# 1957 ANNUAL INSPECTION

## Jet Aircraft Noise Reduction

Within the next year or so, jet airliners will be carrying us swiftly across the continent in a few hours time. The jet transport may bring with it a noise problem unless steps are undertaken to reduce the noise. Military jets, as all of us know, generate extremely loud noises. Everyone concerned with air transportation is anxious that all practical measures be taken to reduce such noises in the coming jet airliners. Consequently, the NACA has an intensive research program underway to find means for reducing the noise generated by jet engines.

An idea of the magnitude of the noise reduction desired is illustrated by a demonstration. The noise from a four-engine, propeller-driven transport as it takes off has been recorded. A similar recording was made of a military jet airplane operating to produce noise similar to a jet transport at take-off (assuming that nothing were done to reduce the noise). These records will be played through the loudspeakers.

A microphone is connected to a sound level meter. The pointer indicates sound levels in decibels. The decibel is a unit of sound; the zero decibel level is just barely audible, and the 140 decibel level is painful. Conversational noise levels are near 70 decibels.

We will play the recording and I will mark the maximum levels on the scale.

The difference in noise levels is very real to the listener. The meter indications are 116 and 101 decibels. Consequently, the jet is 15 decibels louder than the propeller. This difference of

15 decibels then represents the minimum noise reduction that those concerned with the noise problem wish to achieve; that is, we want to reduce the jet level down to the propeller level. We would, of course, like to go even lower.

If you were doing this research, the first question you would ask is: What causes the noise? A first guess might be that the combustion of fuel at tremendous rates within the engine would cause a loud noise; or the rotation of compressor blades would be a possible offender. Strangely enough, however, the big noise is created outside of the engine by the jet as it mixes with the atmosphere. The jet comes tearing out of the nozzle at very high velocity. The jet and air do not mix smoothly; the air and gas roll up into irregular swirls and eddies. These fluctuating eddies, called turbulence, cause fluctuating pressures and the pressures are radiated as sound waves.

Many experiments have been conducted which prove that turbulence generates the noise. We will conduct one of these experiments for you.

Beneath the lower nacelle of the airplane model is a small nozzle. A jet of cold air blows out of the nozzle in simulating the jet from the engine.

To illustrate the violent fluctuations which occur as the jet mixes with the surrounding atmosphere, a ribbon is mounted in the jet. You can see the violent motions of the ribbon as it is pushed around by the fluctuating motions of the jet. The experiment will show that the character of the velocity fluctuations in the jet is closely related to the character of the sound produced by the jet. A device, called a hot wire anemometer, which measures the rapidly fluctuating velocities, has been inserted into the jet. Immediately outside the jet is a microphone which measures the sound pressures generated by the jet.

This microphone produces electrical signals which can be measured and analyzed. Similarly the hot wire anemometer responds to the fluctuating velocities in the jet and produces electrical signals which can also be measured and analyzed. The sensitive element of the anemometer is an extremely small wire stretched between two small supports. The wire is so tiny that it is almost invisible. Its diameter is two-ten thousandths of an inch.

The signals from the microphone and the hot wire anemometer will be reproduced over the speaker system. The kind of sounds you have just heard is classed as broad band. By this we mean that it is composed of many separate sounds of different frequency somewhat like hitting all the keys of a piano simultaneously. The character of the sound is determined by the amount of energy at each frequency.

The outputs of both the microphone and the hot wire sounded quite similar. The velocities in the jet are vibrating at many frequencies and the sound pressures outside the jet are also made up of many frequencies. The analysis of the sound and velocity is accomplished by measuring the amount of energy at each frequency. This is done using an analyzer. The electrical signals from the microphone and the hot wire are fed into the analyzer and the analyzer measures the amount of energy at each frequency. The output of the analyzer is recorded by the plotter. The low frequencies are on the left and the high frequencies on the right. The vertical displacement of the pen indicates the amount of energy at each frequency. The similarity of the two curves is evident. The close relationship of the velocities in the jet to the sound pressures outside the jet is one piece of evidence that the sound pressures are caused by the fluctuating velocities in the jet.

A seemingly obvious cure for the jet noise problem is the elimination of these fluctuating velocities or turbulences. At the present time no one has suggested a practical method for doing this. However, the strength and size of the fluctuations have been reduced and hence the noise has been reduced also.

