STOP I SCRIPT - Part 1

Good afternoon ladies and gentlemen. I'm ________________, and on your left is ____________________. We warn you now, it may get noisy at times. (Noise tape) That was a jet airliner taking off. I'm sure the problem we are dealing with at this stop needs no further introduction. Today we will cover some of the work being done at Lewis and by others to quiet the commercial airline fleet. ~~We warn you now, it may get noisy at times.~~

Noise measurements are generally presented in terms of decibels, or dB. Cutting the intensity of a noise in half causes only a 3-dB decrease. So you can see large noise reductions in dB require extremely large reductions in sound intensity. To give you an idea of what a change in dB means, we'll listen to a series of noise levels. (slide 1) We'll start with a 100 dB reference noise. Then we'll hear a 3-dB reduction, which makes it about as noisy as a freeway intersection, and then ~~and finally~~ a 10-dB reduction. (Noise tape, ~~and slide 1~~ point to slide to identify level.)

There are two major noise sources we have to deal with in reducing aircraft noise: jet noise and turbomachinery noise. For many of our aircraft today, takeoff is dominated by jet noise which is characterized by a low-pitched rumble. Turbomachinery noise is higher-pitched and is prominent during landing approach. We'll listen to the tape of a DC-8 taking off and then on landing approach. You'll notice the difference between the jet rumble on takeoff and the turbomachinery whine on approach. (Takeoff tape and slide 2.) ~~That was takeoff; now we'll hear landing approach.~~ (Approach tape and slide 3.)

To understand how these noises come about, we should know how a jet engine works. (Slide 4) First, let's look at a turbojet engine, such as was used on the early jet airplanes. This is how they work. Air is sucked in and is compressed by the compressor. In the combustor, fuel is sprayed into the air and burned. Then the turbine extracts some of the power from the hot gas to drive the compressor. Finally, the hot gases are exhausted at high velocity, producing the thrust that propels the airplane. Here the more modern, high-bypass turbofan engine, such as used in the new wide-body jets, is shown below the turbojet. ~~In the modern turbofan engine, a fan has~~ A fan has been added (slide 5) that is driven by an additional turbine. Now there are two separate exhaust jets because most of the fan air is immediately exhausted from the engine. The exhaust velocities are lower than for the turbojet, as indicated by the length of the arrows, but the thrust is not reduced because the fan propels huge quantities of air.

Jet noise is produced by the violent mixing of the exhaust jet with the surrounding air. So you might expect that the turbofan, with its lower velocity jets, would produce less jet noise. Now, we'll conduct a simple experiment to show that this is true. Through the window on your left you can see model turbofan and turbojet nozzles. The gages on either side of the window show jet velocity in hundreds of ft/sec and thrust in pounds. The noise will be picked up by that microphone and the level shown on the noise meter here. I'll set the meter to "maximum" for the turbojet nozzle. Then we can read the noise suppression for the turbofan nozzle directly from the meter in dB. After I shut off our microphones, Mr. __________ will set the thrust to ___50___ pounds for the single turbojet nozzle, the one on your right, and we'll note the velocity. (Mics. off, signal; air on; adjust meter to "maximum"; signal; air off, mics. on.) That was rather loud, and the jet velocity was ~~about~~ over 900 ft/sec. Now let's listen to the turbofan nozzle at the same thrust, but lower velocity, and see if it's quieter. (Mics. off, signal; air on, note on meter; air off; mics. on.) The noise reduction was over 10 dB, and the jet velocity was ~530 ft/sec.

~~You may remember that the jet noise you heard earlier, from an airplane, was a low-pitched rumble. While these small nozzles, over here, made a high-pitched hissing noise. (Slide 6) The difference is simply due to the large difference in size of the nozzles. But, the noise reduction would be the same as for the small nozzles we used.~~

You have now seen that the high-bypass turbofan does produce less jet noise than the high-velocity turbojet. And in addition, the turbofan has better fuel economy. Therefore, the modern wide-body jets use high-bypass turbofans and have relatively low jet noise. However, as the jet noise has been reduced, the turbomachinery noise has become dominant. Now further reductions in aircraft noise will require reductions in turbomachinery noise, as ________ will describe. ~~would you like to tell us now about turbomachinery noise.~~

PART 2

There are several sources of machinery noise in the modern turbofan engine. They are illustrated here. The fan located at the front of the engine (point) is the greatest producer of machinery noise. Fan noise propagates forward out of the inlet duct (point to sound waves) and to the rear out of the fan discharge duct as indicated here. In addition, the compressor, combustor, and turbine are producers of noise, but they are at present of secondary importance. So the remainder of our discussion of machinery noise will deal exclusively with fan noise.

