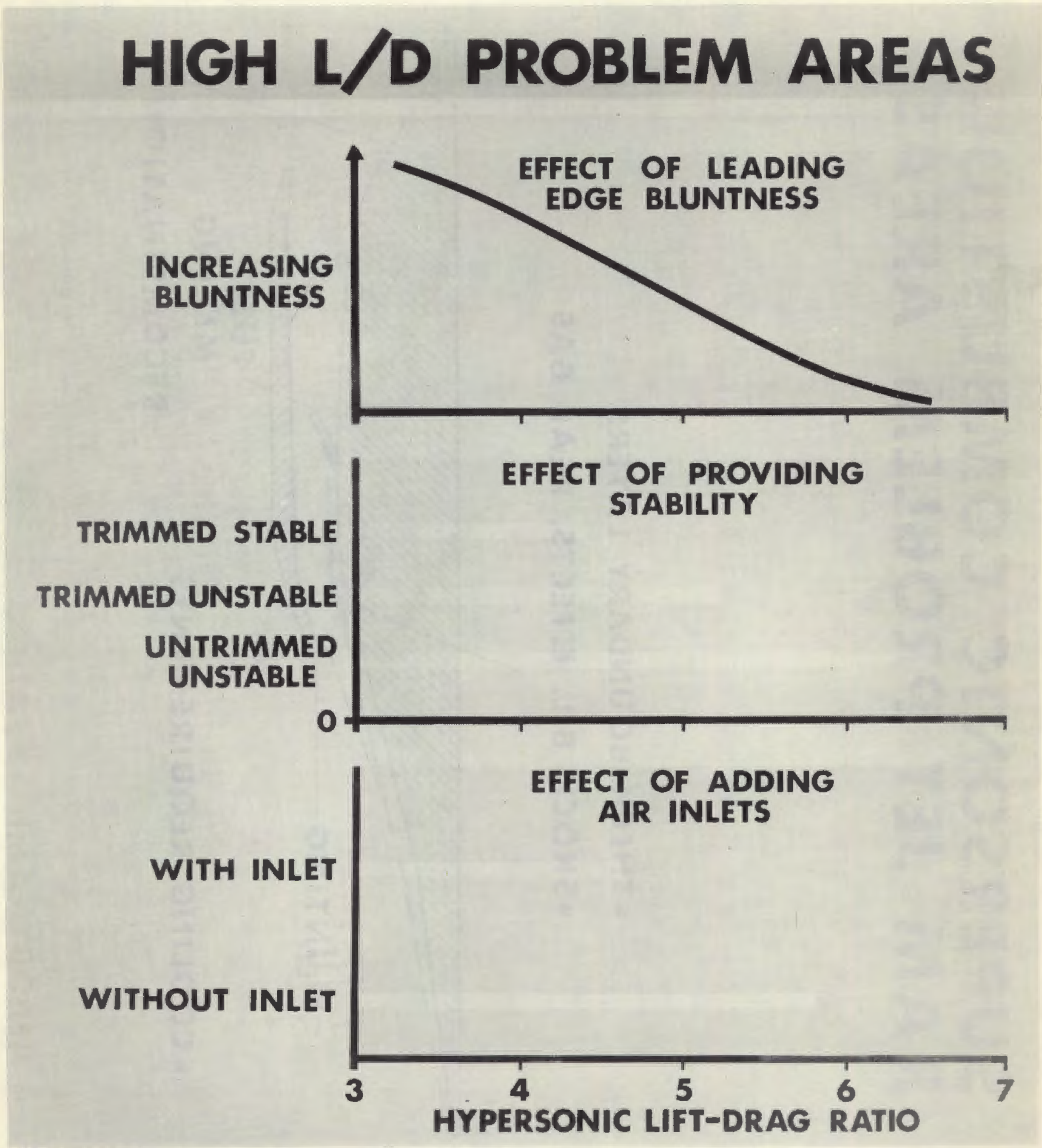

MANNED REENTRY VEHICLES
CONFIGURATIONS
L/D
0
1
2
3
2
1
WEIGHT
W
W
LANDING
AIDS
CONVENTIONAL
HEAT PROTECTION
ABLATION
RADIATION COOLED
RANGE AVAILABLE
L/D:
.5
1.0
2.0
2.5