From the previous experiment we know that jet engine noise is generated principally by turbulent velocities. We immediately suspect that changing the jet velocity will change turbulence; and, therefore, will change the noise. The first chart shows the variation of jet engine noise power with jet velocity. We find that the slope of the curve increases rapidly. During take-off, the current engines operate near the maximum shown. It is apparent that a small reduction of jet velocity will cause a great reduction in noise.

Today's engines were designed to operate at high jet velocities and they do not operate efficiently if the velocity is reduced. It is possible, however, to design new engines which are efficient at low jet velocities.

Studies of low velocity engines have been made at this laboratory. One such engine is shown in cross section on the chart and is compared to a more conventional engine producing the same thrust. The new design operates at a very much reduced turbine inlet temperature, 1200 degrees F., as compared to the more conventional 1600 degrees F. The lower temperature results in a reduced jet velocity, 1550 feet per second, as compared with 2150 feet per second. The noise reduction is 9 decibels. This reduction is not equal to the desired 15 decibels, but it is a large step in the right direction. Another important advantage of the low temperature engine is improved life and reliability. The low temperature engine has a slightly larger diameter than does the conventional engine and, consequently, the drag may be higher. Both of these engines have the same weight. However, the comparison is between a new engine using the most advanced techniques available now, whereas the high temperature engine is in existence and is based on techniques known several years ago. Putting the case another way; we can take advantage of advanced knowledge to design engines which are quieter than today's engines, but with no increase in performance; or we can use the advanced knowledge to provide improved performance with no noise reduction. Although design and development will be a long and costly process, a low temperature engine can be made with over-all performance nearly equal to existing engines.

Another engine which operates at low jet velocity is the by-pass or ducted-fan engine. The by-pass engine has a low energy secondary air flow which, when mixed with the primary flow, results in a low jet velocity. This engine is approximately equal to the low temperature engine on a noise basis.

Another approach to the problem is to select a nozzle shape which reduces turbulence noises. The NACA has conducted an intensive research program with various nozzle shapes. Some of them are displayed on and around the engine. These nozzles are based upon ideas from British and American manufacturers and ideas original with the NACA. These nozzle shapes have been designed to promote the downstream mixing and spread the jet. The one on the engine has deeply folded convolutions which admit secondary air into the jet. The resulting mixing process slows the jet to a lower velocity and reduces the noise by 7 decibels. The thrust loss is 3 percent and probably can be reduced to a lower value.

The "organ pipe" nozzles were designed with the same principle in mind; that is, promote mixing. The particular models shown here had high thrust losses; however, improved internal design should reduce the losses.

The nozzle with the parallel slots show very good noise reduction, but again at the expense of large thrust loss.

The assembly at the end of the stage is an ejector. The ejector admits or pumps secondary air which is mixed with the jet. The mixing process reduces the mean jet velocity and results in lower noise levels. The simple ejector with a circular nozzle is not an effective noise reducing combination. However, a corrugated nozzle, such as the one on the engine, in combination with an ejector shroud will produce significant noise reduction. The thrust loss is very low; in fact, the thrust may even be greater than the thrust of a simple nozzle. However, the ejector is heavy and will create additional drag. A retractable ejector may solve the drag problem for high speed cruise.

Subsonic and transonic drags for several of the more promising suppressor configurations are being measured in our wind tunnels.

A third method of reducing noise is by varying the aircraft flight technique. If we consider a jet transport of medium gross weight, this chart shows the flight paths and the noise reductions which can be realized by two different take-off procedures. In the first case, the airplane takes off, accelerates, then climbs at 300 mph. This path represents the normal jet airplane climb procedure and results in minimum time to climb to altitude. Next the airplane takes off and climbs almost immediately at a lower airspeed of 180 mph, maintaining maximum thrust until an altitude of 1000 feet is reached. At this point the pilot throttles the engines to 50 percent thrust and levels off sufficiently to maintain 180 mph. We have marked on the chart the maximum sound levels which would be heard in a community located 3.5 miles from the start of take-off. The maximum sound level from the first climb procedure is 121 db. However, due to a higher altitude and lower thrust level, the low-noise flight procedure results in a maximum sound level of 98 db. The large reduction at this point due to modified low-noise climb technique is 23 db. In fact, even at a distance of 5.5 miles where the flight paths cross, the reduction in thrust causes a 10 db noise reduction. It is obvious that the type of low-noise climb procedure will depend upon the location of the surrounding communities.

