ALTITUDE ENGINE RESEARCH

Speakers: William A. Fleming
Bruce T. Lundin

The background noise or rumble that you may notice here is caused by the operation of a turbojet engine in the test section of the altitude wind tunnel that will be used in a later part of our demonstration.

As essential phase, or part, of the over-all engine research program of the Lewis laboratory is research that is conducted with the complete, full-scale engine. It is this work with the full-scale engine that serves to bring together or integrate into the complete engine many of our research contributions on various engine components and to investigate the problems of interaction of one engine component on another. The processes of combustion in the engine are, for example, dependent upon the nature of the air flow delivered by the compressor and, conversely, the problems of compressor design are influenced by the operation of the turbine or the manner in which fuel is burned in the combustor.

In addition to these problems of component interaction, a modern aircraft power plant is a complicated and delicate piece of machinery and is sensitive to the environment in which it is operated. When an engine is operated in the upper atmosphere, where temperatures as low as -100° F and pressures down to 1 or 2 inches of mercury are encountered, it does not perform exactly the same as on sea-level test stands or as may be predicted by theoretical studies. The operation of actual prototype engines in altitude facilities thus not only provides evaluation and further development of the application of fundamental research contributions to actual engines, but also serves to discover and solve many difficulties of operation that were not previously known or even anticipated. By working closely with the engine designers and manufacturers, this applied research has contributed greatly to the technical excellence of our country's engines and largely avoided the need for extremely costly, hazardous, and time-consuming engine development by means of flight testing. Some of the facilities required for this full-scale engine research work, such as this altitude wind tunnel or our altitude test chamber, have already been or will be subsequently described to you in the demonstration in our central control room. In addition to these large research facilities, accurate measurement of engine performance is necessary, which requires a multitude of complex and frequently unique instruments. Some of these instruments have been assembled for your inspection on the table at the rear of this room.

As representative examples of this work with full-scale engines, we have selected for your review today a demonstration of engine controls research and of research on tail-pipe burners for turbojet engines. The first of these two demonstrations, that on engine-control systems, will be presented by Mr. Novik (Ketchum).

Thrust Augmentation

Speakers: Martin J. Saari
E. William Conrad

One of the most spectacular accomplishments in the field of aircraft propulsion in recent years has been the development of tail-pipe burners for turbojet engines. As with many important scientific contributions, the tail-pipe burner is characterized by simplicity of concept and application. It consists essentially of an enlarged tail pipe which incorporates a suitable fuel distribution system, a flame holder, a combustion chamber, and a variable-area exhaust nozzle. Fuel is injected into the gas stream leaving the turbine, and is burned, thereby increasing the temperature of the gases within the burner. The elevated temperature results in an increase in jet velocity which produces a much greater thrust than can be obtained with the basic engine alone. By application of tail-pipe burners in combat aircraft, the take-off distance is considerably reduced, the rate of climb greatly increased, and additional thrust is provided for high speed bursts during tactical maneuvers.

While the tail-pipe burner plays an important role in improving the performance of the subsonic airplane, it has become a vital and necessary integral part of the turbojet power plant for the supersonic airplane. This point is illustrated in this chart (fig. 4), which shows the drag characteristic of a typical supersonic airplane and the thrust that can be obtained from its engines both with and without tail-pipe burners. Since the thrust must be greater than the drag to sustain level flight, it is evident that flight at supersonic speeds is impossible without the tail-pipe burner; in fact, the basic turbojet engine can furnish only half of the thrust required to overcome the drag in the region of sonic speed. On the other hand, the tail-pipe burner provides sufficient additional thrust to propel the airplane not only through the speed of sound, but far beyond into the supersonic speed range.

It is, of course, possible to obtain the thrust required for supersonic flight by enlarging the basic turbojet engine. With this possibility in mind, let us consider these models of two supersonic interceptor airplanes designed for the same flight conditions. This airplane is powered by basic turbojet engines which have been enlarged to provide the thrust required for supersonic flight. The extremely large engines required when tail-pipe burners are not utilized results in an unrealistic and impractical airplane having poor combat performance because of the great weight and high aerodynamic drag of the engines. In contrast, this airplane is powered by turbojet engines with tail-pipe burners, where the high thrust increase provided by the tail-pipe burners permits the use of much smaller engines which impose smaller drag and weight penalties on the airplane. While many significant contributions have been made to the art of tail-pipe burning by utilization of the altitude research facilities at this laboratory, many operational problems must as yet be investigated to meet the ever present demand for flight at greater flight speeds and higher altitudes.

