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ROCKET RESEARCH

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1949 ANNUAL INSPECTION

Rocket Laboratory

Part I

The questions to be discussed with you here today are, first, what are the potentialities of the rocket as a flight propulsion power plant, and second, what is the NACA doing to hasten the realization of these potentials?

The rocket engine is unsurpassed wherever high thrust from a small package is required for a short period of time, and it is the only engine we have today in which thrust does not decrease and disappear as higher and higher altitudes are reached, but even increases with altitude. Because it carries its own oxidant, the rocket has no need of the earth's atmosphere, and, in fact, develops higher thrust without it.

The first chart is a diagrammatic view of a rocket power plant installation. It comprises the fuel and oxidant tanks, a pumping system, a flow control valve, and the engine. The fuel and oxidant mix and burn in a combustion chamber. The hot gases are expanded through the convergent-divergent nozzle are accelerated to the rear and thus exert a forward thrust upon the rocket.

A comparison of the rocket engine with other types of engines - the ramjet, the turbojet, and the reciprocating - is shown by the next chart. The data for each engine was taken for conditions of maximum range. The rocket develops the greatest thrust per unit engine weight and has the minimum frontal area per pound of thrust of all engines used for flight propulsion. Further, this thrust is instantly available as the rocket needs no "warm up" in the usual sense. The specific fuel or liquid consumption of the rocket is, however, much greater than any of the other engines, partly because the rocket carries its own oxidant as well as fuel. These comparisons show the rocket engine's usefulness to applications requiring very great thrust for a relatively short period of time. This type of performance is of extreme value for launching and accelerating missiles or aircraft and in assisting other power plants. For example, it is useful in assisting the rocket engine which is incapable of delivering thrust until it is moving through the air at high speeds; for rockets it is also of value for providing high thrust quickly when an emergency requires an airplane to climb rapidly or travel very fast. All of these uses have been realized. The rocket engine has also been used as a primary power plant for military missiles, for upper atmosphere research vehicles, and as the primary power plant for research airplanes. The first piloted airplane actually to operate in the supersonic regime, the X-1, was rocket powered. This is a cut-away of one of the four thrust cylinders used on this airplane. The engine of four of these cylinders can out-pust any existing turbojet engine at any altitude above 35,000 feet.

In view of the high performance potentiality of the rocket engine at any altitude the NACA is conducting research on major problems that must be solved in order to realize the unique advantages of the rocket engine. What are these major problems?

A first problem is that of providing the best propellants - fuel and oxidant - for use in the engine. The highest possible thrust is desired from a given quantity of material to obtain a low specific propellant consumption and in this way increase the distance of travel or range. The next chart illustrates the importance of low specific propellant consumption on range assuming a ballistic flight. Shown here are a few of the many possible rocket propellant combinations. The range for nitric acid and gasoline is taken as a basis of comparison. Alcohol oxygen has a relative range of 1.08, hydrazine-chloride tri-fluoride 1.29, diborane-oxygen 1.81, diborane-fluorine 2.0, hydrogen-oxygen 2.3 percent, and hydrogen-fluorine 2.5 percent. Other factors than low specific propellant consumption must be considered in selecting propellants. Properties such as ignitability, density of propellants, their boiling and freezing points, stability, toxcity, and availability, must also be considered. The final choice of propellants is always governed by the specific purpose for which the rocket engine will be used. Only after extensive research and development can the best choice be made. The NACA has made theoretical studies of all the combinations shown here and has completed or is working on the ones indicated in blue.

I would like to show movies taken during the experiments with hydrazine-chlorine trifluoride, diborane-hydrogen peroxide, and diborane-oxygen.

(MOVIE COMMENTARY)

1. This is a view of the 100-pound thrust rocket engine using chlorine-trifluoride and hydrazine as propellants.

2. This is the exhaust flame. The flame is not very

luminous. The exhaust fumes are toxic and for this reason the engine was operated from a distance.

3. Here is a second run of the same engine.

4. This is a view of the 100-pound thrust rocket engine using diborane as a fuel.

5. This is a run using diborane and hydrogen peroxide as propellants.

6. This and following runs are for experiments using diborane and oxygen as propellants, both in the liquid state. This combination has a theoretical gas temperature of 6780° F.

7. In this run you will see a slight explosion and fire at the rear of the engine. This is caused by the extremely high heat transfer from the hot gases which burn through the engine walls, and emphasizes the need for positive cooling methods.

A second major problem in the use of liquid rocket engines is cooling. Because the rocket engine is supplied with fuel and oxidant in concentrated form a tremendous amount of energy is liberated in a small combustion chamber. The gas temperatures range from 4000 to over 6000° F and hence a considerable amount of heat is transferred to the combustion chamber by radiation and forced convection. To get some concept of the magnitude of the problem consider a specific example. This rocket engine uses nitric acid and aniline and produces 1000 pounds of thrust. The heat release is 520,000,000 btu/hr/cu. ft or 20 times greater than a turbojet engine or 10,000 times greater than a modern boiler. This particular engine is uncooled because it only operates for a few seconds. One method of cooling that is used for rockets is to circulate one or both propellants over the engine surface prior to injection and combustion. For example the X-1 engine here has the fuel first circulating in a spiral path around the nozzle and combustion chamber prior to injection. With many high energy propellants this manner of cooling is not sufficient or the propellants are not suitable as coolants. In these cases an effective method of cooling is internal film cooling, in which a film of coolant is maintained along the inner surfaces of the rocket combustion chamber and nozzle in direct contact with the hot gases. One method for doing this is to make all or part of the rocket of porous metal such as this sample and allow the coolant to seep through it and form a **protective** layer on the inside. Here is a model to illustrate this method of cooling. A second method of film cooling is to introduce the current at discrete positions in the combustion chamber and nozzle. The red fluid similates the hot combustion gases which, as I have said, may be at a temperature of 6000° F or more. The temperature of the walls of the chamber and nozzle would rise quickly above their melting point if they were not cooled. The blue fluid which you see along the walls of the chamber and nozzle simulates the coolant. Note that it dissipates itself by mixing with the hot gas stream and must be introduced at several positions along the combustion chamber walls for maximum effectiveness.