We will now demonstrate the effectiveness of a full-scale suppressor and also this 23 db difference due to the low-noise climb procedure. On the hangar apron we have a B-47 airplane. We will operate two of the engines. First, the engine which is located in the inboard pod, will be operated at maximum thrust. The sound level should be approximately the maximum you would hear from a four-engine jet transport during normal climb if you were located 3.5 miles from the start of the take-off roll. We will mark the maximum sound level as indicated by the meter. Next the outboard engine, which incorporates a sound suppressor, will be run-up to the same thrust level and the maximum noise level will be indicated on the meter. Finally, the standard engine will be run up again, but this time to a reduced thrust condition which produces about 98 db which represents the maximum noise level when the standard airplane follows the low-noise flight procedure.

(DEMONSTRATION)

The demonstration showed noise levels of 121 decibels for the normal engine and 108 decibels for the engine with suppressor. The reduction is, therefore, 13 decibels. This reduction is nearly equal to the desired reduction. However, this suppressor may impose drag penalties at cruising conditions or weight penalties. Further research will be necessary to adequately evaluate the usefulness of this nozzle. The simpler corrugated nozzle produces 7 decibels reduction and a combination of this nozzle with the low temperature or by-pass engine may provide the desired reduction.

The last part of the experiment, where the engine power was reduced, simply illustrates the estimated effect of selecting a low noise climb technique. This result is not general and depends greatly upon the specific situation at individual airports.

Other means for alleviating the noise nuisance may be employed such as careful selection of airport location, use of preferential runways, and restriction of housing. These techniques are outside of the scope of NACA research.

We wish to caution you that we have not solved the noise problem. As you heard before, problems concerning drag and weight must be resolved. The devices shown here are heavy laboratory models and they have not been given extensive life tests. Much research is still necessary to produce safe and practical answers to the jet noise problem.

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31 TUBE
ORGAN PIPE NOZZLE
EJECTOR
AND
CORRUGATED NOZZLE
TAPE RECORDER
SOUND LEVEL METER

NACA
C-46149

JET NOISE RESEARCH
NOISE RESEARCH ON MODEL JETS
TURBOJET ENGINE NOISE SUPPRESSORS
CORRELATION COMPUTER
OSCILLOSCOPE
HOT WIRE ANEMOMETER
PROFILE PLOTTER

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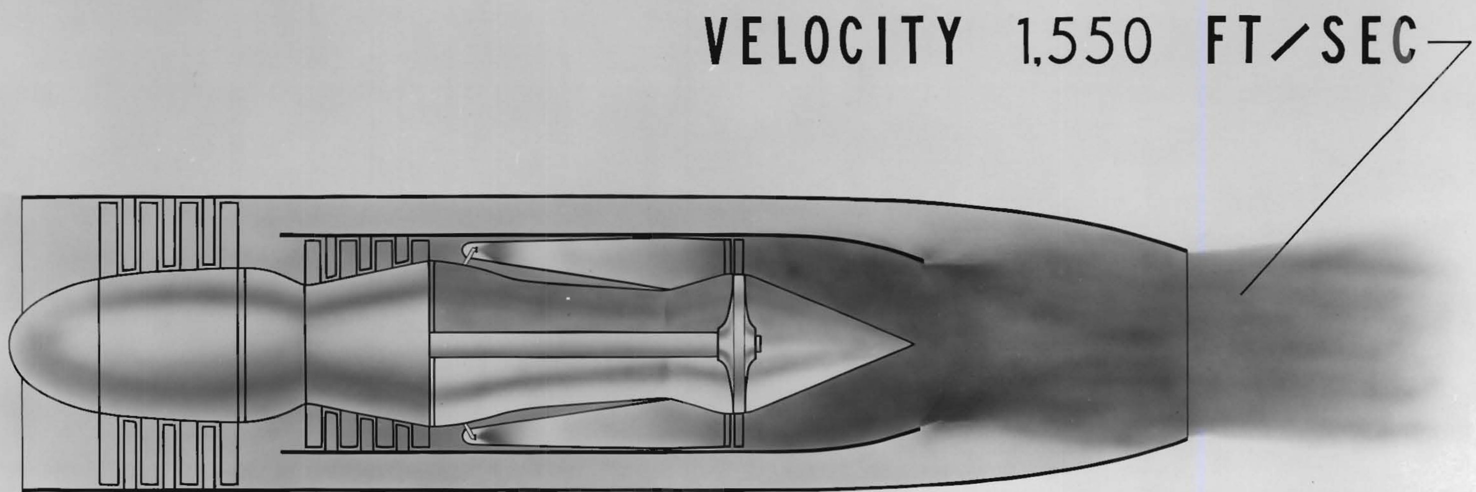
46145