The problems of supersonic flight are of particular importance. To obtain the high thrust required for supersonic flight, the gas temperatures must be considerably higher than those previously employed. Inasmuch as no presently known materials will successfully withstand these temperatures, cooling of the burner shell becomes a vital necessity. Methods for providing cooling air with minimum losses in engine and airplane performance are being investigated at this laboratory.

Also, since it is important to keep the tail-pipe burner as small as possible, problems of burning fuel efficiently at very high gas velocities and the elimination of combustion instabilities encountered under these conditions are also the subject of considerable research effort.

Since many of you have not had the opportunity to see a tail-pipe burner in operation, we will conclude this presentation by demonstrating a burner in action. The engine and tail-pipe burner will be run in the test section of the altitude wind tunnel and a television camera will transmit the view across the burner nozzle to the screens indicated by the lights. A microphone located at the test section will give you an idea of the noise generated.

Controls Research

Speakers: David Novik
James R. Ketchum

Our discussion here today will include two phases of research in the altitude wind tunnel, both of which are receiving a good deal of emphasis and priority at the present time. These are engine controls research and tail-pipe burner research.

We will first discuss controls research and I will attempt to indicate its importance by pointing out the various functions of a control system for a turbojet engine, the type of problems that exist, and the methods and facilities required.

Let's start out by putting ourselves in the pilot's seat with a single control lever (or throttle) with which we are to control the engine over its complete operating range. Our engine is above us here on the display panel.

Phase of Operation	Function of Control
Start	Fuel flow, ignition, prevent overtemperature
Acceleration	Fuel flow, prevent surge and blowout
Full Power	Maximum RPM and temperature, prevent exceeding limits
Augmentation	Tail pipe fuel, maintenance of limiting RPM and temperature

Coming back to earth again, we find that there are a considerable number of required control functions and control sequences. In order to relieve the pilot of these responsibilities, it is necessary that the control functions be taken care of automatically, with a single control lever. The pilot can then devote his attention to flight and combat duties.

Now let's see how just a motion of a single lever in the pilot's cockpit must actuate other components in the control system in order that the functions of the control system can be fulfilled. As an example of this, I want to refer to the first chart (fig. 1), which shows a schematic diagram of an engine speed control system.

A generator is geared to the engine which develops a voltage proportional to the engine speed. This voltage is brought down to this point, where it is bucked up against a voltage determined by the position of the throttle. The difference in voltage, then, is proportional to the difference between the actual speed and the desired or set speed. This voltage difference is amplified in the amplifier so that sufficient power is obtained to operate a motor which turns the fuel valve. The change in fuel valve position results in a change of fuel flow to the engine and an attendant change in engine speed. The new engine speed causes a change in generator voltage so that the voltage supplied by the generator approaches the voltage from the throttle. When the two voltages are equal, then the actual engine speed is equal to the desired speed; there is no signal into the amplifier so that the fuel valve remains fixed, the engine speed stops changing, and the system is in equilibrium.

Some of the actual components of a speed control system such as this may be seen on the display panel. Here is the throttle, this is the amplifier, this if the fuel valve, and this black part is the motor that operates the valve, and this is the generator.

It should be pointed out that control of engine speed is often only a small part of the over-all engine control system. For instance, a control system for a turbojet engine with a tail-pipe burner becomes much more complex, as shown on the next chart (fig. 2). The part shown in blue is the speed control system just discussed. The scheduler is for the purpose of separating the engine speed control system from the control of the variables required by the tail-pipe burner, which are tail-pipe fuel flow and temperature. The temperature control operates from a thermocouple that develops a voltage proportional to temperature. This voltage is bucked up against a voltage proportional to the desired temperature, the voltage difference is amplified until it is sufficiently large to run a motor which changes the area of a variable-area exhaust nozzle.

Now here's a typical example of how we can get into trouble with a control system such as this. Suppose that the temperature changes as a result of a change in tail-pipe fuel flow. The temperature control then changes the exhaust nozzle area. This causes a change in engine speed, the speed control changes engine fuel flow to bring back the speed and this change in fuel flow also changes the temperature again. The temperature control changes the exhaust nozzle area once more and we go round and round the cycle.

This type of interaction is not a hypothetical case. We have actually encountered it with many of the tail-pipe burning controls that we have investigated.

On top of these exceedingly complicated interaction problems, we have the fact that even the control of individual variables presents a number of problems. As an example of this, let's go back to the speed control system discussed previously.

In controlling the speed of an engine, it is, of course, desirable to be able to accelerate or decelerate as rapidly as possible. One way of doing this is to have a very high amplification factor in the amplifier--or as we call it, a high control sensitivity. This would mean that only a small voltage signal into the amplifier would result in a large change in fuel flow and, therefore, a rapid change in engine speed. We have found, however, that in certain cases, operation at a high control sensitivity results in extremely undesirable engine characteristics.