Another film cooling method is the use of porous metal. The coolant flows through the porous metal into the rocket engine. Here is a model to illustrate this method of cooling. Both disks shown here are similar except that this one is rigged so that water can flow through it in this manner. A hot flame, such as this acetylene oxygen flame can be played directly on the porous section without overheating the metal. Without the coolant the flame would quickly burn through the metal. The NACA has in progress a basic study to determine the characteristics of internal film cooling. The study is being made first at temperatures up to 1800°F and in the future the results will be extended to higher temperatures. The next chart illustrates some of the results that have been obtained from this study. The first plot shows the length of the duct that is effectively cooled as a function of gas velocity for several gas temperatures. For a given gas temperature the data show that the effective film length decreases as the gas velocity increases. ~~The second plot shows the effective film length as a function of the amount of coolant flow for several gas temperatures. For a given gas temperature the data show that the effective length decreases as the gas velocity increases.~~ The second plot shows the effective film length as a function of the amount of coolant flow for several gas temperatures. For a given gas temperature, the effect of film length increases as the coolant flow increases. The data from this research project are used to determine the rules that a designer must follow in meeting a specific cooling problem at high temperatures and high gas velocities. And now I would like to introduce Mr. Paul Ordin who will continue the discussion of rocket problems.

Part II

A third major problem encountered in the design and use of liquid propellant rocket engines is altitude starting. This includes the injection and mixing of the propellants and their ignition.

As more and different tactical demands are made of engines, new problems arise. The successful ignition of rocket propellants at high altitude and low temperature has been emphasized as a real and present problem as a result of a broadening usage of rocket power plants. For example, a rocket engine intended for use as a thrust augmentation device to provide super performance of an airplane is carried several hours at high altitude - long enough to become thoroughly chilled to 40 or 50° below zero F. But it is required that its propellants shall ignite and provide thrust immediately.

The NACA has recently installed facilities for studying the starting or rocket engines at altitude and with the rocket and propellants at low temperature you will see this equipment after your stop here.

Test of a conventional rocket engine like this one using acid and aniline as propellants are on the way with this altitude equipment. This engine was designed to start at sea-level and normal temperatures but new uses contemplated by the military require starting at altitude and low temperatures. This chart depicts the first findings of an investigation to determine the effect of low propellant temperature and low atmospheric pressure on the starting of this particular engine. The chart shows that at sea-level air temperatures warmer than 0° F successful starting was obtained. At temperatures between 0° F and -25° F ignition was uncertain and below -25° F ignition could not be obtained. At very high altitudes and warm temperature above 0° F either explosions were experienced or ignition failure occurred. Here is one engine that exploded during these tests.

The NACA is studying this problem of ignition in an effort to explain and to eliminate explosions and ignition failures. Since this chart shows that temperature is a major factor causing ignition failures and explosions, a simple bench experiment has been made to measure the effect of temperature on ignition delay and to seek additives or new fuels to reduce or to eliminate this delay. The effect of temperature on the ignition delay of acid and aniline can be demonstrated by means of this apparatus shown diagrammatically by the next chart.

It is desired to mix the fuel and oxidant at low temperature and to measure the time interval between mixing and flame appearance. This is done by placing the fuel in a sealed glass ampoule and immersing it in the oxidant in a test tube as shown. The test tube contained fuel and oxidant is itself immersed in an alcohol bath that is maintained at 30° below 0° F by a circulating coolant. The glass ampoule of fuel is broken by means of a falling weight which when released by the trigger strikes this rod and breaks the ampoule. This switch starts an electronic timer at the time the ampoule is struck and this photo cell stops the timer when a flame appears.

This apparatus is set up here to demonstrate ignition delay at low temperature. Here is the timer and this potentiometer shows the temperature of the coolant around the test tubes. Two identical sets of apparatus are shown. In the first, on the left we have placed an ampoule of crude monoethylaniline in a tube containing mixed acid which is mostly nitric. This is the combination used in the engine just described. The acid-aniline combination has an ignition delay of 35/1000 second at room temperature but now see what happens at 30° below zero. The timer shows a delay of ____ seconds or ____ times longer than for room temperature. This time difference is sufficiently long to permit accumulation of propellants in quantities capable of producing an explosion when they do ignite, or even so long that ignition never occurs with, fresh charge continuously sweeping through the engine. One proven cure is to keep the engine and propellants warm.

A second possible curve now under study is the use of chemical additives to the fuel to shorten ignition delay at low temperature or the use of different fuels. The second apparatus on the right, has a fuel containing aniline and furfuryl alcohol which is one combination which was found to have a short delay at low temperature. It is also immersed in mixed acid and at -30° F. Now see what happens. The timer shows a delay of ____ seconds or roughly 1/8 the delay of the original fuel. This study is still in progress.

A fourth problem of liquid fuel rockets is combustion or more specifically the obtaining of efficient combustion to increase performance and to do so in as small a volume as possible to decrease heat losses. Satisfactory combustion is a function of the injection and mixing processes and the combustion chamber volume and shape. It was pointed out at the inspection last year that this laboratory has been studying various injection methods by taking high speed photographs of the resulting combustion patterns. Since that time the apparatus has been used to study another combustion problem that is closely connected with injector design. This is the phenomenon of combustion vibration or chugging which causes violent fluctuations or pressure, to be set up in the combustion chamber and supply lines. The chamber pressure may reach a maximum that is double the normal value and the excessive forces frequently result in the structural failure of the chamber in supporting members. This phenomena has been encountered in the course of rocket development and has occurred at unpredictable times.

This laboratory first made an analysis of the "chugging" problem from a theoretical standpoint to determine the conditions at which chugging can occur. A rocket was then set up to check the theory experimentally. Experiments are being conducted to determine how chugging is effected by such variables as combustion chamber pressure, injection pressure, and combustion volume. This information will permit the design of rockets in which chugging will be avoided in the desired operating range. You will now be shown some motion pictures illustrating this phenomena.

(MOVIE COMMENTARY)

1. This is a view of the setup.

2. Here is a normal run. The engine is producing 1000-pound thrust with nitric acid and gasoline as propellants.

3. Here the rocket is chugging at a frequency of about 30 cycles per second.

4. This is another view of the same run taken through the operator's observation window.

5. This is another run with chugging at about 30 cycles per second.

6. These are high speed photographs at about 3000 frames per second of normal combustion. Notice the shock patterns in the flame.