Fans have two characteristic types of noise. We call them BPF and buzz saw. Listen to the following tape and you will hear the distinctive difference between them. First you will hear BPF and then buzz-saw noise. (Tape BPF and MPT). You probably noticed that BPF noise is a high pitched, whine-type of sound. While buzz saw noise is lower pitched and has the characteristic buzz-saw type of sound from which its name was derived. Buzz saw noise is developed as a result of the shock waves formed at the fan blade tips when they operate at supersonic speeds.

A typical modern fan stage looks like this. As the air enters, it is compressed by the rotor. The rotor also imparts a swirl to the flow which is eliminated by these straightening vanes. We call these vanes the stator.

Research on fan noise production had identified several methods for its reduction. One way to reduce fan noise is shown in the next figure. As we increase the spacing (point) between the rotor and stator, a gradual reduction in fan noise is obtained as shown in the curve below. You can see that when the spacing is twice the rotor-blade width a 6 to 8 dB reduction in noise is obtained.

Why does the greater spacing reduce fan noise? Each rotor blade has a low velocity wake behind it (point). The wake is similar to that behind a sail boat as it cuts thru the water. Rotor rotation produces a periodic impingement of these wakes on the stator vanes. This produces the blade-passage frequency type noise you heard earlier on my tape. By increasing the spacing, the wakes dissipate more before they hit the stator vanes and the noise is reduced.

Another technique which reduces fan noise is to select the optimum number of rotor blades and stator vanes. (Next figure) The lowest noise is obtained when there are about two vanes for each blade. This noise reduction technique results from a sophisticated acoustic theory that was discovered by two researchers at Pratt & Whitney Aircraft Co.

Another technique that shows promise for fan noise reduction involves leaning the stators. Stators are usually radially oriented but in that experimental ~~model~~ stator over there they have been leaned 30° circumferentially. These leaned stators reduced back end noise by 2-3 dB. Stator lean reduces blade passage frequency type noise.

Finally, we have over there an experimental ~~a model~~ fan rotor which has the blade leading edges serrated much like the edge of a saw blade. These serrations, as found in wind tunnel tests, reduce the width of the blade wake and thus hopefully would reduce BPF noise. The serrated rotor did reduce fan front end noise, but unfortunately it also increased back end noise. While this technique shows promise, it needs more work. Other promising techniques are also being researched and will probably bear fruit in the future.

If we incorporate the best noise reduction techniques into new fan designs, we can significantly lower their noise levels. However, the noise levels will still be too high for community acceptance. Fortunately, we have another noise abatement tool to turn to. We can add acoustic suppression. Acoustic suppressors absorb or eliminate noise energy. ~~I'll illustrate the principle of noise absorption with this model I have in my hand.~~ The ~~This~~ suppressor ~~design~~ is similar in design to that you may have noticed in phone booths or in ceiling tile. ~~The surface that faces the noise source (point) contains small holes, or it can be made of a porous material. Behind this surface, we have enclosed cavities. The holes and cavity volumes are sized to suppress the most objectionable frequencies using Helmholz resonator theory. This is how it works! Noise energy, in the form of small pressure waves, enters the cavities thru these holes and then bounces out again. This entering and exiting action reduces the noise energy by the friction or viscous losses encountered in this process.~~

Now let's see where we use this suppression material. This is a typical engine with acoustic suppression added. Suppression material is usually placed on the inlet ~~flow passage~~ duct walls. (Point) The fan discharge duct walls are similarly treated. (Point) It can be also used ahead of the compressor, here, or behind the turbine over here. If we need more acoustic treatment, this can be done by placing additional surfaces in the flow passages. We call these flow splitter rings. Three acoustically treated splitters are shown in the engine inlet (point) and one in the fan discharge duct in this design. Later on I'll show you some engine data that illustrates how well this suppression works.

Now I want to show you a novel method of suppressing fan noise. This technique makes use of the physical principle that sound waves cannot propogate upstream thru air flowing at the speed of sound. We call this concept the sonic inlet. It is illustrated here. The upper sketch is a conventional inlet with its wide inlet throat. The sonic inlet below has a smaller throat area which raises the inlet air velocity to ~~sonic~~ the speed of sound here ~~conditions here~~. When the sound waves from the fan reach the sonic point, their ~~forward~~ outward speed is the same as the incoming air speed ~~flow~~ and they cannot get out. Now We have a little demonstration of the sonic inlet to show you.