STUDY AREAS
TRAJECTORIES AND ENTRY ENVIRONMENT
STATIC AERODYNAMICS
BOOSTER COMPATABILITY
HEAT TRANSFER
PRESSURE DISTRIBUTION
STRUCTURES AND THERMAL PROTECTION
LANDING-GEAR DESIGN
VISIBILITY AND INTERNAL ARRANGEMENT
DYNAMIC STABILITY AND CONTROL
HANDLING QUALITY
LANDING, CONVENTIONAL AND EMERGENCY

PROBLEM AREAS

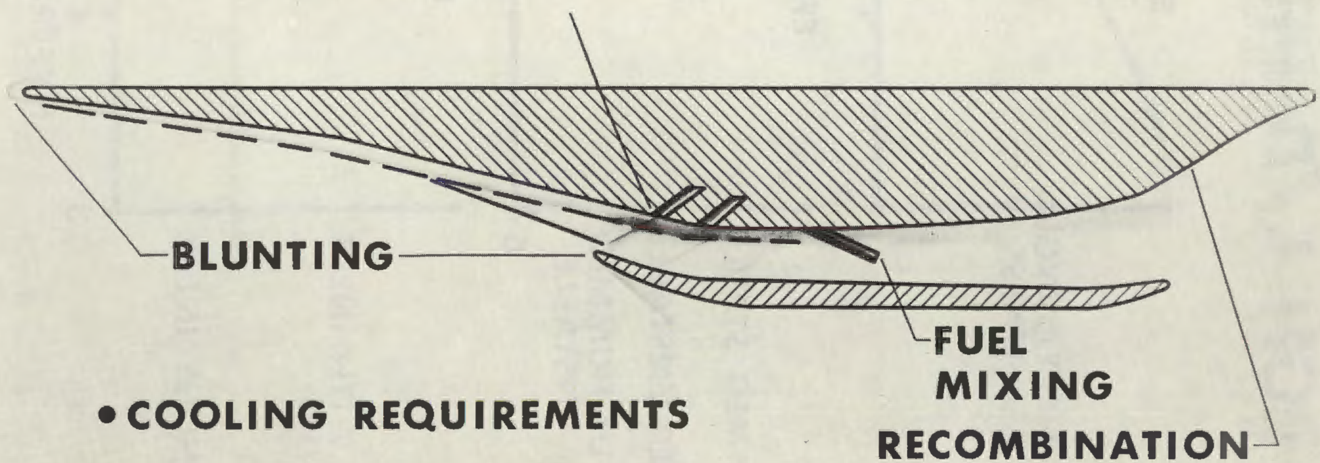