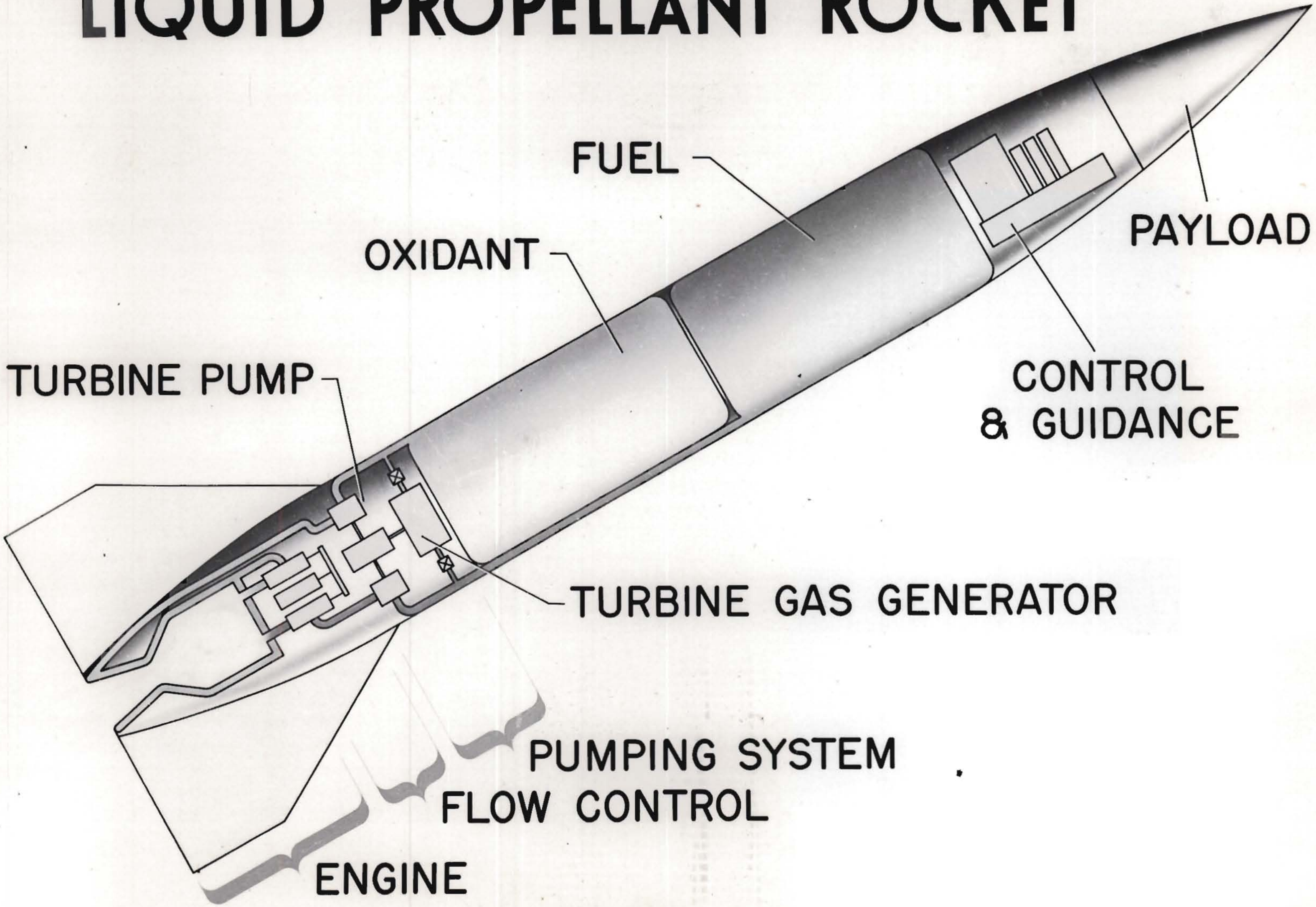
7. Here are high speed photographs at 3000 frames per second of chugging. The frequency is about 18 cycles per second. The little white dot right behind the nozzle lever is stationary and shows how much the rocket is moving because of the rocket chugging. Note that at times the flame disappears completely.

To further demonstrate this phenomena of chugging a rocket engine will be operated for you, and regular research data will be obtained during the run.

The rocket will operate with two short bursts of five seconds each. The first burst will be with chugging and the second burst with the same rocket operating in a normal manner.

Fair Weather	When you hear the siren please hold your hands over your ears until you are accustomed to the noise. If you prefer you may remain seated here and watch the flame by television. Those who wish to go to the observation point, please follow the guide. Thank you.
Rainy Weather	Because of the rain you will not be able to see the rocket directly. If you remain in your seats you can see the flame through television and hear the noise directly. The demonstration will start soon after the start of the siren. Thank you.