Behind the stage, we have set up a 5 1/2 inch diameter research fan. You can see the side of the fan inlet thru that window or look into the fan inlet on that TV screen. When the fan is operated, you can read its RPM on the gage under the TV screen and its noise level on the same meter used in the jet noise demonstration. First, we will run the fan with a standard inlet, then we'll put a model sonic inlet on and see what difference it makes. Okay lets try the standard inlet. (Run fan) While my colleague installs the sonic inlet, I'll point out something to watch when we test it. The fan noise will be about the same as before until the fan reaches about 28 to 30,000 RPM. At that point the inlet air reaches sonic conditions and the noise will then change suddenly. Okay we are ready to try it. (Run fan) Our meter showed that the large reduction in noise you heard was equal to about _x_ dB. We think the sonic inlet looks attractive acoustically and we are therefore planning more work on it. We need to develop [redacted] confidence in it's performance and mechanical operation before we can eventually consider it for use in airliners.

Up till now, I've been discussing a number of noise reduction technologies for turbofan engines. Much of this technology was embodied in our Quiet Engine Program here at Lewis. This program demonstrated, with experimental full scale, engine tests, the practical limit to which engine noise could be reduced with current technology.

There were two Quiet Engines in the program. They were built under contract for NASA by the Gen. Elec. Co. Here are two photographs of one of the engines~~. installed in our test stand at Lewis.~~ On the left you can see the basic or unsuppressed engine. By the way, you will be able to see both actual engines [redacted] in an unsuppressed configuration at stops 2 and 10 on your tour today. On the right the engine has a flight type nacelle installed which contains acoustic suppression. The nacelle inlet is over there. Notice the three splitter rings which have acoustic treatment on them. The nacelle was built under contract for NASA by the Boeing Aircraft Co.

The next figure illustrates the major noise reduction features put into the Quiet Engines. The engines both have high bypass ratios which produce low exhaust jet velocities and accordingly low jet noise. Each engine contained a different type of fan design. One engine had a low speed fan which was chosen because lower speed fans generally produce less noise. The other contained a high speed fan which results in lower engine weight and cost, but it is noisier and thus requires more acoustic suppression for equally low noise. The fans also contained many of the noise reduction concepts which I previously described. Extensive use of acoustic treatment was employed in the Quiet Engines. [redacted] ~~acoustic suppression was used similar to that I~~ [redacted]

After extensive ground testing of the Quiet Engines, calculations were made of typical aircraft flyover noise levels using the Quiet Engine noise data. A DC-8 aircraft was used in the calculations, because the Quiet Engine has the right thrust for this aircraft. The results are shown here (table). Take-off and landing approach noise levels at the standard FAA measuring points are shown. The EPNdB noise unit is a measure of annoyance that accounts not only for the noise intensity, but also the ears sensitivity and noise duration. Measurements of the noise levels of the DC-8, shows that the takeoff and approach levels are 116 and 118 dB respectively. If we equip the same aircraft with engines incorporating Quiet Engine technology, without acoustic treatment, the aircraft noise levels are reduced by 20dB. Further, the use of extensive engine acoustic treatment (point to nacelle) reduces aircraft noise another 7-8dB and we are now some 27 dB below the standard aircraft. Let me demonstrate these noise reductions by playing recordings of the DC-8 engine and our Quiet Engines taken during ground tests. You'll hear the ~~standard~~ DC-8 engine first, then the Quiet Engine without acoustic suppression and then the Quiet Engine with full suppression. (Tape) I think you can see that the technology demonstrated by our exp. Q.E.'s holds promise for significantly reducing the noise levels of future aircraft. Additional work is essential, however, in order to reduce the performance penalties accompanying these major reductions in noise level. But what about the existing aircraft and the prospects for reducing their annoyance? Jim?

Part 3

There are about 2400 airplanes in the Nation's commercial jet fleet. The new wide-bodied aircraft which have high-bypass engines and incorporate much new noise reduction technology are comparatively quiet, but compromise only about 6 percent of the fleet at this time. The older, narrow-bodied class of aircraft, which were introduced prior to the noise regulations, are the worst noise offenders. This class comprises the bulk of the fleet.

What can we do about the noise of the narrow-bodied aircraft which may be in service for many more years? We have four alternatives listed here (Slide ___):

1. We could retire the noisy airplanes from service and replace them with newer, quieter planes. Although this would greatly reduce aircraft noise, the cost would be prohibitive.
2. We could replace the engines with new, quiet engines; but even this would be prohibitively expensive.
3. We could add suppression treatment to the nacelles of existing engines. This approach offers only moderate noise reduction, but is relatively low in cost.
4. And finally, we could modify the existing engines and add suppression treatment. This approach would give better noise reduction than nacelle treatment alone, but would be somewhat more expensive.

These last two approaches are being studied in a joint program by NASA and the FAA, with NASA concentrating on the latter.