We are going to illustrate these undesirable engine characteristics by running the engine now in the test section of the wind tunnel. The engine is instrumented with electrical pick-ups that develop voltages proportional to the variables being measured--as for instance, the generator which produces a voltage proportional to engine speed. These voltages are then amplified with amplifiers such as shown here on the rack and the amplified voltages then can be traced on a recorder such as shown here. This recorder is set now to give us a trace of engine speed and when I turn it on, we will be able to see the changes in engine speed as they actually occur. The engine operator in the control room has set a condition of high control sensitivity and we are now ready to witness the undesirable engine operation that I want to demonstrate. A loud speaker will also be turned on to transmit the engine noise and thereby allow us to hear the engine as well as see the engine data.

We have just seen that operation at a high control sensitivity can result in engine instability. These oscillations, incidentally, were about 100 rpm and at a slightly higher control sensitivity would have increased in magnitude and probably destroyed the engine. This means that if we are to use a high control sensitivity, we must find some means of stabilizing the engine.

Problems such as these can be calculated mathematically but, from a practical standpoint, life is too short. In dealing with the control of many variables and with the interaction of these variables as indicated for tail-pipe burning control, there are so many combinations and permutations of possible solutions that the time required for these calculations becomes prohibitive. So, in order to reduce the time required, we make use of an electronic analog which can give us solutions in less time than it often takes to write the problem down.

Our analog is essentially a combination of electrical networks, each of which is used to simulate an engine or control characteristic. By referring to the next chart (fig. 3) I believe I can give you a better understanding of how this simulation is achieved. This lower figure shows how engine speed varies with time for a sudden increase in fuel flow as shown by the upper figure. This variation of engine speed with time can be described by a mathematical equation and the same mathematical equation is also descriptive of a very simple electrical network, consisting only of a resistor and a condenser. If a sudden change in voltage is put into this resistor-condenser circuit, the voltage out of the circuit will vary with time as shown here. You will note that the two sets of curves are identical so that if we removed the descriptive legends, it would be impossible to tell which curves were for the engine and which curves were for the electrical network. This is exactly what we do in using the analog -- we say that the voltage trace as shown on an oscilloscope is not just a voltage but is the engine variable itself.

A part of our analog is shown here -- the various knobs are for adjustment of simulated engine and control characteristics and the plug-in cords are for interconnecting various engine and control components. The characteristics of the engine that we have just operated have been set up on the analog and by turning on the oscilloscope we can see how the engine speed is shown to increase at a setting of low control sensitivity. Now, as I increase the control sensitivity with this knob, you can see that the engine speed increases at a faster rate but that we obtain more and more oscillations -- until we finally arrive at the same type of instability that we have just witnessed with the actual engine.