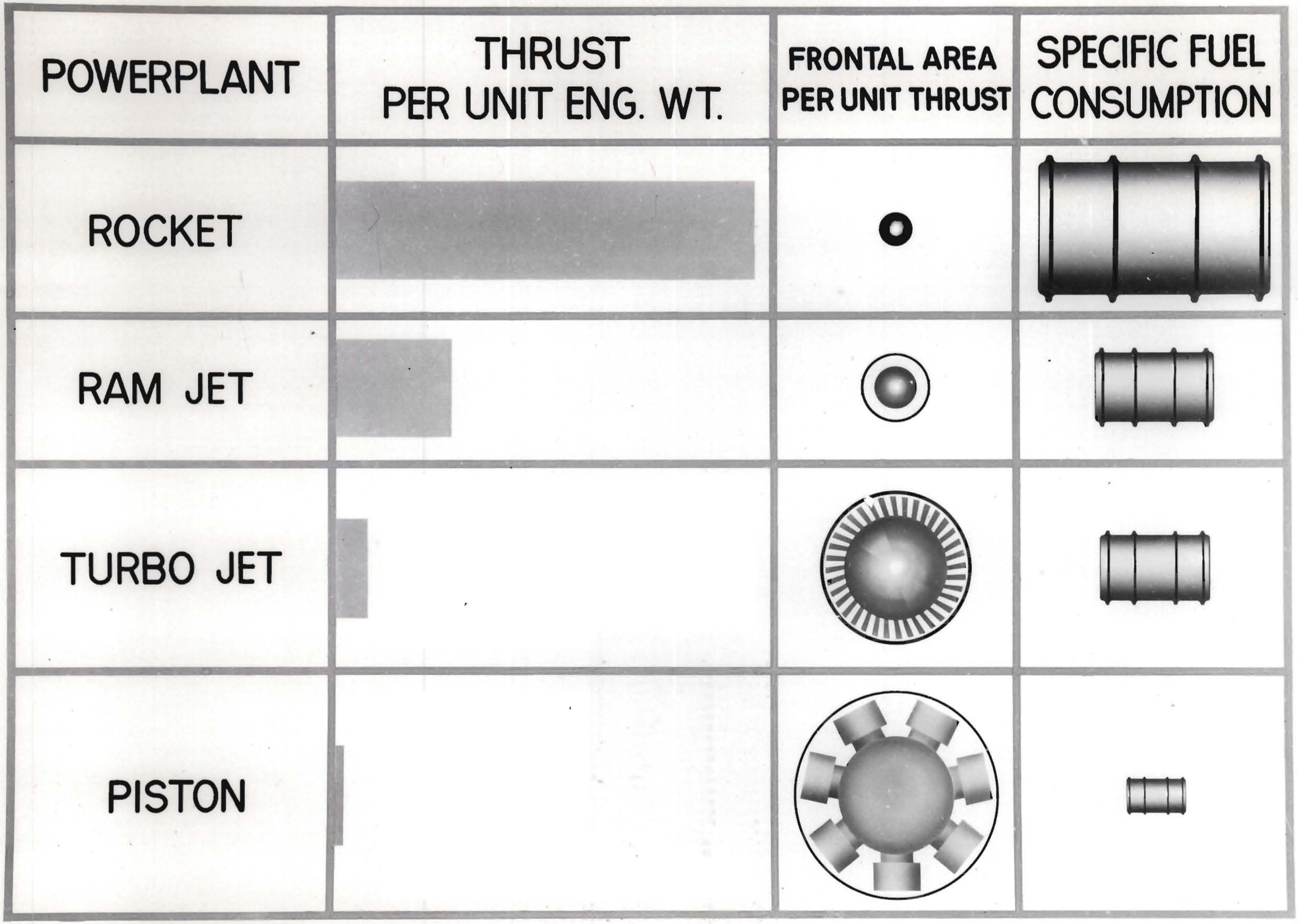
LIQUID PROPELLANT ROCKET



C-24476
10-13-49

NACA

POWERPLANT COMPARISONS



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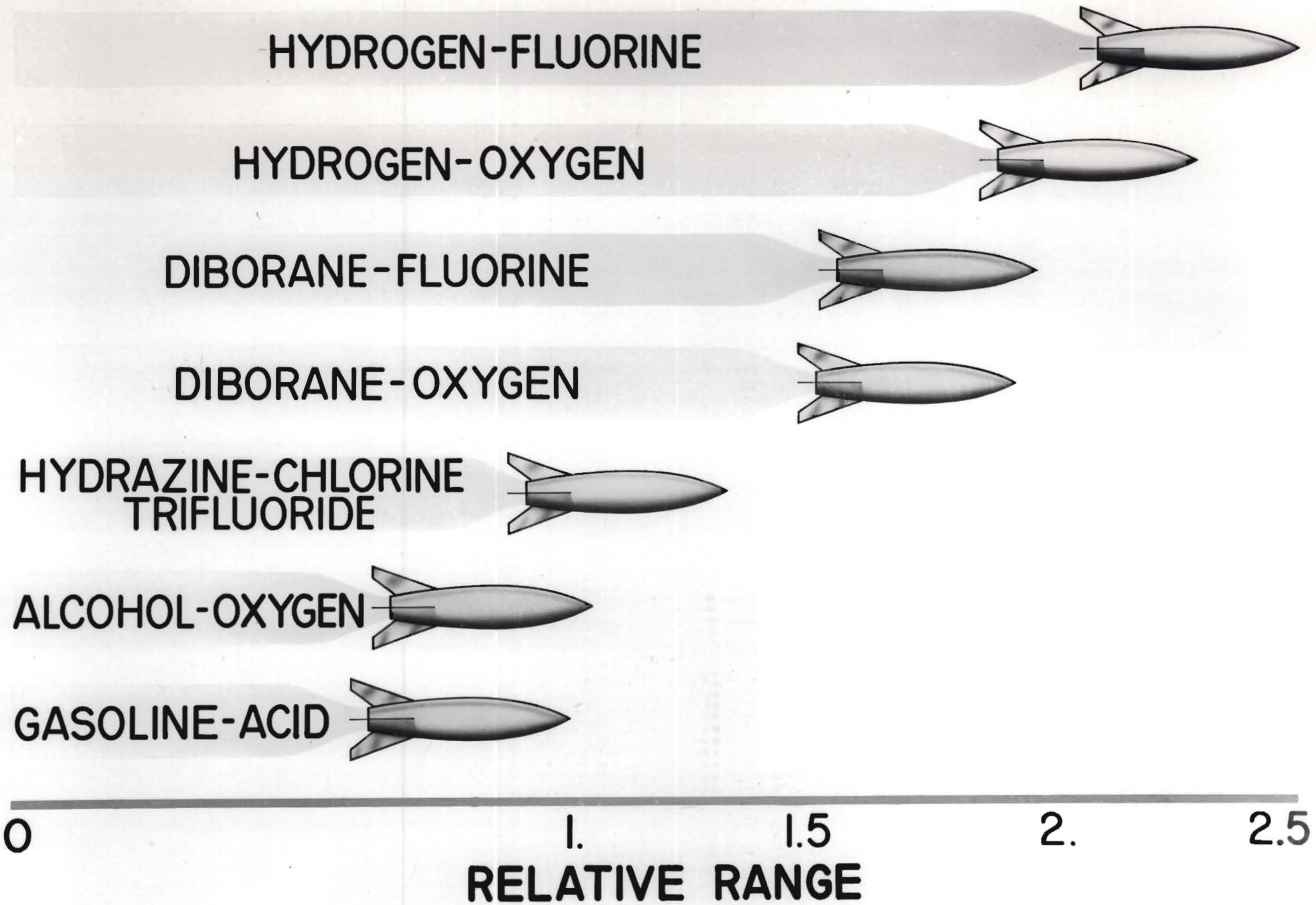
THEORETICAL RELATIVE BALLISTIC RANGE