In this refan program, [redacted] we have contracted for the development of the engine modifications and demonstrations of performance in ground and flight tests. At present, this program concentrates on the JT8D engine, which powers the 727, 737, and DC-9. The engine will be modified to reduce both jet noise and fan noise, ~~The goal is to get the most noise reduction for the least~~ while minimizing the cost. The companies should be ready to start retrofitting in 1976, if new government noise regulations require it.

As shown here (Slide _____), and by the model engine over there, the original two-stage fan is replaced by a larger-diameter single-stage fan. This gives lower jet velocities, reducing jet noise. Notice the wide spacing between the rotor and stator to reduce fan noise production. (Point) This is an inlet guide vane. The acoustic treatment being considered is shown here in the fan duct walls and around the engine exhaust. An acoustically-treated splitter ring is contemplated ahead of the fan.

(Slide _____) On this map we illustrate the benefits of refanning. ~~95 EPNdB~~ Noise contours, or "footprints", around Chicago O'Hare Airport are shown. The people and area within the contours would be exposed to a 95 EPNdB or greater noise level. ~95 EPNdB is like a freeway intersection. You can see that the exposed area is much less for the refanned 727 than for the current 727. The approach leg area is reduced by 94%, and the takeoff leg by 78%. On the wall as you leave you can see similar "footprints" for Washington and Cleveland.

I think you can see from what we've presented that NASA programs have contributed much to quieting the commercial jet fleet. We've developed methods of suppressing the two major noise sources, jet and fan. (Slide _____). Noise level ranges for several types of aircraft are shown here at the FAA takeoff measuring point~~s~~. We've added the typical levels you saw before ~~of some familiar noises~~ to give these numbers meaning. ~~The upper end of the scale corresponds to being 20 ft. from a freight train, while the lower end is typical of a quiet street.~~ The older jet liners are up here. The newer planes, with their high-bypass engines and consequent lower jet noise, are much better, but they are still quite noisy, as you can see. Refanning the older planes would put them down here. And finally, new aircraft, incorporating new technology such as from our Quiet Engine Program, could be even quieter. (Slide off)

In addition to our Quiet Engine and Refan programs, we are looking at other promising noise reduction concepts, such as flight path control. ~~One of these is the sonic inlet, which we demonstrated earlier today. Here it is shown, mounted on a Quiet Engine, both in use as a noise suppressor and in its cruise position. Still~~ Another concept is to place the engines over-the-wing, reflecting some of the noise away from the ground. ~~We're investigating this concept with a Quiet Engine.~~ The model at the left end of the stage illustrates this concept.

~~As illustrated here~~, The traveler will have to pay for reduced noise levels. (Slide) The ticket price from New York to Los Angeles, for example would have to go up 20 dollars to get 15 dB lower, using current technology. But our aim is to improve technology so that the suppression can be obtained for only a 2 or 3 dollar increase. ~~It is our aim to reduce the costs from what they are now to a point where large noise reductions can be made without excessive costs.~~

We thank you for your attention. Now, please follow your guides out through our display area.

