NACA LEWIS INSPECTION

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HIGH ENERGY AIRCRAFT FUELS

Many of you have heard of new plants being built to produce exotic aircraft fuels that contain boron. These new fuels promise flight gains, but they also pose problems that must be solved before boron fuels can be used in aircraft. During eleven years of NACA research in this field we have worked with the unique properties of these high energy fuels. Now we'd like to tell you about the promise -- and the problems -- of boron-containing fuels.

High energy fuels being considered for jet aircraft contain chemically combined boron, hydrogen, and carbon. We can't give you commercial formulations, but we can acquaint you with the reasons for interest in these fuels and with particular compounds used in our research.

To introduce our demonstration, I'll answer briefly three questions:

(1) Why do we want high energy fuels?

(2) What do we mean by high energy fuels?

(3) How can we get high energy fuels?

First, we want high energy fuels to increase flight range of aircraft. Greater range can be obtained with aerodynamic and propulsion improvements. Higher fuel energy yields a direct propulsion gain. Roughly, if we double the available energy of a fuel, we double flight range.

Second, what do we mean by high energy fuels? A high energy fuel is one that has a heat of combustion higher than our current jet aircraft fuels. Jet fuels are hydrocarbon mixtures from petroleum with heats of combustion of about 18,500 Btu/lb.

Third, how do we get high-energy fuels? This answer is a little more complicated so let's take a look at the chart relating heat of combustion and atomic number. Here we see that the element hydrogen has the highest heat of combustion, 51,500 Btu/lb. Beryllium is very toxic, and both beryllium and lithium are relatively unavailable. This brings us to boron at a respectable value of about 25,000 Btu/lb. If we combine hydrogen and boron chemically, we obtain a compound with a heating value between those of the two elements -- and greater than those for petroleum fuels. Furthermore, by varying the hydrogen-to-boron ratio in this chemical combination, we can make a liquid, solid, or gas. But for aircraft we much prefer liquids.

In research on performance of high energy fuels, we have used both gaseous and liquid compounds of boron and hydrogen. These fuels are members of the chemical family called boron hydrides or boranes. The two we have used in most of our work are diborane and pentaborane. This model represents diborane; in this molecule two atoms of boron and six atoms of hydrogen are combined. The heat of combustion is 31,100 Btu/lb. Diborane is a gas at room conditions.

Pentaborane, represented by this model, is a liquid. Five boron atoms and nine hydrogen atoms combine to form the pentaborane molecule; its heat of combustion is about 29,000 Btu/lb.

The high heating values of the boron hydrides are attended by extreme reactivities. Under control in a jet engine, high reactivity is a real advantage. A more reactive fuel tends to burn more completely at severe conditions. This means that aircraft can fly higher without flame failure due to low pressures encountered at high altitudes. However, the violent reactivity of the boranes can cause handling problems. If some boron hydrides are exposed to air, they ignite spontaneously and are difficult to extinguish.

An additional handling problem of the boranes is toxicity. These materials are much more toxic than petroleum fuels, but the effective toxicity can be controlled by introducing carbon into the molecule. The resulting compounds have greater reactivity and higher heats of combustion than petroleum fuels -- with lower effective toxicities and better handling characteristics than unmodified boron hydrides.

Now let's see what has been accomplished experimentally. Since the beginning of our research program we have investigated performance of boron fuels in small-scale experimental equipment -- and in full-scale ramjet and turbojet engines. The fuels we used in this research were supplied by Air Force and Navy contractors.

The following speaker, Mr. __________, will describe results of our experimental programs. Mr. __________.

BREAK

Mr. __________ has mentioned the high heats of combustion and high reactivity of the boranes. To illustrate these characteristics two combustion rigs have been set up to compare diborane with a hydrocarbon fuel, ethylene. These two gaseous fuels have about the same molecular weights and require about the same quantity of air for complete combustion.

The airflow in these burners is from left to right. Diborane will be injected in the upper burner and ethylene in the lower. The fuels are injected here and here. Two spark plugs here and here will ignite the fuel-air mixture. Thermocouples at the end of the burners will detect the exhaust temperatures and register on these dials.

The one difference between the two burners is this flameholder in the ethylene burner. A flameholder provides a sheltered combustion zone and promotes stable, efficient burning. You will see in the test that diborane does not need a flameholder for stable combustion.

The first objective of the demonstration will be to compare the heats of combustion of the two fuels. Remember that a high heat of combustion will enable us to increase flight range.