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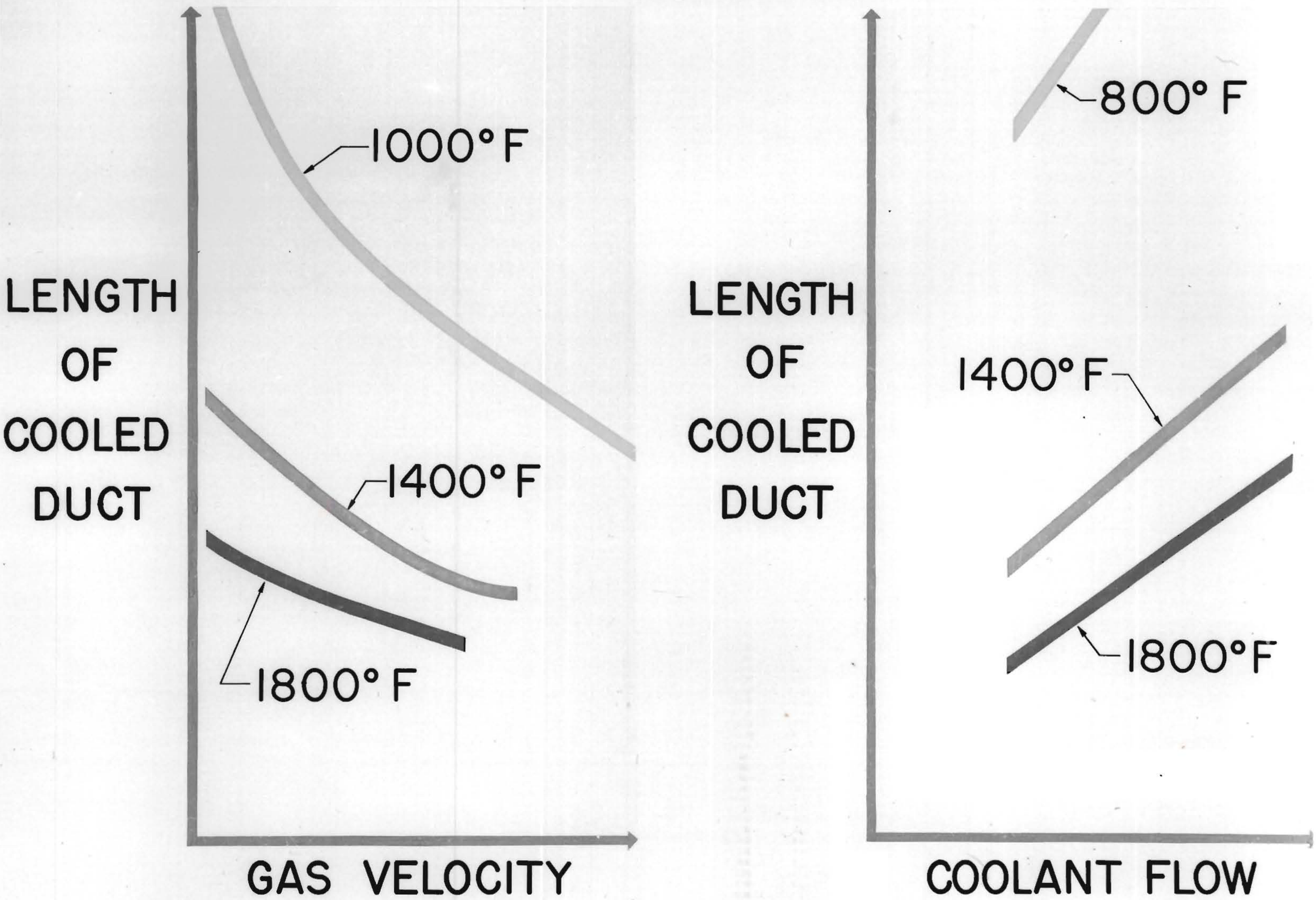
INTERNAL FILM COOLING