STOP 1 CARL CIEPLUCH 4277

1) REFERENCE LEVEL CS 67546

2) DC8 - TAKEOFF CS 67547

3) DC8 - APPROACH CS 67548

4) EVOLUTION OF ENGINES CS 67549

5) MACHINERY NOISE SOURCES CS 67550

6) TYPICAL FAN STAGE CS 67551

7) EFFECT OF ROTOR-STATOR SPACING CS 67552

8) VANE AND BLADE COMBINATION CS 67553

9) TYPICAL ENGINE WITH ACOUSTIC SUPPRESSION CS 67554

10) (CONVENTIONAL INLET/SONIC INLET) CS 67555

11) QUIET ENGINES CS 67556

12) FLYOVER NOISE COMPARISON CS 67557

13) OPTIONS FOR QUIETING OLDER JET AIRCRAFT CS 67558

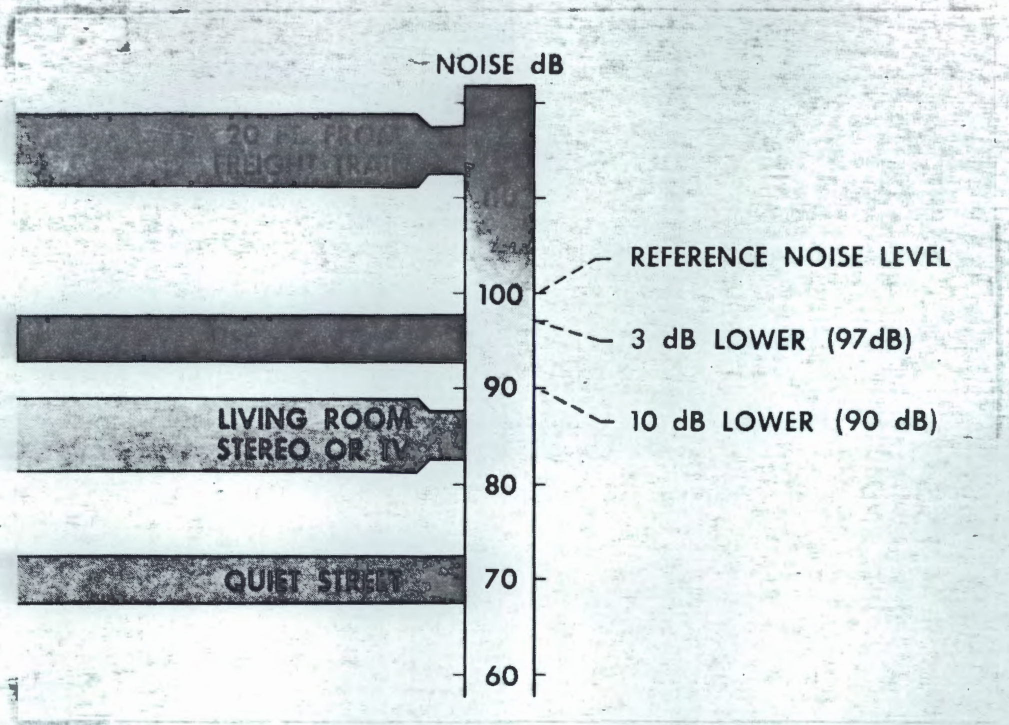
14) CURRENT AND REFAN JT8D CS 67559

15) NOISE CONTOURS AT CHICAGO O'HARE CS 67560

16) (TABLE NOISE dB) CS 67561

17) NY TO LA COST VS NOISE CS 67562

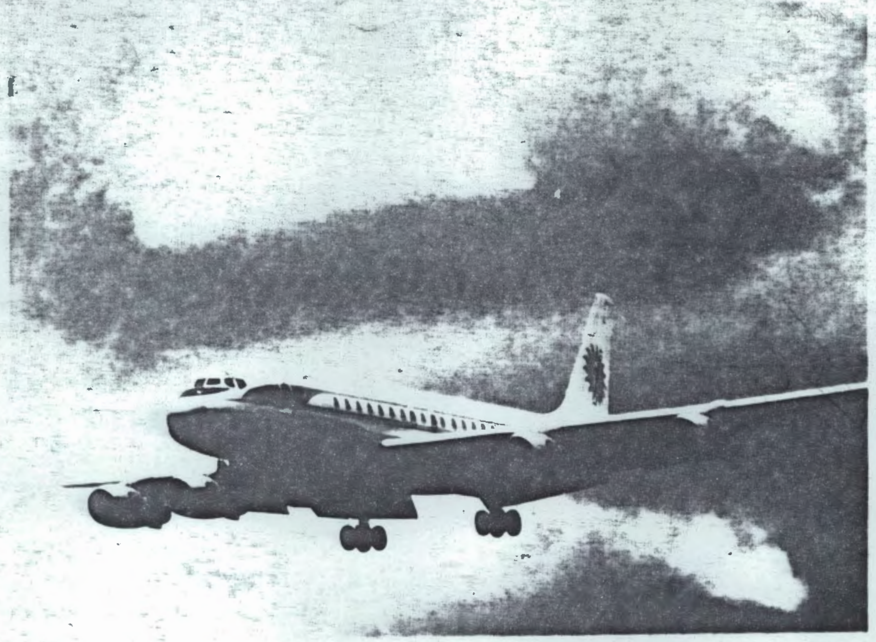
STOP 1



SLIDE 1 (CS-67546)