Here's how we will operate these burners. The operator will now set identical airflow in the two burners. The operator is now starting airflow in the ethylene burner. We will now inject ethylene until the temperature measured at the exhaust is 1000° F. The fuel flow is _____ pounds per second (observe both charts and rig).

In the diborane burner the operator will set the airflow equal to the airflow in the ethylene burner. Diborane will now be injected until the exhaust temperature is the same as that obtained with ethylene. You will note that when the exhaust temperatures are the same, a lower fuel flow, _____, is required for diborane. This means that it takes less diborane per pound of air than ethylene to get the same performance.

Next we will increase the airflow in the burners to see which flame is more difficult to extinguish. First, the diborane burner. Blowout occurs at a velocity of _____ feet per second. Now for the ethylene burner. Blowout occurs at _____ feet per second. This demonstration of blowout has indicated reactivity of the fuels. Even with a flameholder to aid in stabilizing the flame, ethylene was extinguished at a lower velocity than diborane and therefore is less reactive.

So we have shown that less diborane is required to produce the same performance as ethylene and that diborane burns more stably. In other words, boron fuels promise greater aircraft range and more stable engine combustion under conditions of high speed and high altitude.

Now let's take a look at what happened inside these burners. First we were burning ethylene and air as shown by these molecular models. Ethylene is composed of two carbon atoms and four hydrogen atoms. It burns with three molecules of oxygen to produce two molecules each of carbon dioxide and water. Both of these products are gases in the exhaust stream, and as you would expect the burner is clean.

However, diborane with two boron atoms and six hydrogen atoms burns with three molecules of oxygen to yield three molecules of water as a gas and one molecule of boric oxide. Unfortunately boric oxide does not always appear as a gas. The deposits in the exhaust end of the burner illustrate this fact.

Also in this burner you can see dark hard deposits near the injector. These deposits are decomposed diborane. Boranes when exposed to heat decompose or degrade forming solid products.

Because of this decomposition and oxide formation, ways must be found to cope with problems in:

(1) fuel storage and flow equipment

(2) fuel injectors

(3) equipment in and following the engine combustor

Even though some of these problems can be solved or minimized, the problem of handling a non-gaseous exhaust product in a turbojet engine is certainly difficult.

If you will take a look at some of these samples of boric oxide, you can see a little better just what I mean. This is one form the oxide takes -- hard glassy deposit at temperatures below about 1000° F. At temperatures above 1000° F and below 4000° F the oxide is a viscous, syrupy liquid. Just to illustrate, I will pour some of the molten oxide through this screen. This is the physical state of the oxide at many conditions prevailing in jet engines.

Boranes burned in turbojet primary combustors would be expected to deposit boric oxide on all hot parts of the engine including:

(1) primary combustor walls

(2) turbine stators and rotors

(3) afterburner walls, injectors and flameholders

(4) variable-area nozzles

These deposits collect and flow along jet-engine parts, feeding viscous liquid oxide films to downstream components. Accumulations of oxide from the combustor must pass through a stator and turbine. Obviously, this is asking a lot of an engine.

We can demonstrate this on the test rig the operator has just started. The flow in this rig is from right to left. A gas stream containing molten oxide is directed through a simulated turbojet stator and turbine. You can see the oxide streaming off the vanes and into the rotating turbine. The oxide hits the blades and forms a thin sheet, but if the turbine were operating at high speed some of the oxide would be thrown off at the tips of the blades.

As you might well guess, accumulations of the oxide in the turbine and stators could seriously decrease performance. If we intend to use boron fuels, engines must be built to tolerate the oxide.

In our research we have conducted investigations in full-scale turbojet engines to determine the seriousness of this problem (lower screen, start movie). The film strip now being projected shows the engine in an altitude tank. Through a window in the tailpipe of the engine we photographed the oxide as it flowed through the rotating turbine wheel. The turbine is on your right. The flash of light you see indicates that pentaborane has ignited. Shortly the oxide will begin to show up as it passes through the turbine. Look toward the bottom of the turbine wheel, and you can see globules of liquid oxide tumbling through the blades and along the tailpipe. The rotating feeler gage gives us an indication of the thickness of the film of oxide -- about _____ inch (end movie).

In addition to full-scale engine studies, we have conducted small-scale experiments to help us find ways to minimize the effect of the oxide on performance. The next film strip (start film) illustrates one such experiment and shows the oxide flowing over stator blades. You can see that the viscous liquid oxide flows over the entire blade surface (end film).

So far our demonstration has highlighted the turbojet engine problem. In other propulsion systems such as ramjets and afterburners the presence of the oxide is not as imposing since no moving engine parts are present.