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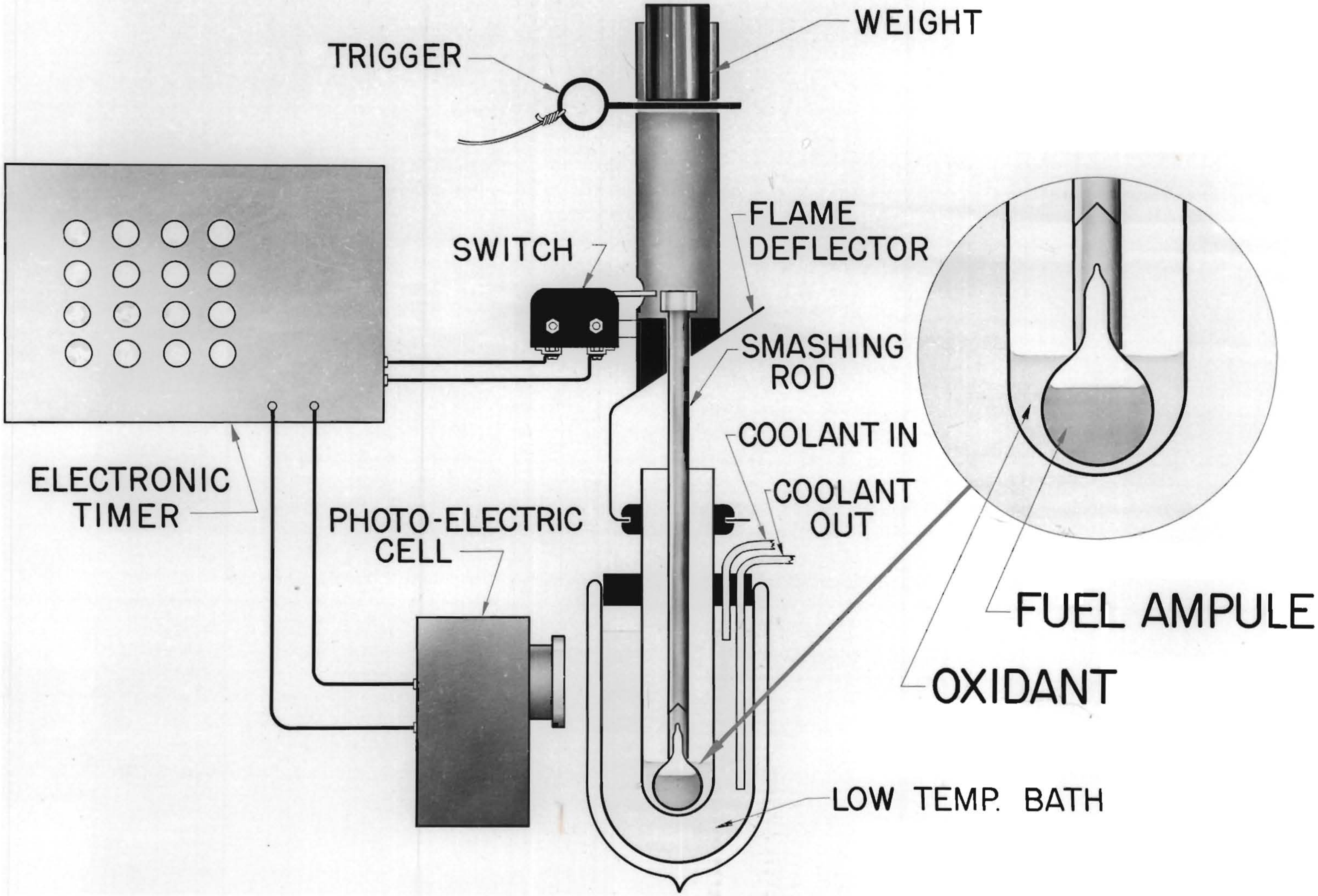
IGNITION APPARATUS



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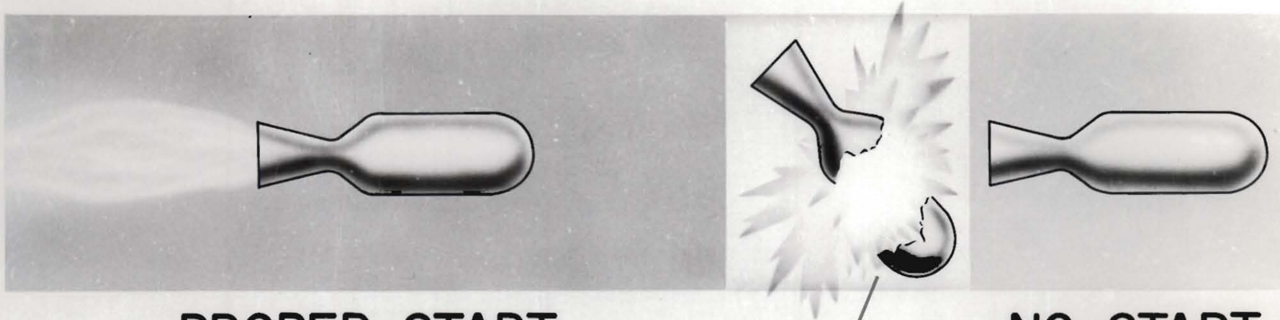
ALTITUDE STARTING

ALTITUDE ABOVE 50, 000 FT.