CS-67547

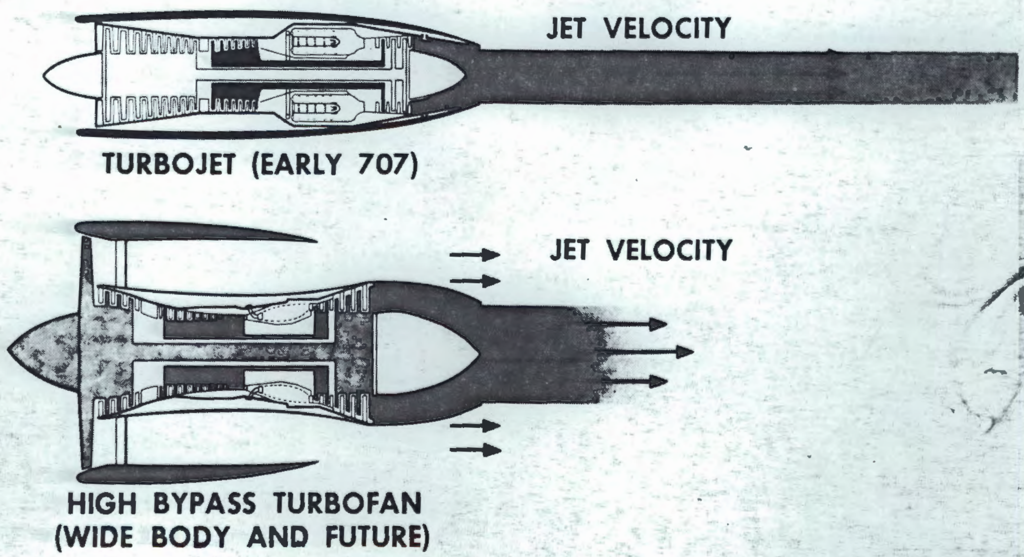
SLIDE 2



CS-67548

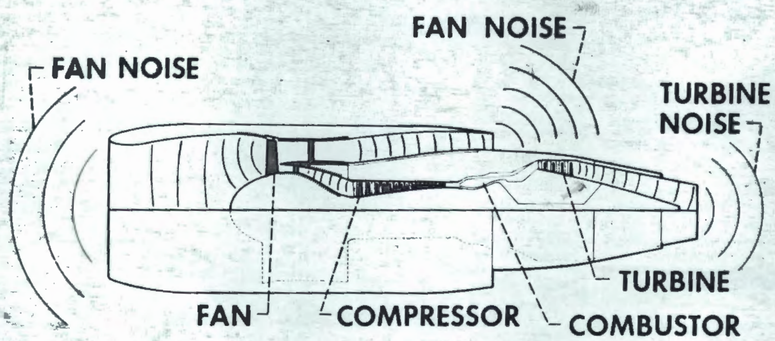
SLIDE 3

EVOLUTION OF ENGINES-SAME THRUST



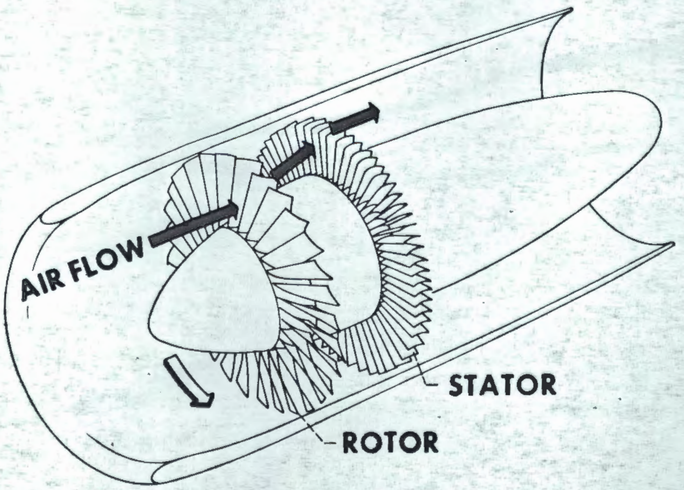
SLIDE 4 CS-67549

MACHINERY NOISE SOURCES



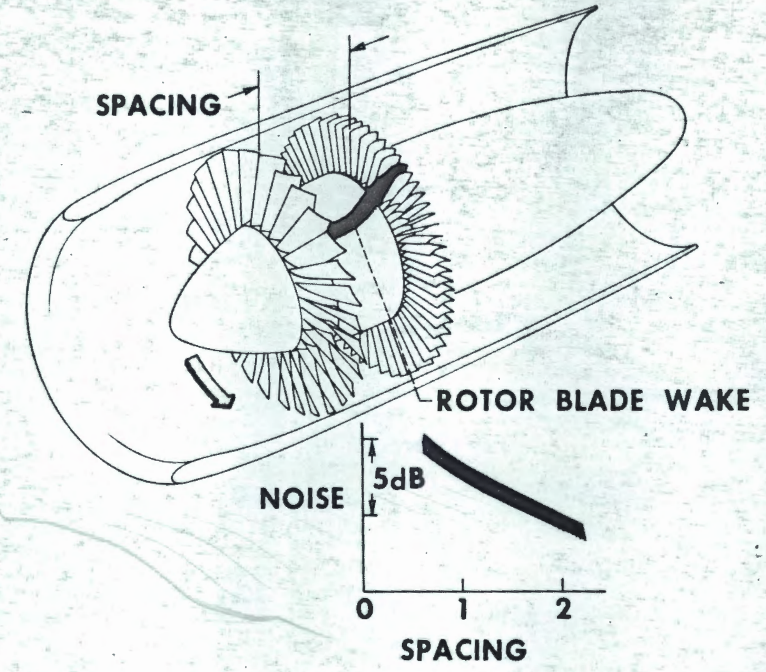
SLIDE 5 CS-67550