• AERODYNAMIC HEATING

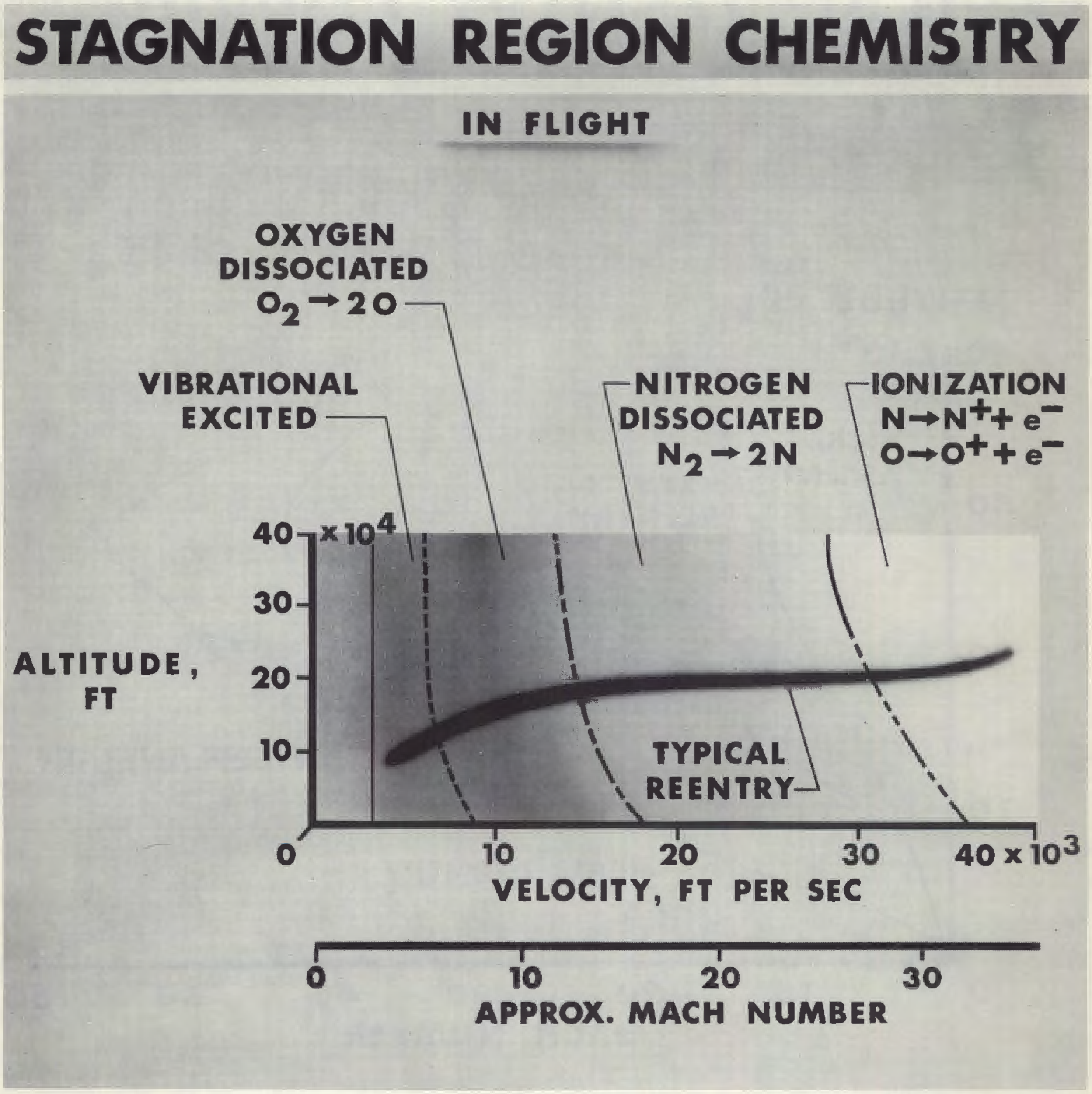

HIGH L/D PROBLEM AREAS
EFFECT OF LEADING EDGE BLUNTNESS
INCREASING BLUNTNESS
EFFECT OF PROVIDING STABILITY
TRIMMED STABLE
TRIMMED UNSTABLE
UNTRIMMED UNSTABLE
0
EFFECT OF ADDING AIR INLETS
WITH INLET
WITHOUT INLET
3
4
5
6
7
HYPERSONIC LIFT-DRAG RATIO