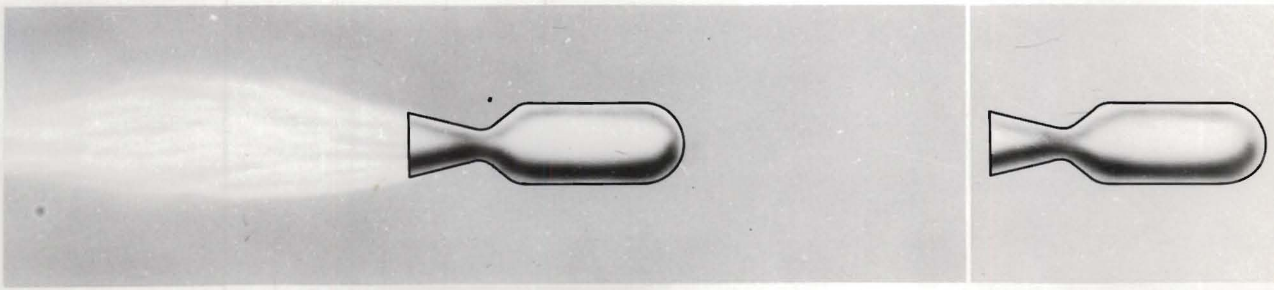


PROPER START

EXPLOSION

NO START

SEA LEVEL



PROPER START

NO START

WARM

COLD

PROPELLANT TEMPERATURE

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10-13-49

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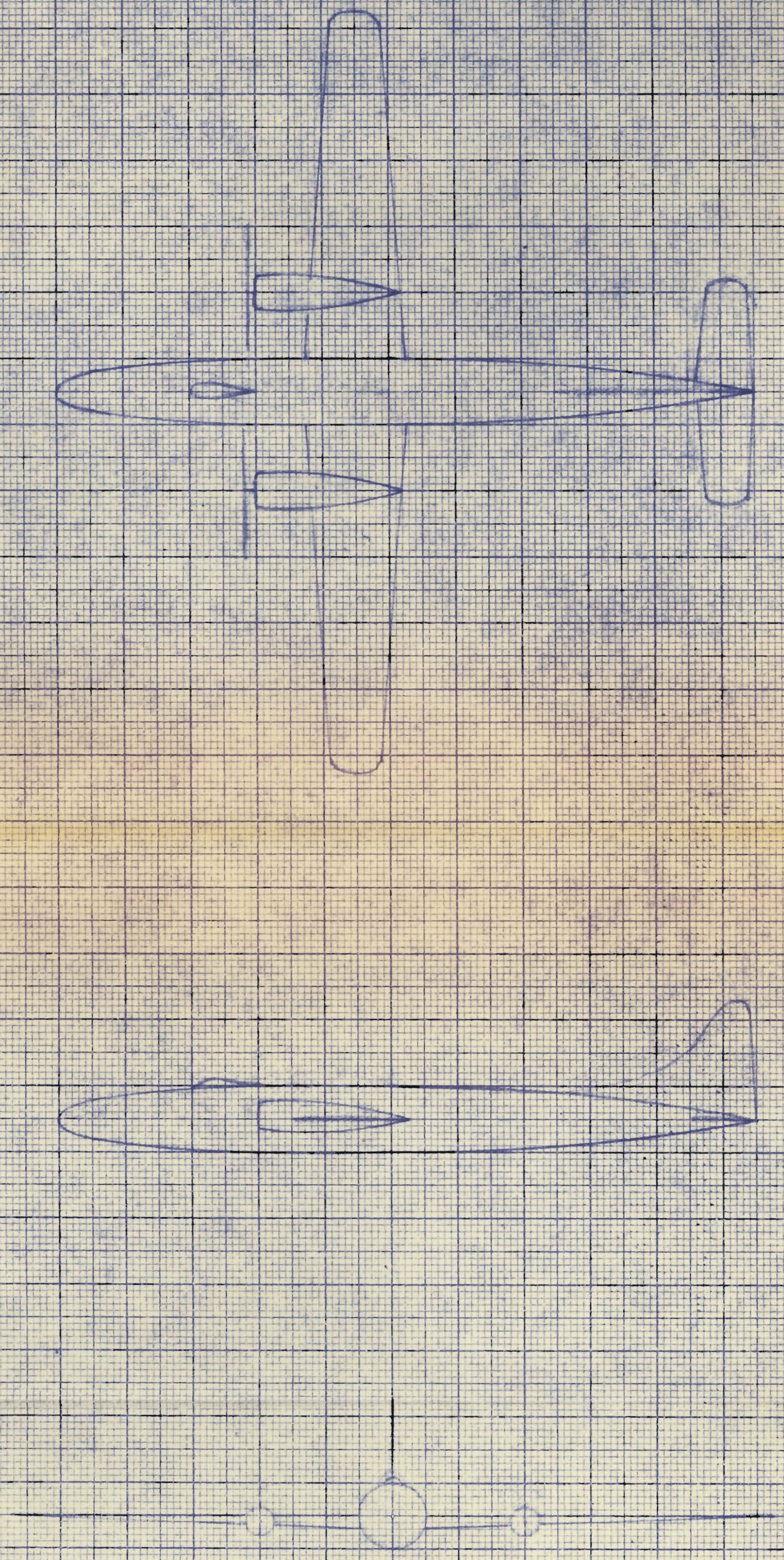
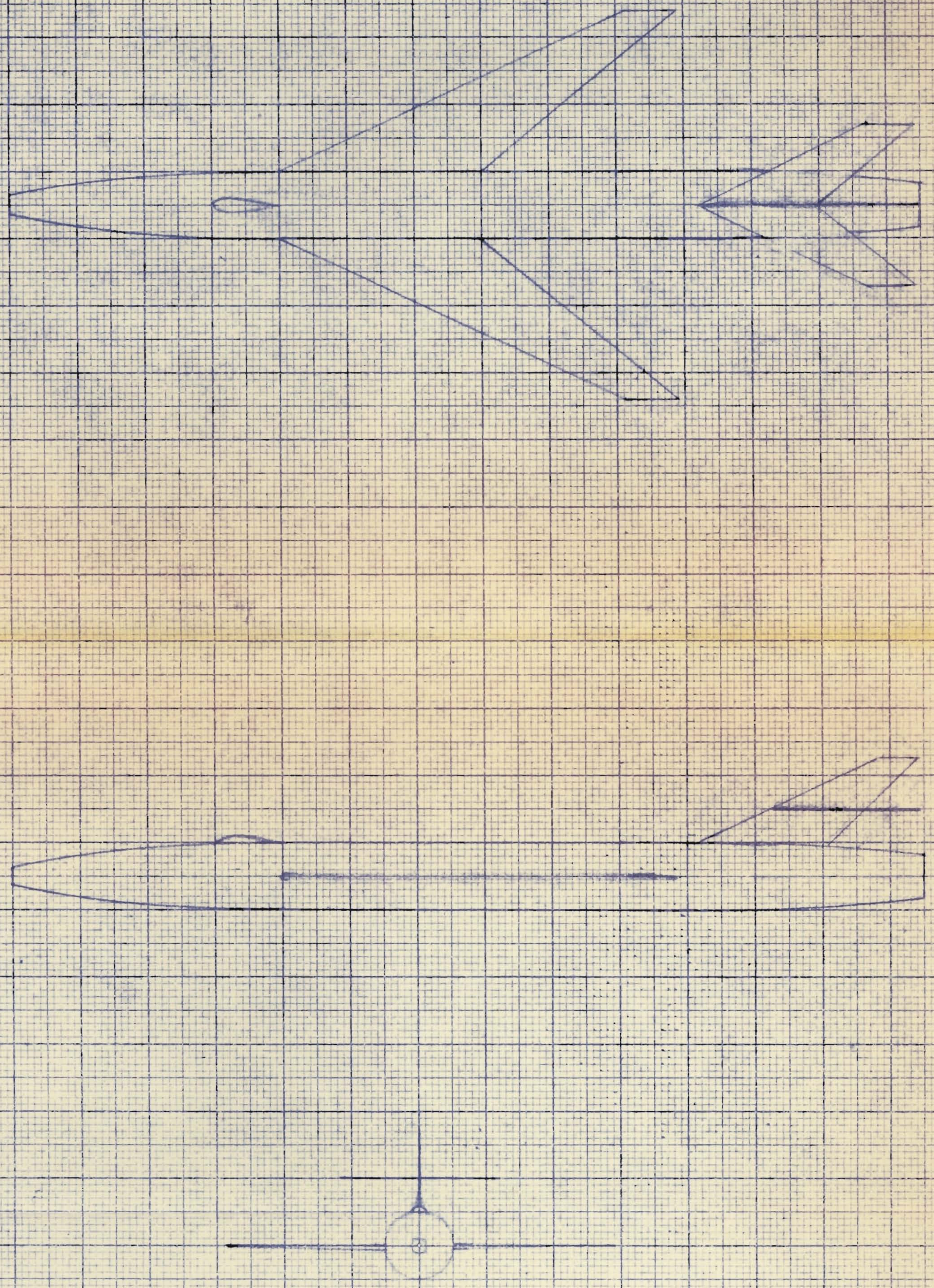