TYPICAL FAN STAGE



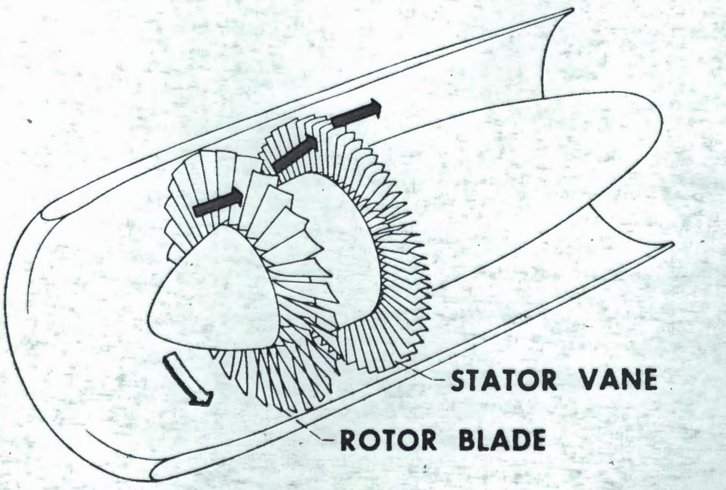
SLIDE 6 CS-67551

EFFECT OF ROTOR-STATOR SPACING



SLIDE 7 CS-67552

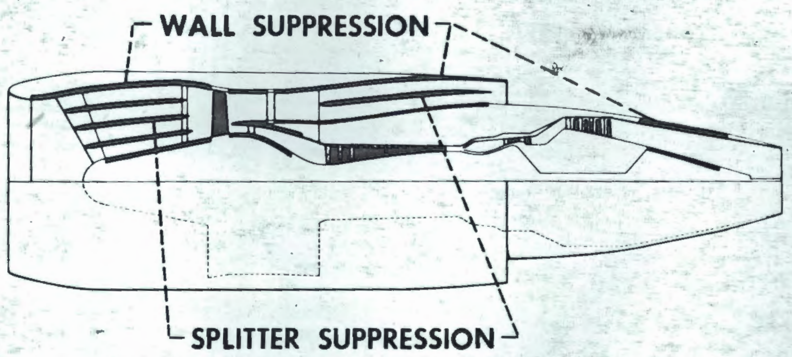
VANE & BLADE COMBINATION



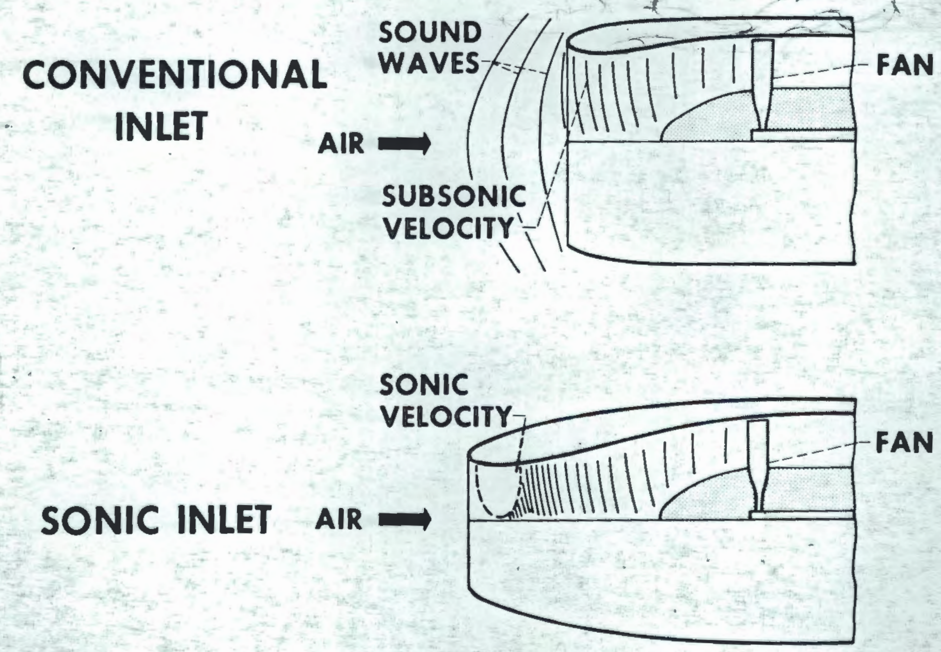
FOR MINIMUM NOISE:
ABOUT 2 VANES PER BLADE