SUPERSONIC COMBUSTION RAM JET PROBLEM AREAS

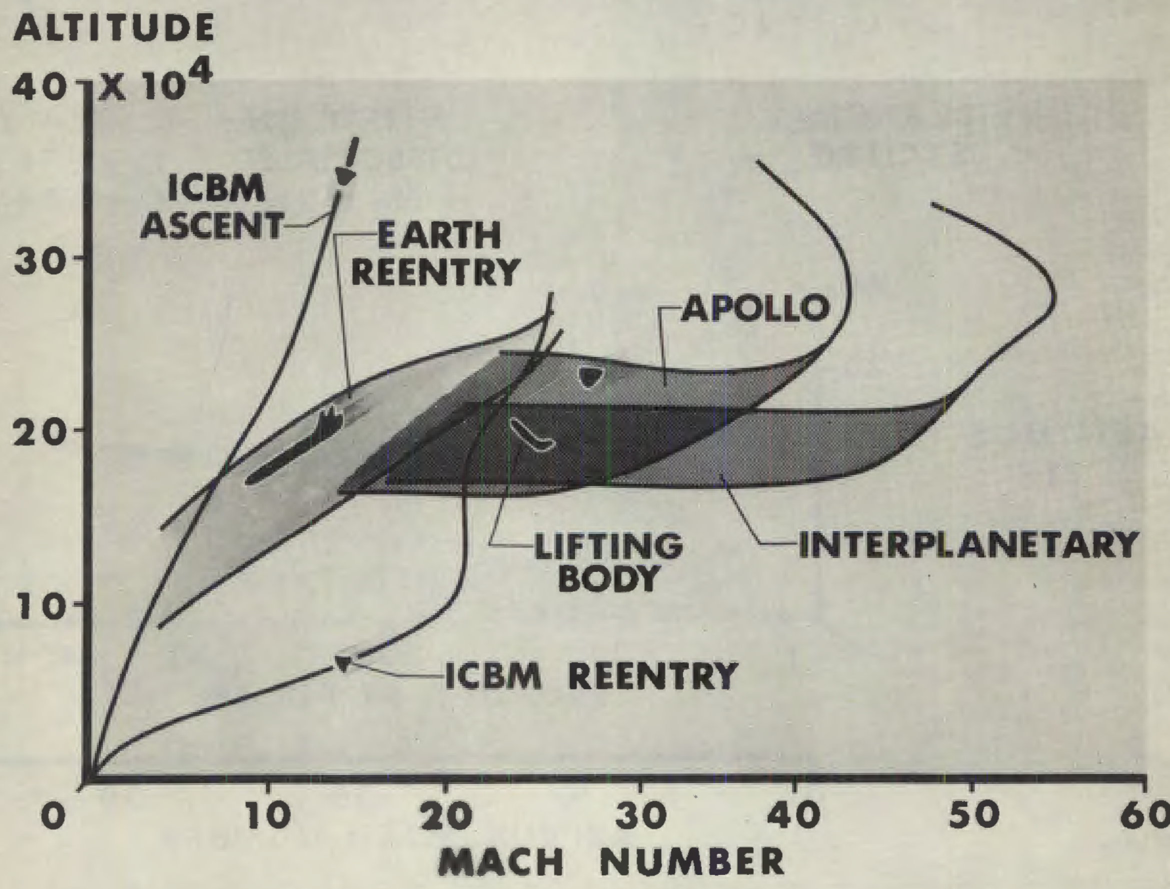
- THICK BOUNDARY LAYERS
- SHOCK B.L. EFFECTS, REAL GAS



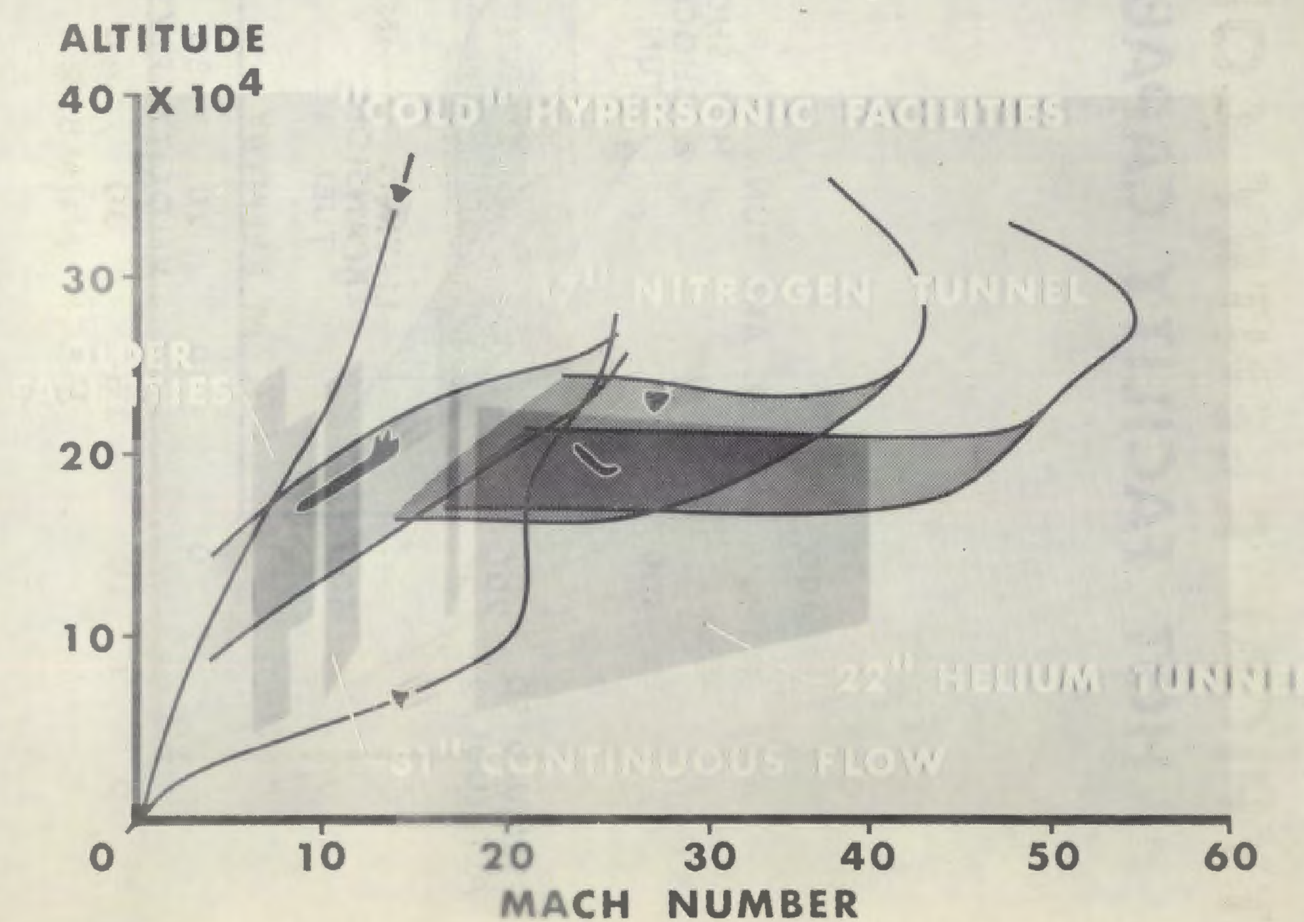
- COOLING REQUIREMENTS


STAGNATION REGION CHEMISTRY
IN FLIGHT
OXYGEN
DISSOCIATED
O2 → 2O
VIBRATIONAL
EXCITED
NITROGEN
DISSOCIATED
N2 → 2N
IONIZATION
N → N+ + e−
O → O+ + e−
40 x 10^4
30
20
10
0
ALTITUDE, FT
TYPICAL
REENTRY
10
20
30
40 x 10^3
VELOCITY, FT PER SEC
0
10
20
30
APPROX. MACH NUMBER