# BY-PASS ENGINE



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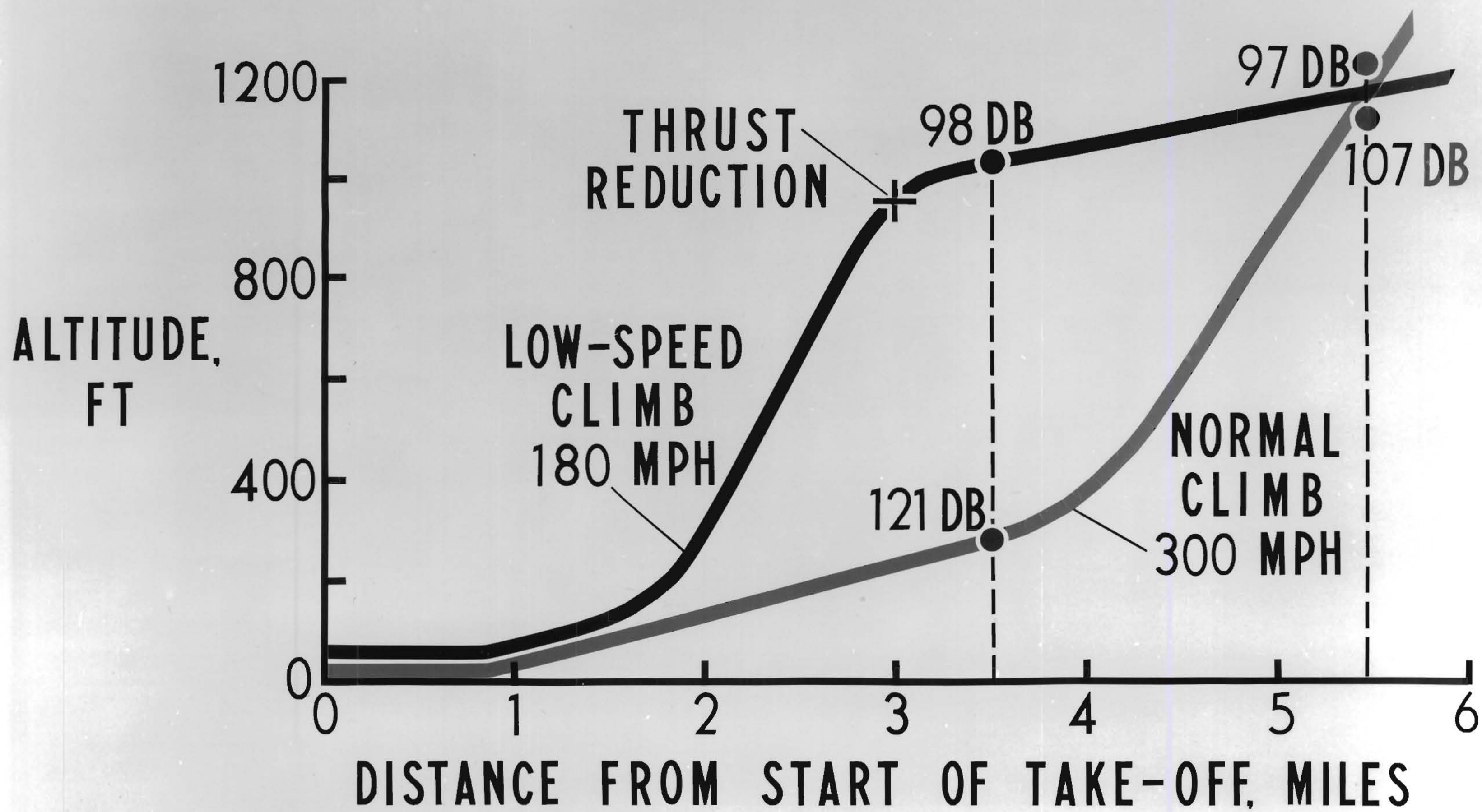
# EFFECT OF CLIMB PROCEDURE ON NOISE