Our research program has covered investigations of ramjets from experimental rigs to flight vehicles. A ramjet vehicle similar to the one you see here has been flight tested with pentaborane as the fuel. This vehicle is about ten inches in diameter and about eight feet long. Telemetering and radar equipment are used in collecting data and tracking during flight. In this particular flight the vehicle reached a Mach number of 3.

These vehicles are launched at altitudes of 30 to 45,000 feet. Here is a short film (start film) that shows the launching of a pentaborane-fueled ramjet. Flight Mach number and altitude are plotted to show the flight progress.

CONCLUSION

As our missile slowly sinks into the sea -- and I hope this is not prophetic -- I would like to summarize briefly our research on boron fuels. Although you have seen and heard only a small segment of our effort, we hope that you take away with you a better understanding of the potentialities and the problems of these fuels. You know now that these fuels contain sufficient energy to make their use attractive. You know, also, that their properties are such that handling on the ground and in aircraft will be more difficult but not impossible. Last but by no means least, you have seen that the formation of boric oxide in engines presents a problem inherently associated with boron fuels and our research program is aimed at its solution.

A number of important things have been learned about boron fuels, yet many questions remain unanswered. A small fraction of required research has been completed with the quantities of experimental fuel available for our research.

Only continued research will indicate the place of these fuels in the propulsion spectrum. This concludes our demonstration. Thank you!