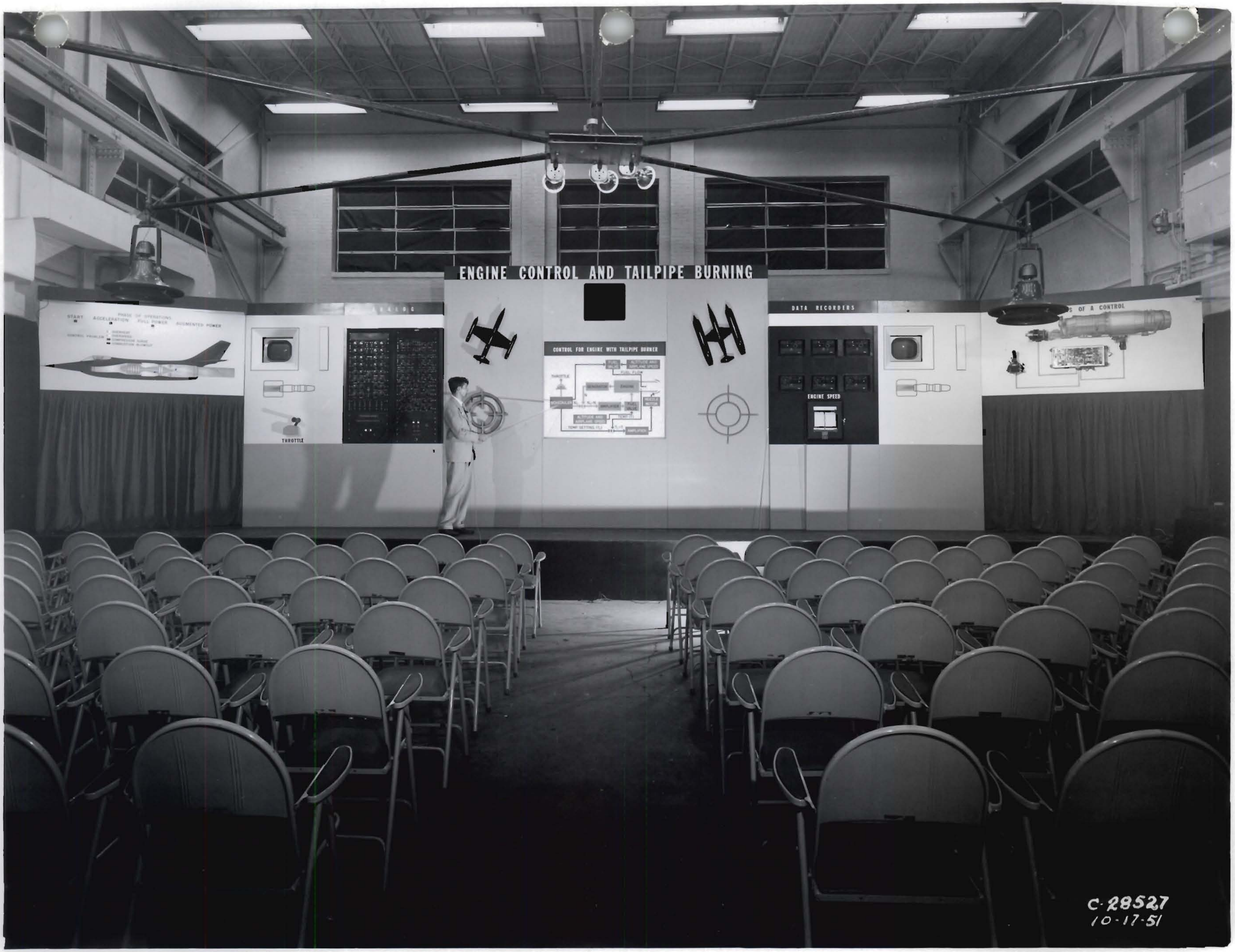
Through the use of the analog we have been able to determine a corrective network that will allow us to eliminate the engine instability and still permit the use of high control sensitivity. This corrective network has been set up on the analog and as I switch it in you can see that the engine has become stable without reduction of the control sensitivity.

Now let's go back to the engine and see if this corrective network will work in actual practice. While I have been talking, the operator in the control room has incorporated the corrective network into the control system and we will now witness the engine operation with the same high control sensitivity as used previously, but with the corrective network.