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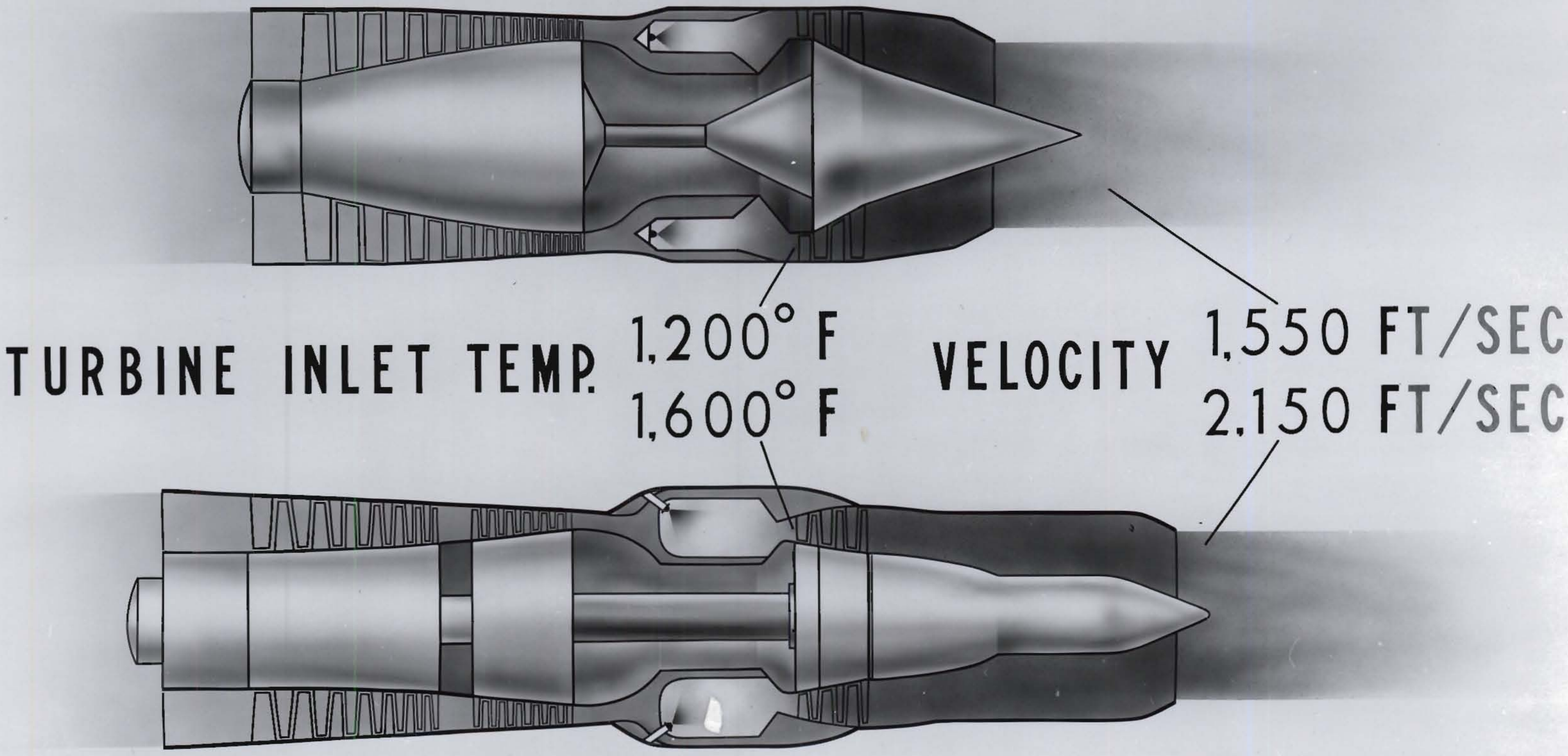
# LOW AND HIGH TEMPERATURE ENGINES