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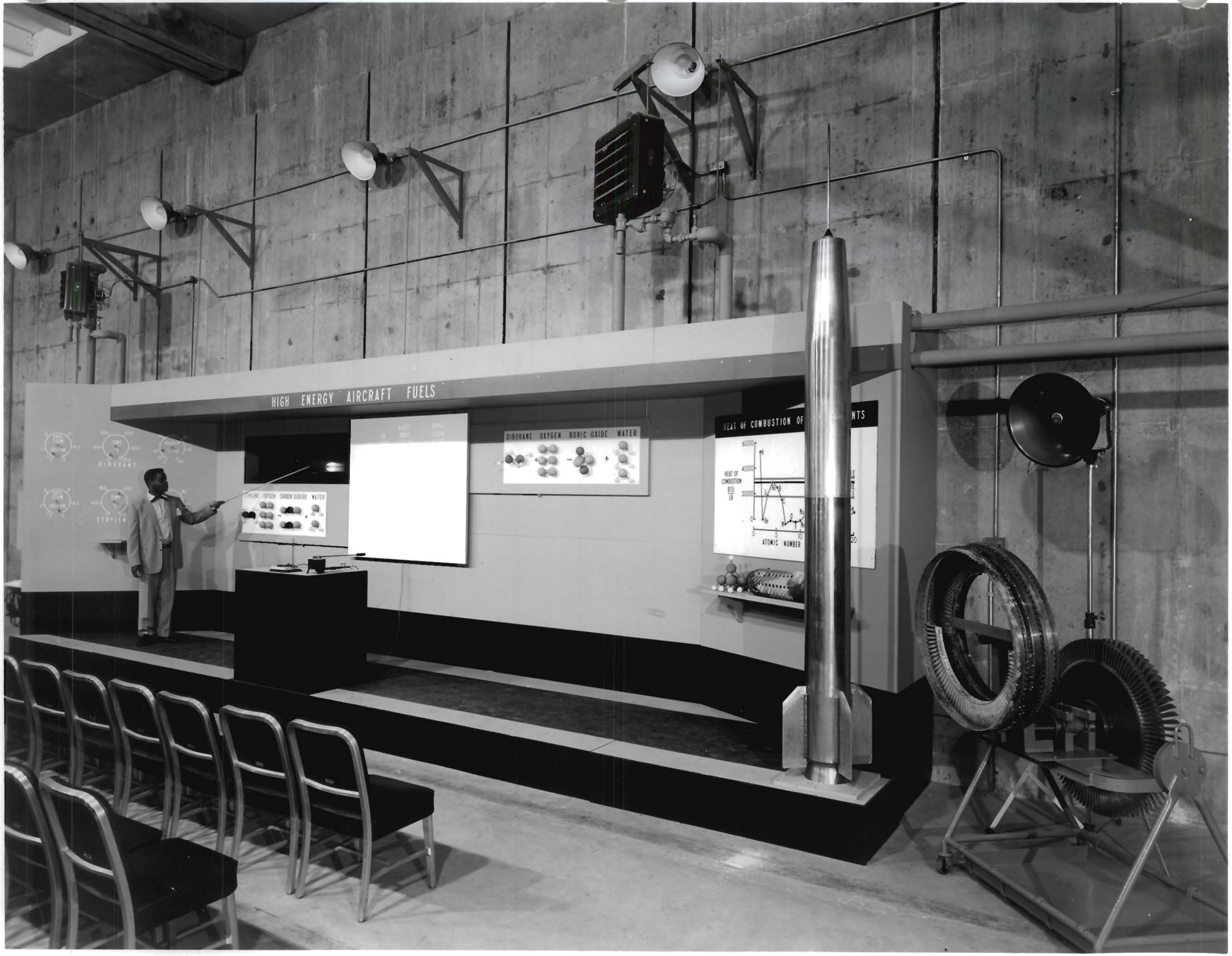
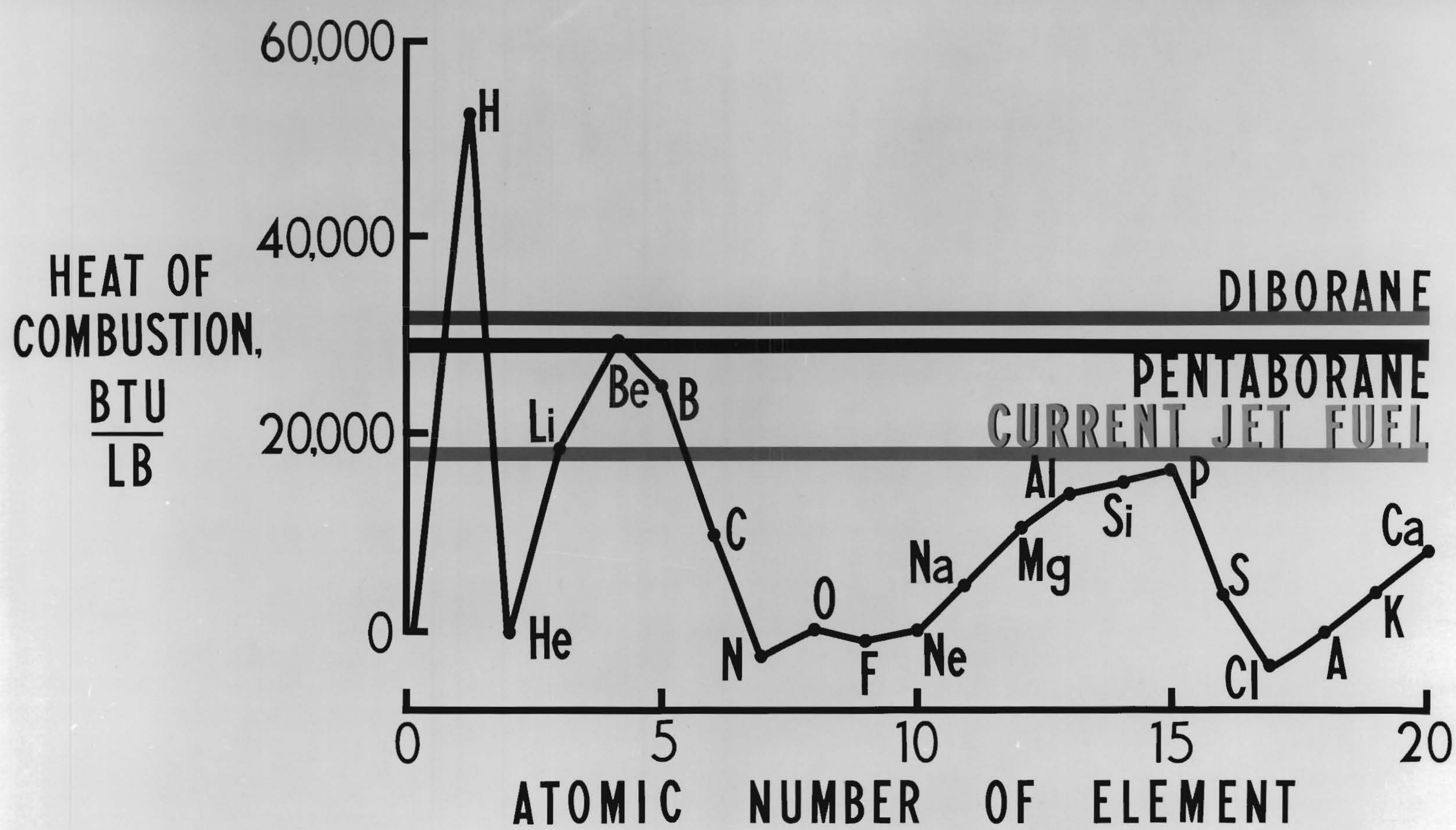