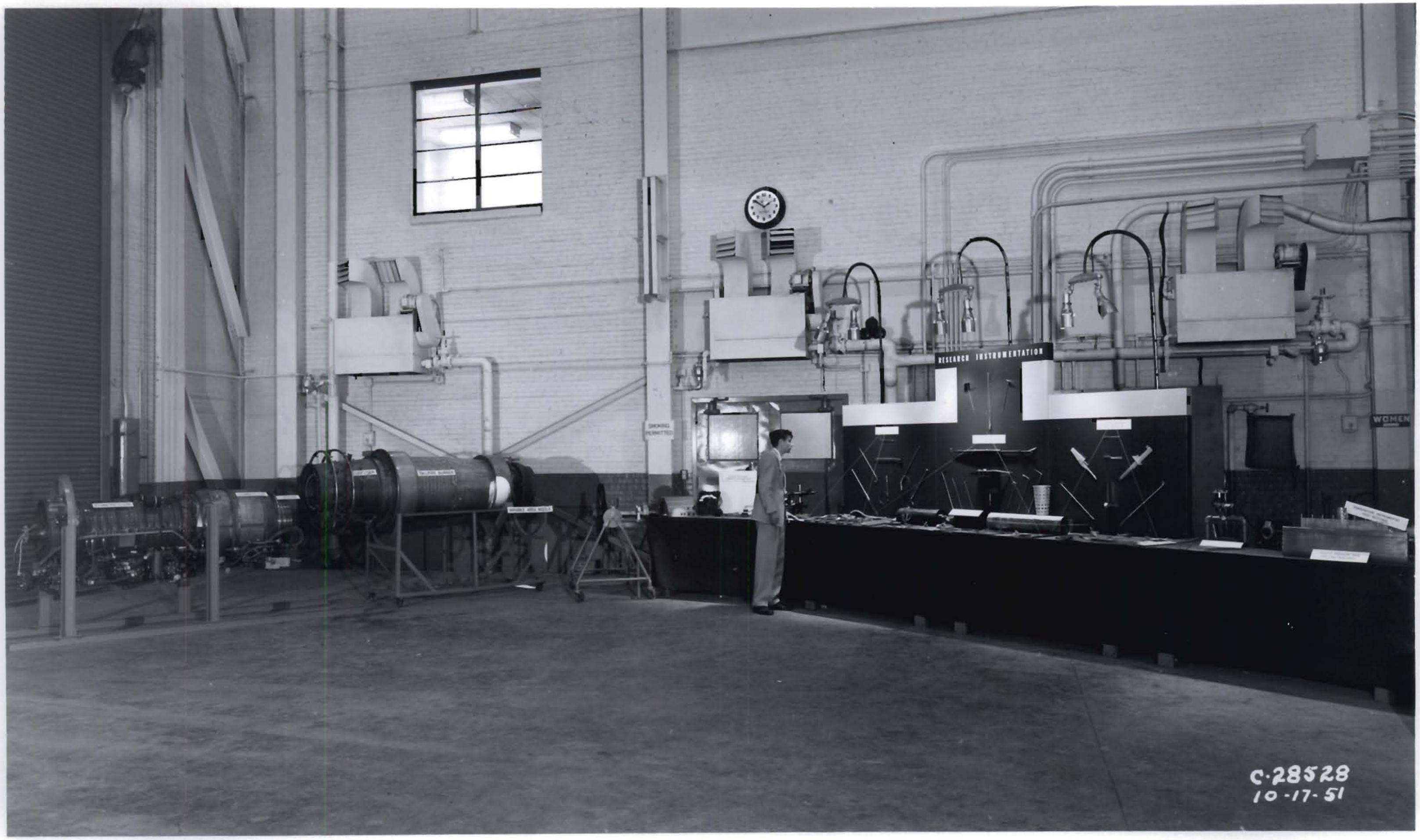
We have seen then, that the analog has given us a suitable solution to our problem of operation at high control sensitivity. Of course, this doesn't mean that we don't need facilities such as the altitude wind tunnel. In setting up the problem for the analog we make simplifying assumptions in which we idealize the components and consider only the dominant factors involved. An experimental proving ground is therefore necessary in order to verify the validity of our assumptions, in addition to providing us with the engine characteristics that we must know before we can simulate them on the analog.

We hope that this discussion has succeeded in acquainting you with the nature of control problems and with the methods and facilities we use in our controls research at this laboratory.

We would now like to discuss another phase of work of utmost importance in the development of superior engines. Mr. _______ will take over at this point to discuss research concerned with the development of tail-pipe burners.