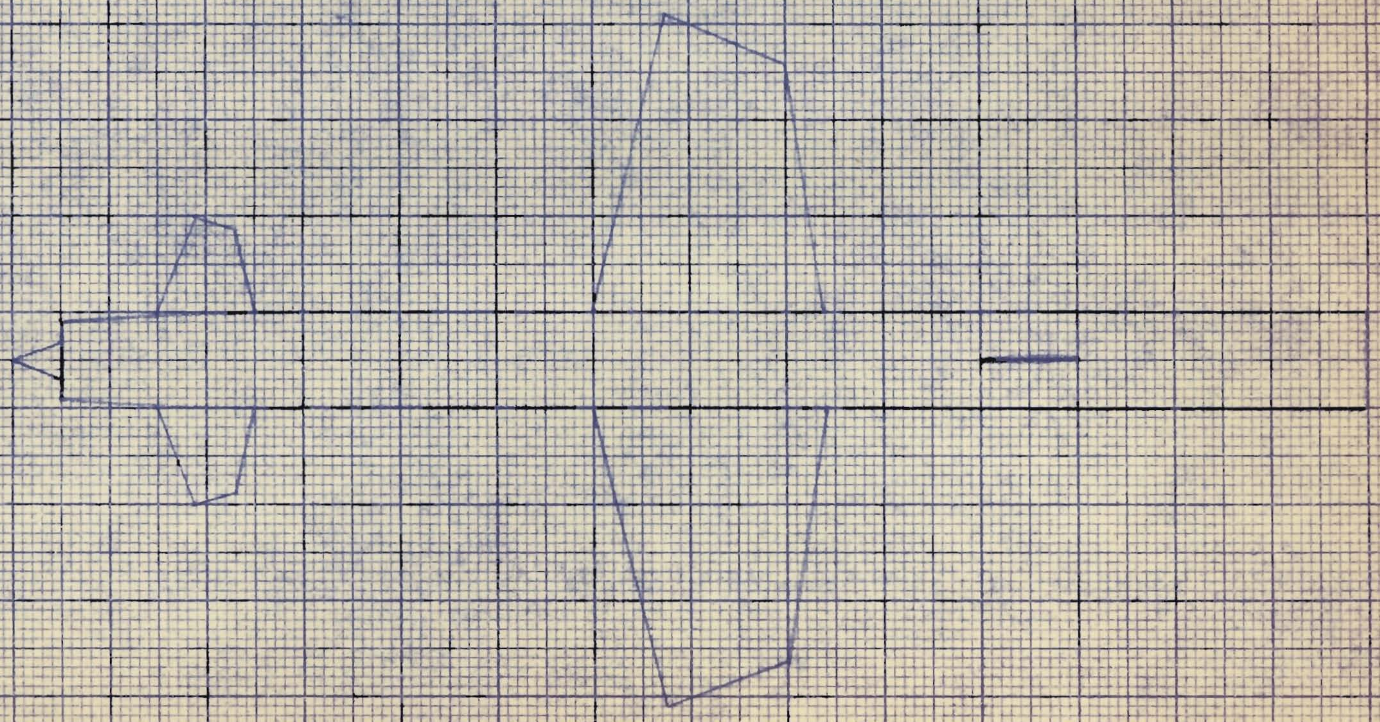
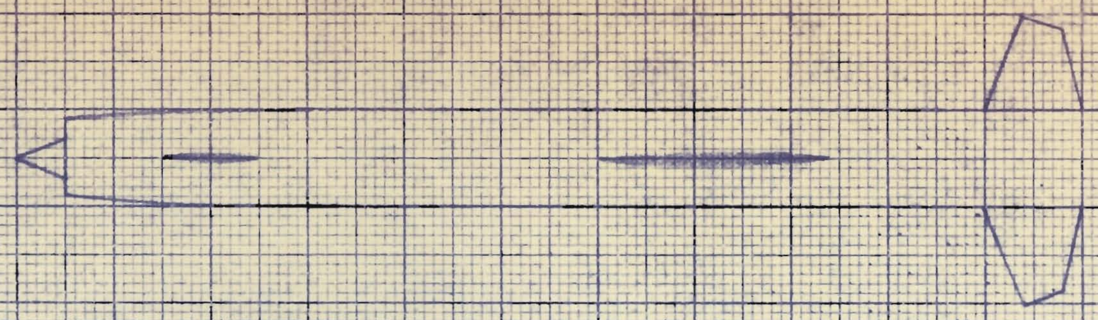


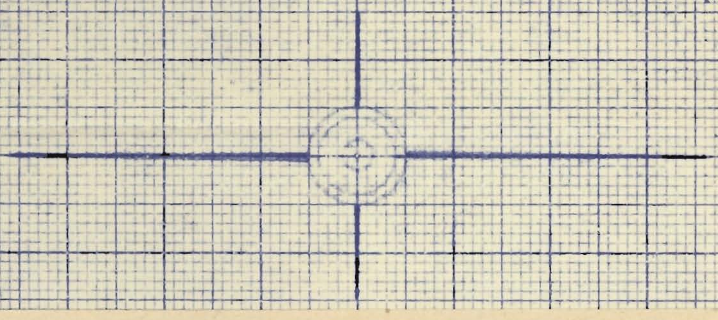
400 MPH AIRPLANE 3000 HP 30,000 FT



1500 MPH AIRPLANE 15000 HP 50,000 FT







Drawings that were sent to Mr. Rothrock per his request. They are drawings of the models used for the SWT demonstration during Annual Inspection. (1949)