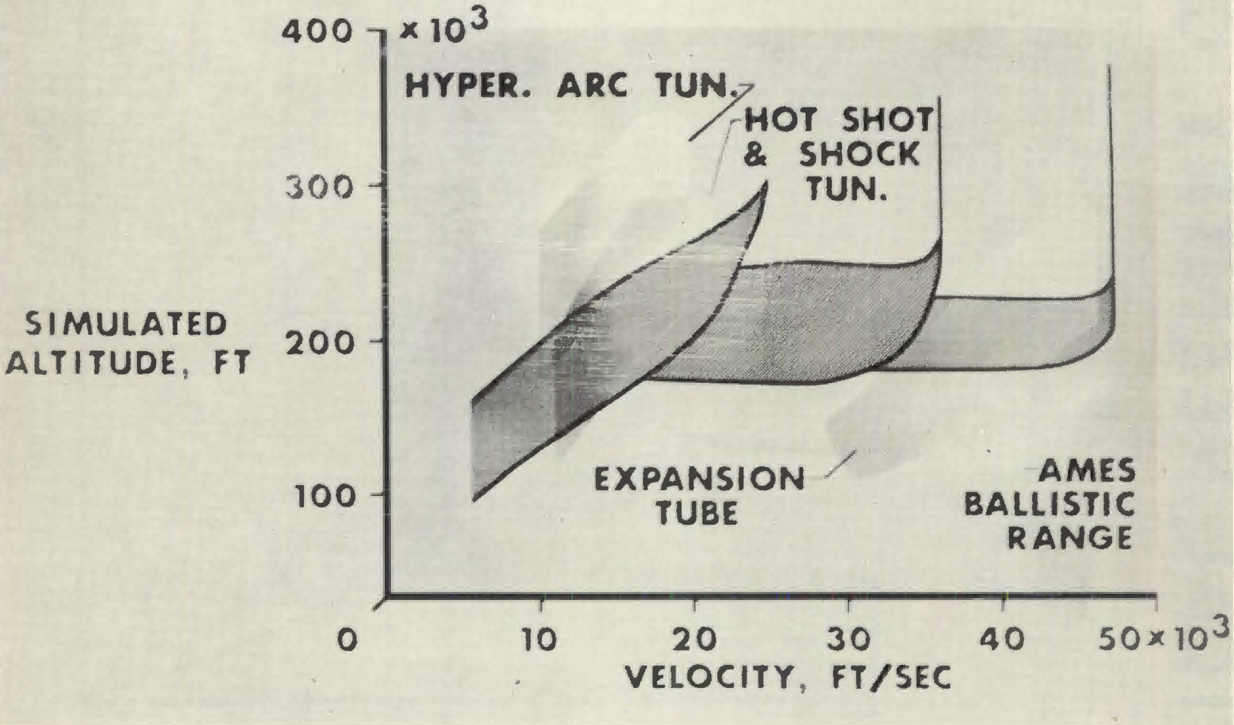
TYPICAL REENTRY CORRIDORS



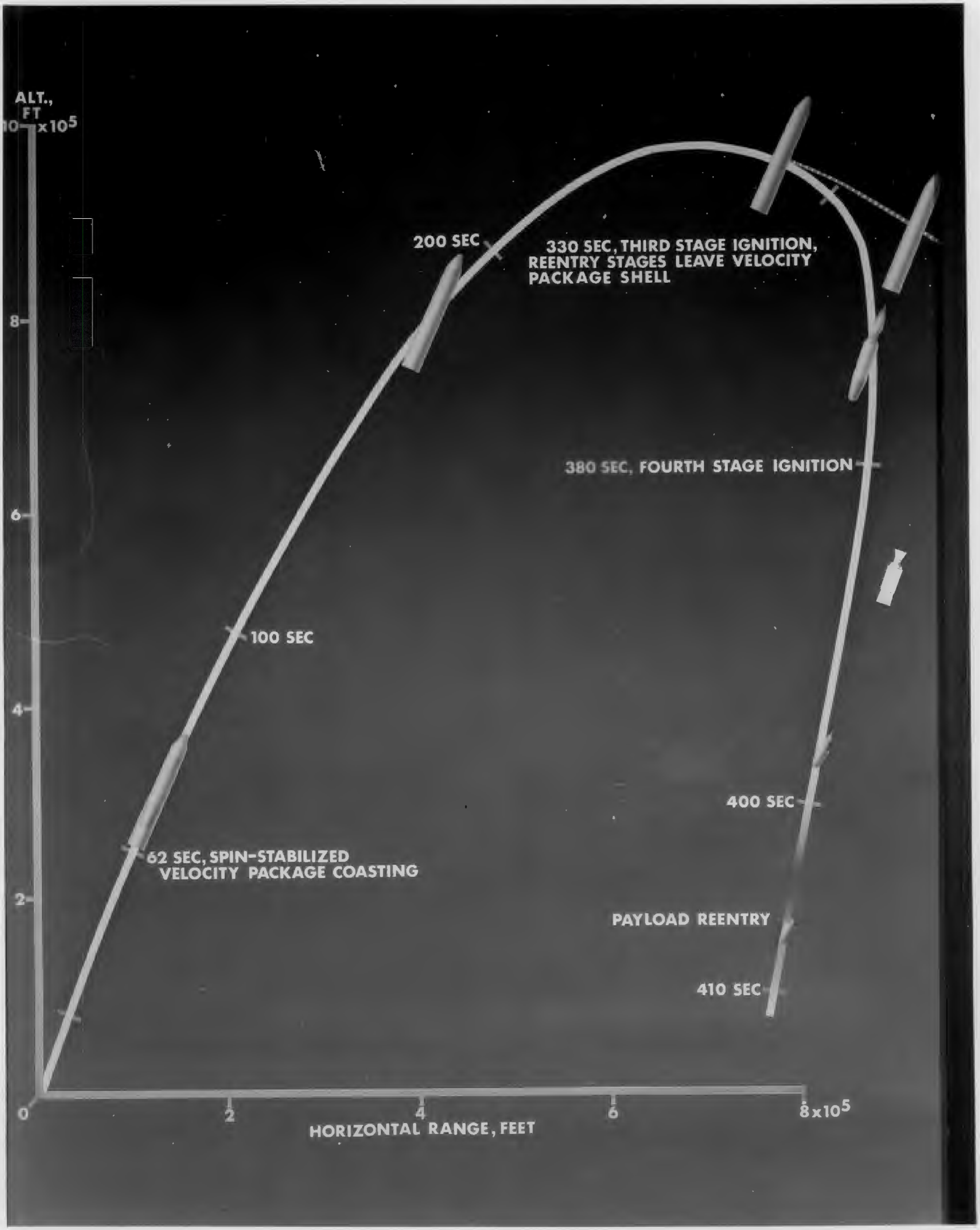
TYPICAL REENTRY CORRIDORS



HOT FACILITY CAPABILITY



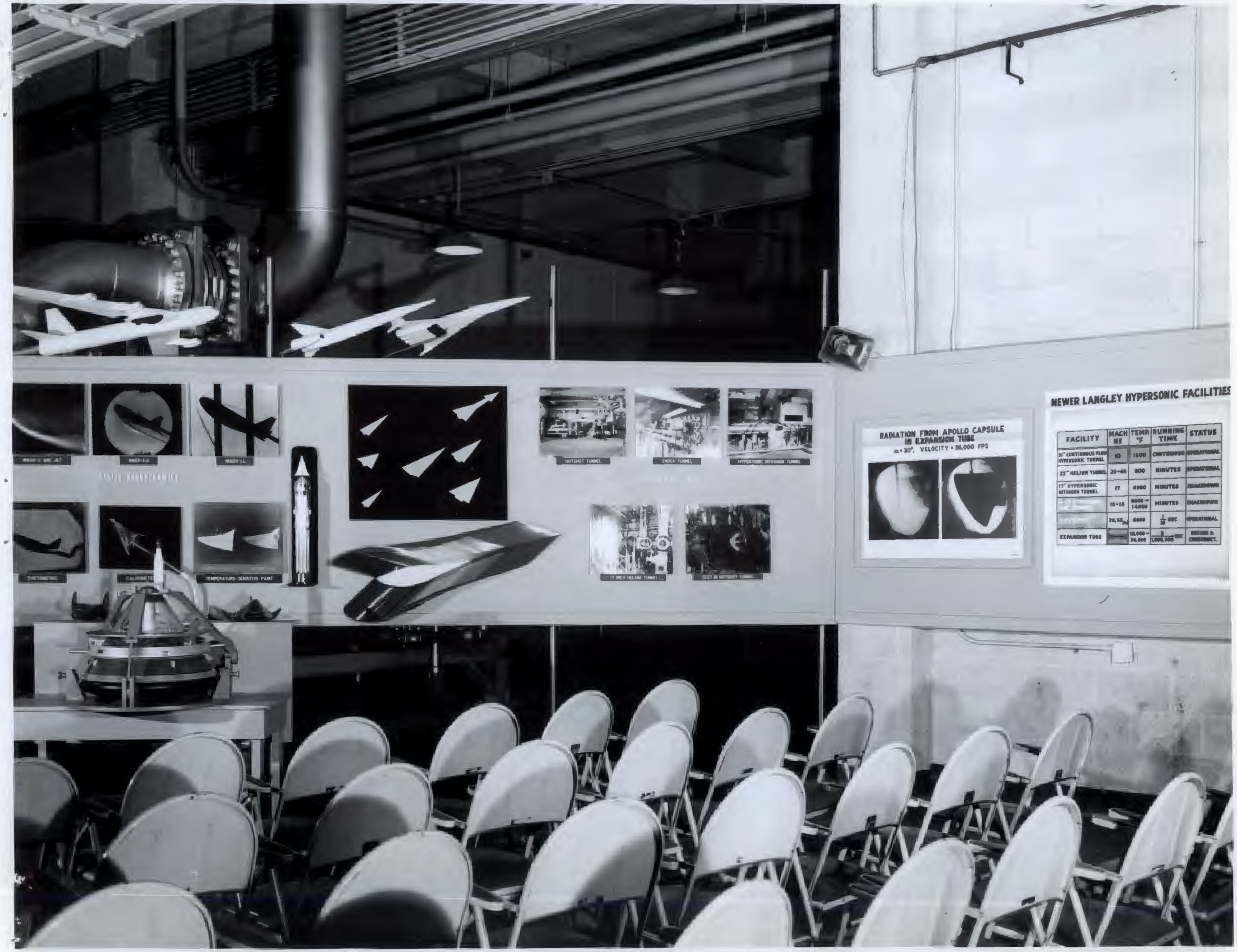
NASA-Langley, 1964



ALT., FT
x10^5
10
8
6
4
2
0
2
4
6
8 x10^5
HORIZONTAL RANGE, FEET
200 SEC
330 SEC, THIRD STAGE IGNITION, REENTRY STAGES LEAVE VELOCITY PACKAGE SHELL
380 SEC, FOURTH STAGE IGNITION
100 SEC
400 SEC
62 SEC, SPIN-STABILIZED VELOCITY PACKAGE COASTING
PAYLOAD REENTRY
410 SEC

L-1914

NASA
L-64-4889



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NEWER LANGLEY HYPERSONIC FACILITIES

FACILITY	MACH №	TEMP. °F	RUNNING TIME	STATUS
31" CONTINUOUS FLOW HYPERSONIC TUNNEL	10	1500	CONTINUOUS	OPERATIONAL
22" HELIUM TUNNEL	20→40	600	MINUTES	OPERATIONAL
17" HYPERSONIC NITROGEN TUNNEL	17	4000	MINUTES	SHAKEDOWN
4-FT HYPERSONIC ARC TUNNEL	10→18	6000 → 14000	MINUTES	SHAKEDOWN
HOTSHOT	20, 60 (He)	6000	$\frac{1}{10}$ SEC	OPERATIONAL
EXPANSION TUBE	20→45	10,000 → 50,000	$\frac{5}{1,000,000}$ SEC	DESIGN & CONSTRUCT.

L-1864