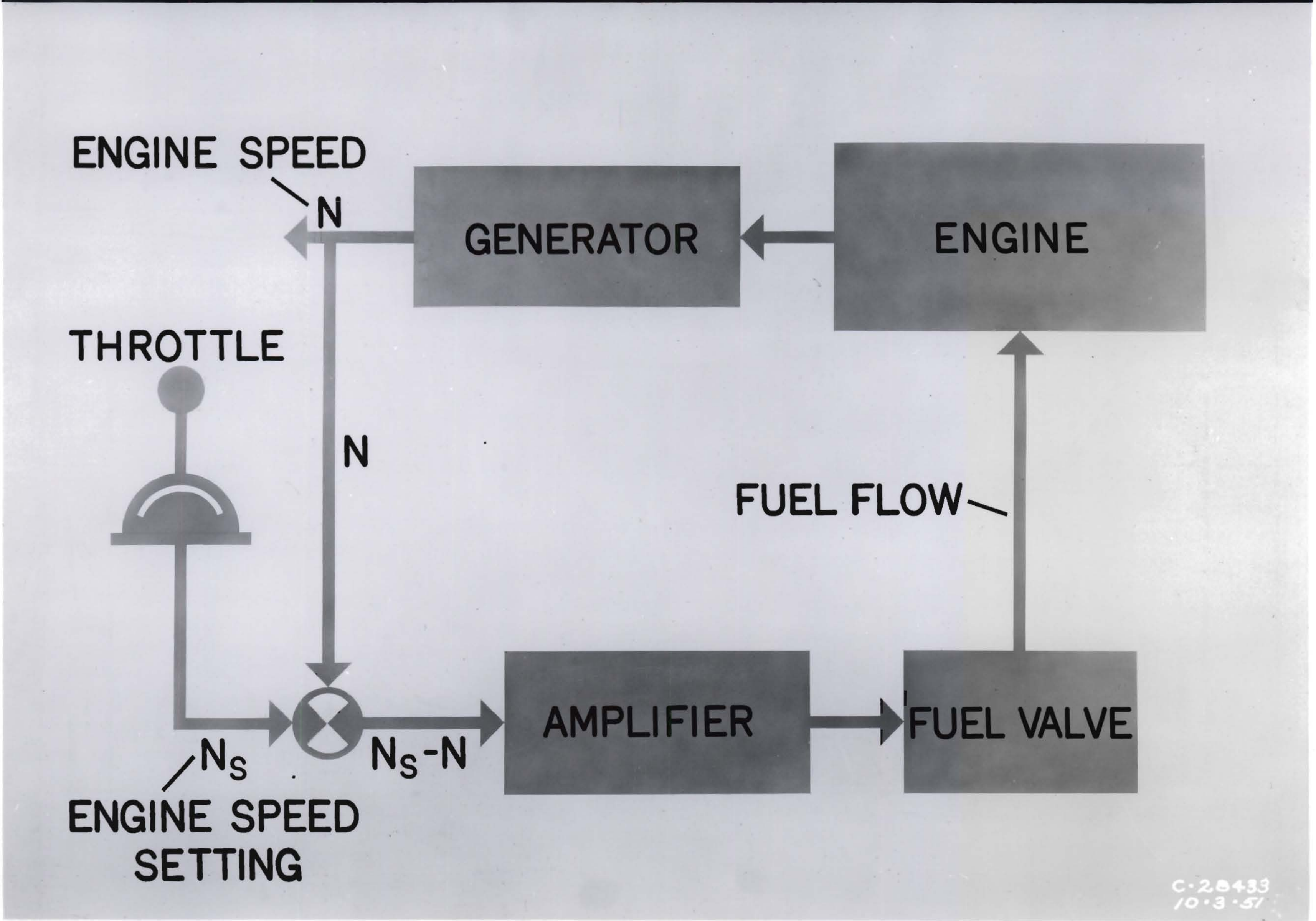
Setup - Altitude Engine Research



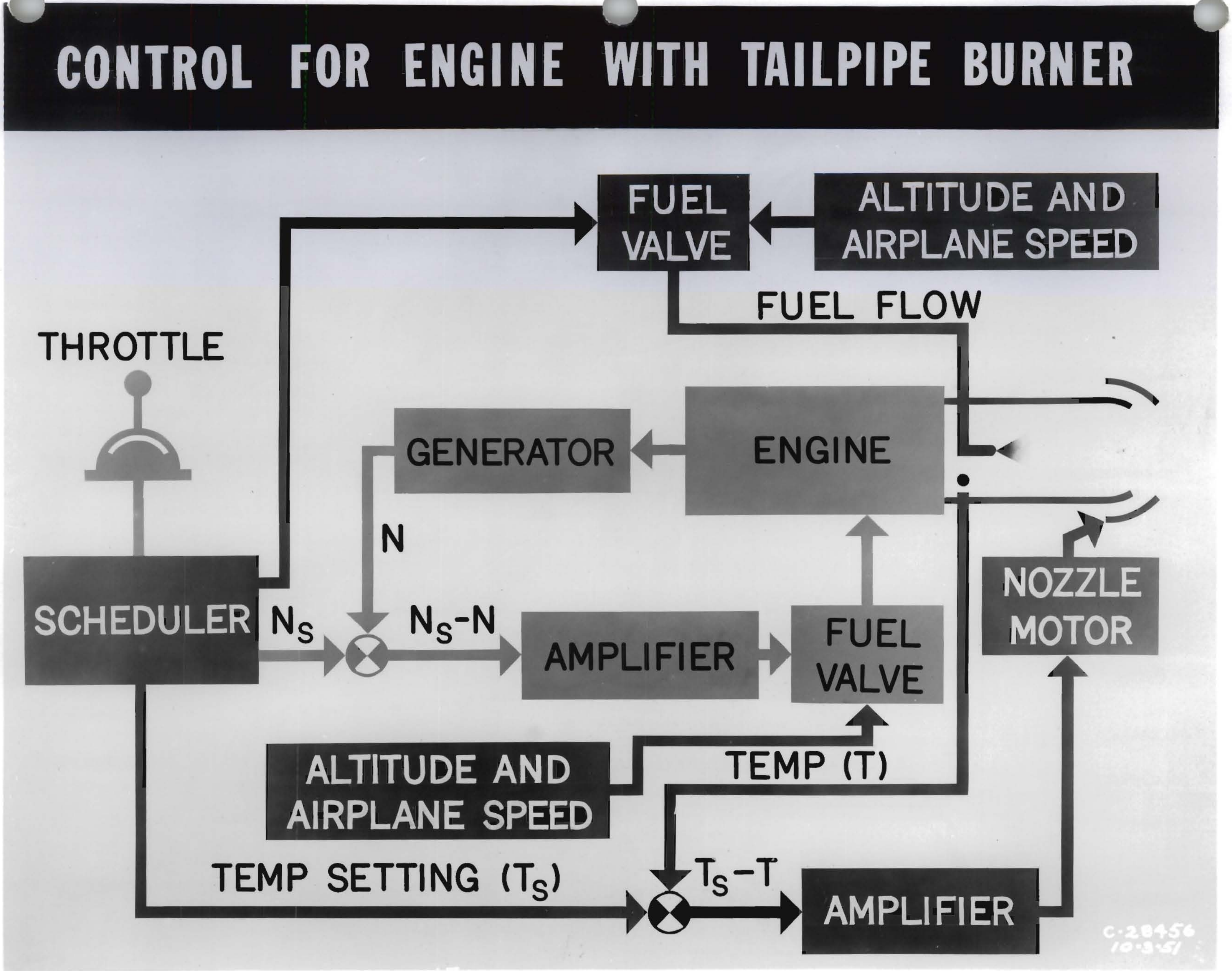
Altitude Engine Research -- Display