HIGH ENERGY AIRCRAFT FUELS
DIBORANE OXYGEN BORIC OXIDE WATER
HEAT OF COMBUSTION
ATOMIC NUMBER

HEAT OF COMBUSTION OF THE ELEMENTS



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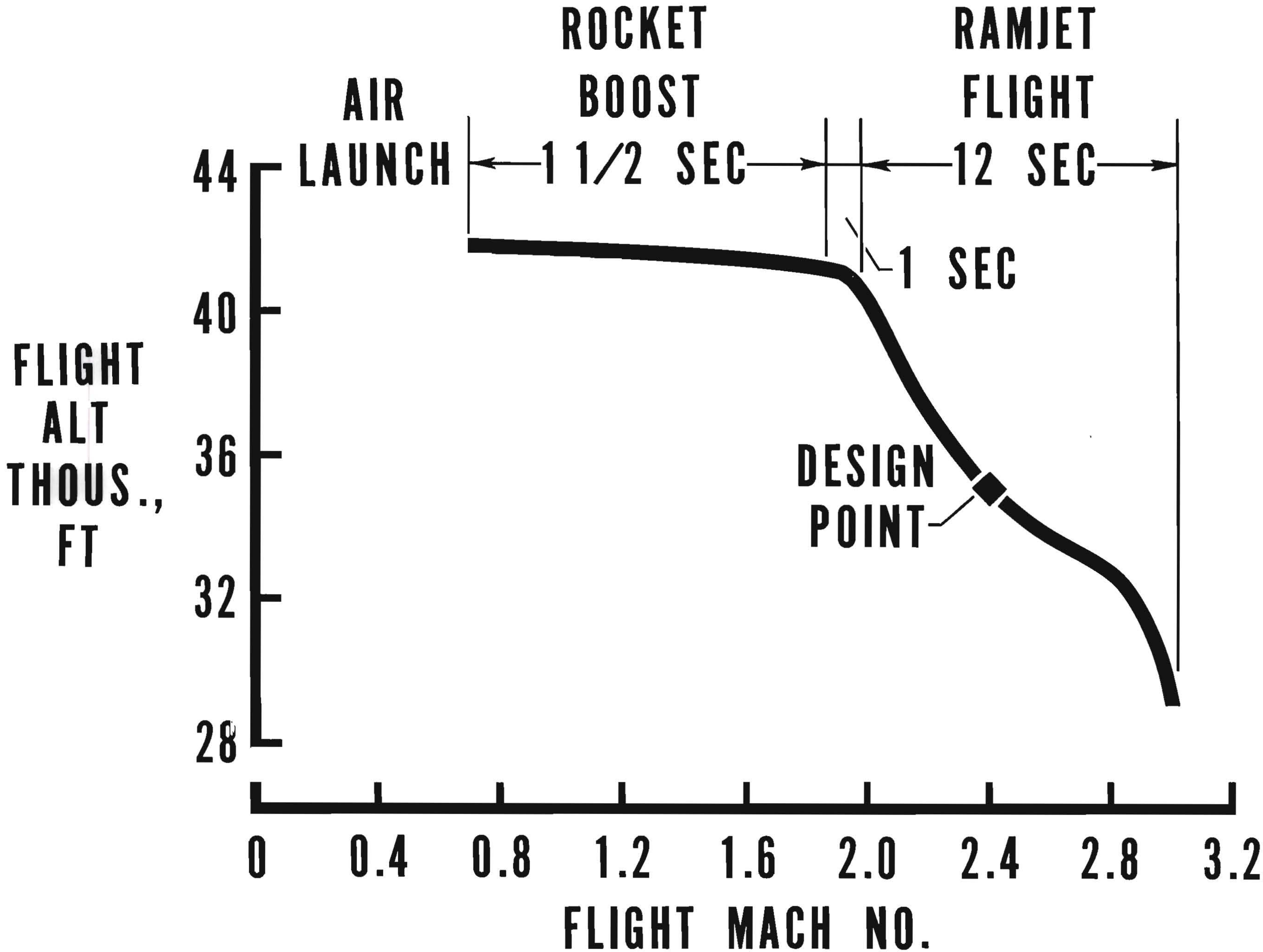

AIR LAUNCH
ROCKET BOOST
1 1/2 SEC
RAMJET FLIGHT
12 SEC
1 SEC
DESIGN POINT
FLIGHT ALT THOUS., FT
44
40
36
32
28
0
0.4
0.8
1.2
1.6
2.0
2.4
2.8
3.2
FLIGHT MACH NO.