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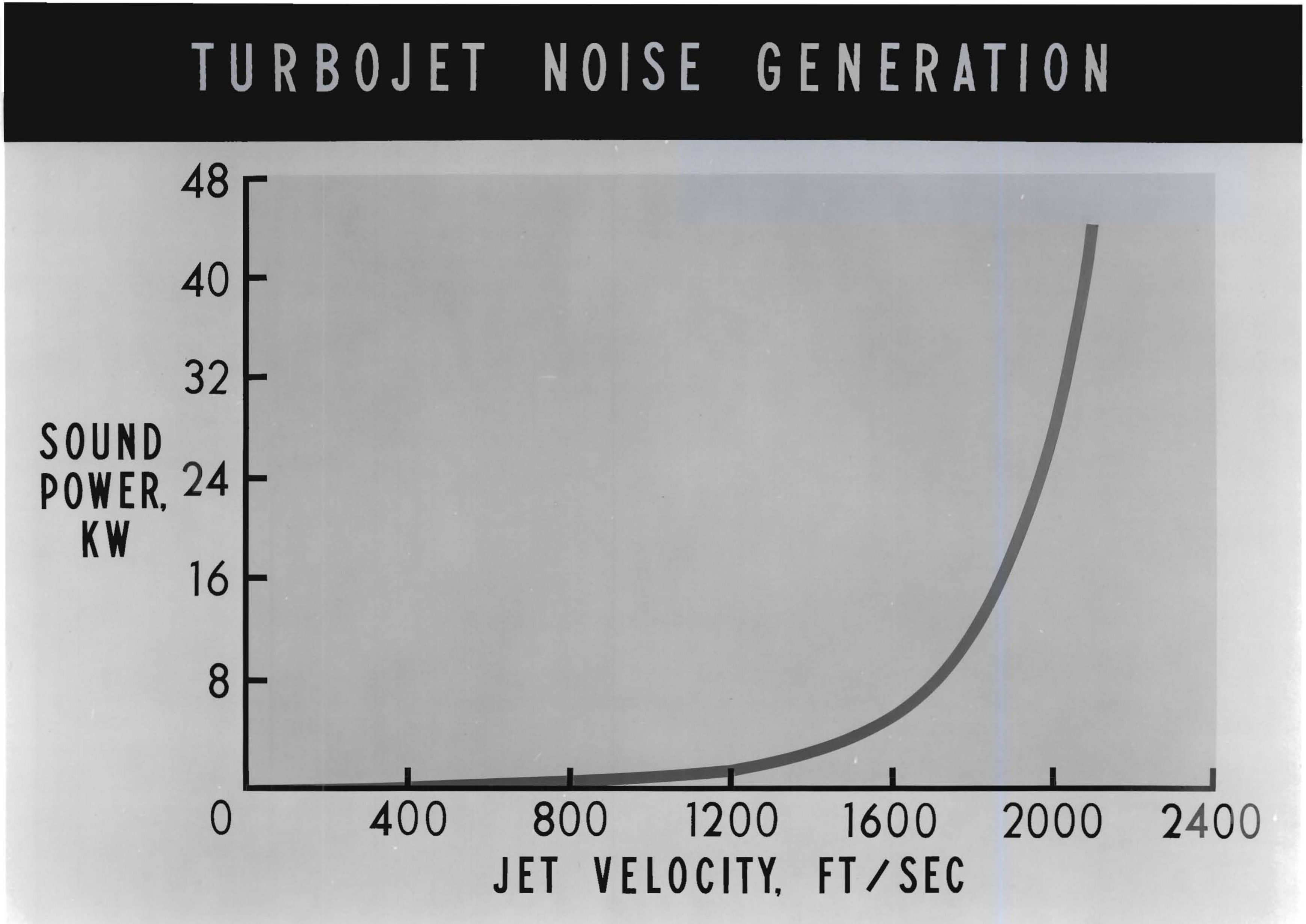

TURBOJET NOISE GENERATION
SOUND POWER, KW
48
40
32
24
16
8
0
400
800
1200
1600
2000
2400
JET VELOCITY, FT/SEC

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# FREQUENCY SPECTRUM