NACA

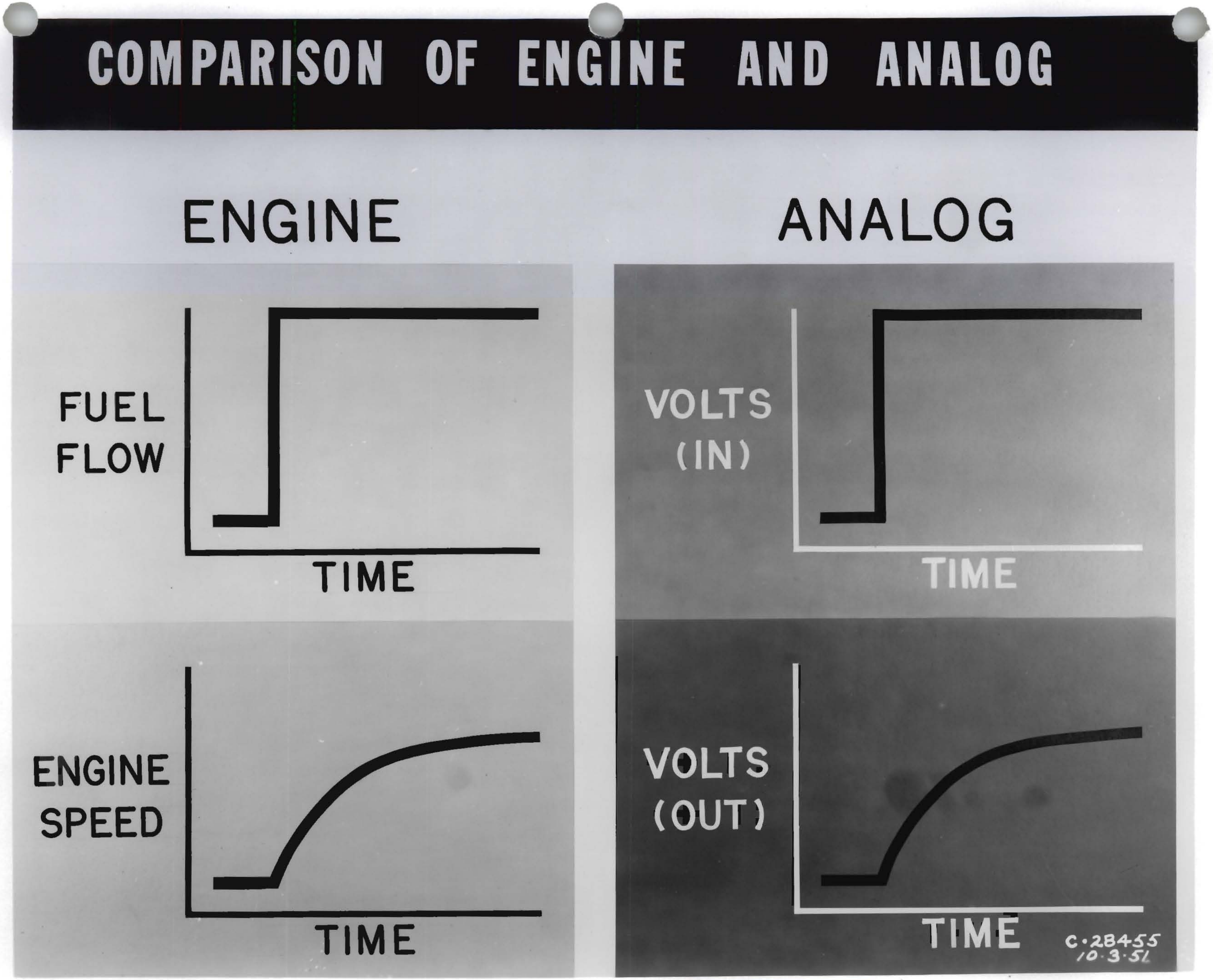
ENGINE SPEED CONTROL



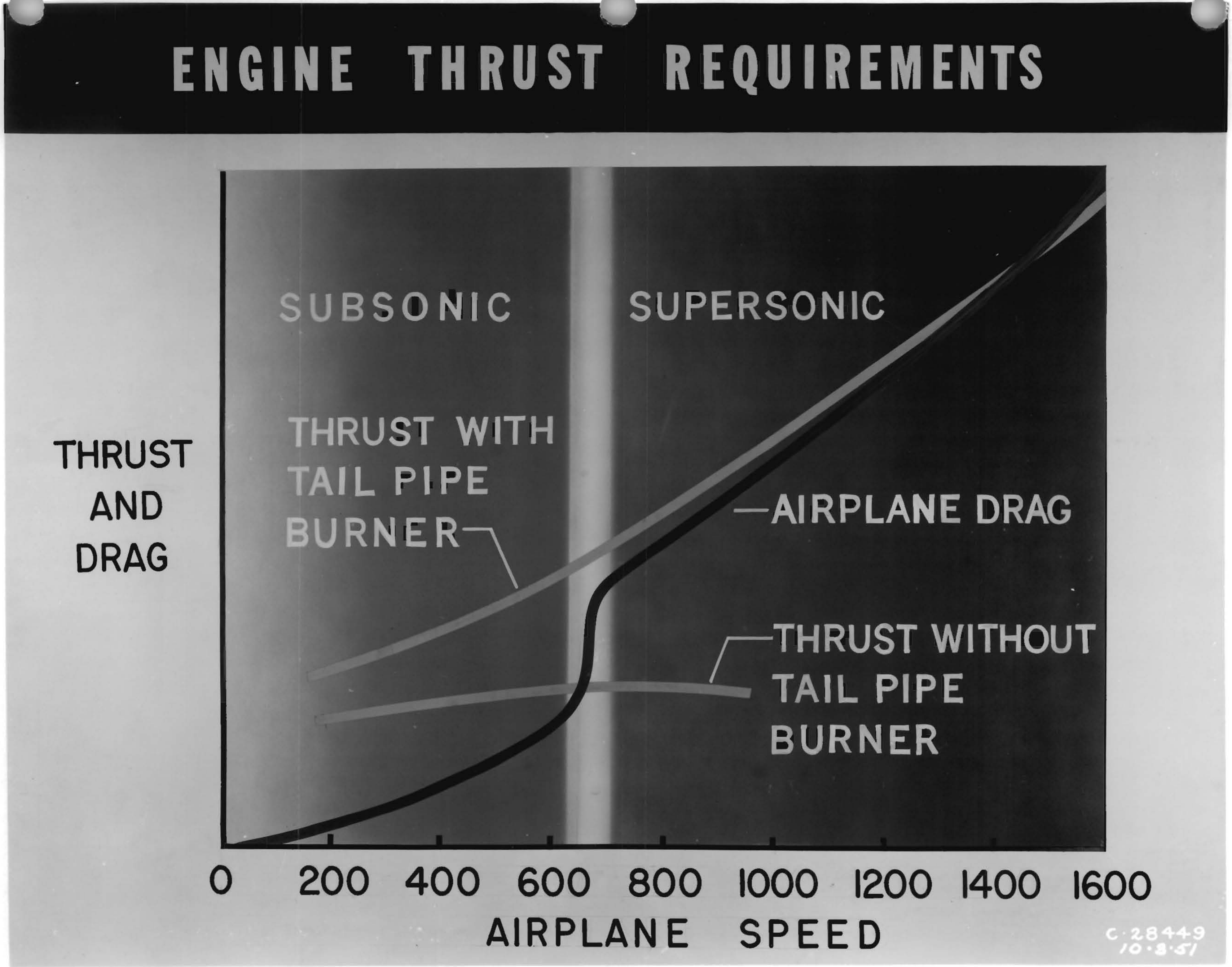
Altitude Engine Research -- Figure 1



Altitude Engine Research -- Figure 2



Altitude Engine Research -- Figure 3



Altitude Engine Research -- Figure 4


ALTITUDE ENGINE RESEARCH