SLIDE 8 CS-67553

TYPICAL ENGINE WITH ACOUSTIC SUPPRESSION

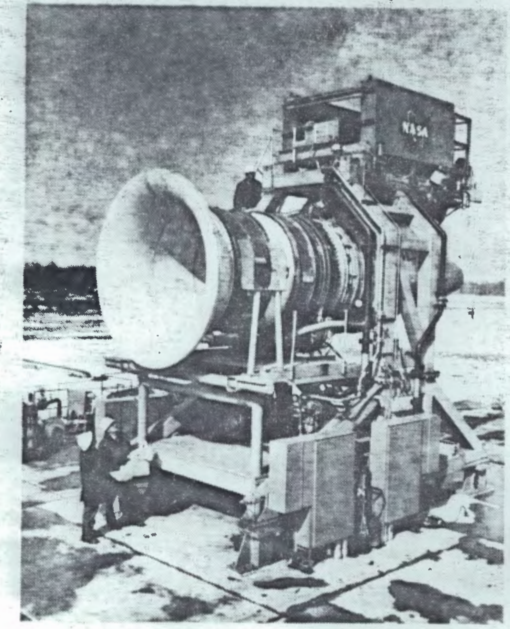


SLIDE 9 CS-67554

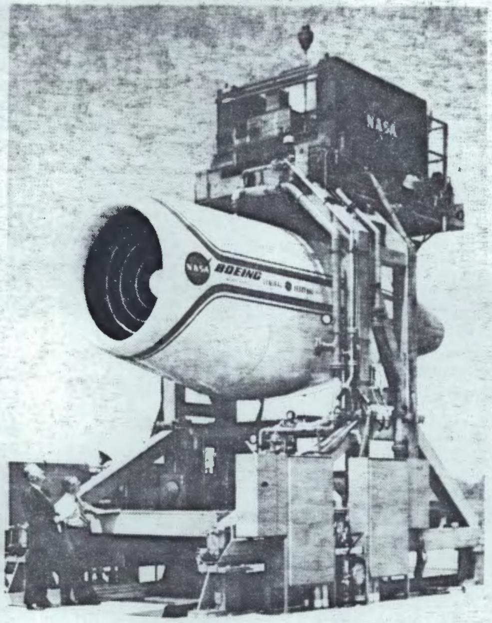


SLIDE 10 CS-67555

QUIET ENGINES



WITHOUT ACOUSTIC SUPPRESSION



NACELLE WITH ACOUSTIC SUPPRESSION

SLIDE 11 CS-67556

FLYOVER NOISE COMPARISON

	TAKEOFF	APPROACH
	EPNdB	
DC-8 STANDARD	116	118
DC-8 QUIET ENGINE TECHNOLOGY UNTREATED	97	98
DC-8 QUIET ENGINE TECHNOLOGY ACOUSTIC NACELLE	90	89

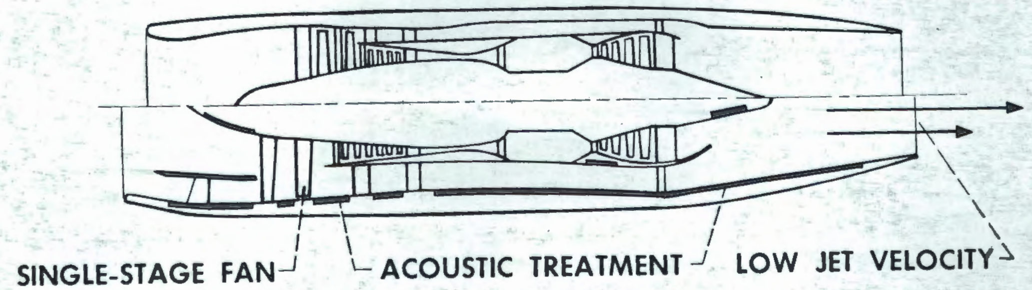
SLIDE 12 CS-67557

OPTIONS FOR QUIETING OLDER JET AIRCRAFT

1)	REPLACE AIRCRAFT	PROHIBITIVE COST
2)	REPLACE ENGINES	VERY HIGH COST
3)	RENACELLE ENGINES	LOWEST COST MODERATE NOISE REDUCTION
4)	REFAN ENGINES	INTERMEDIATE COST BETTER NOISE REDUCTION

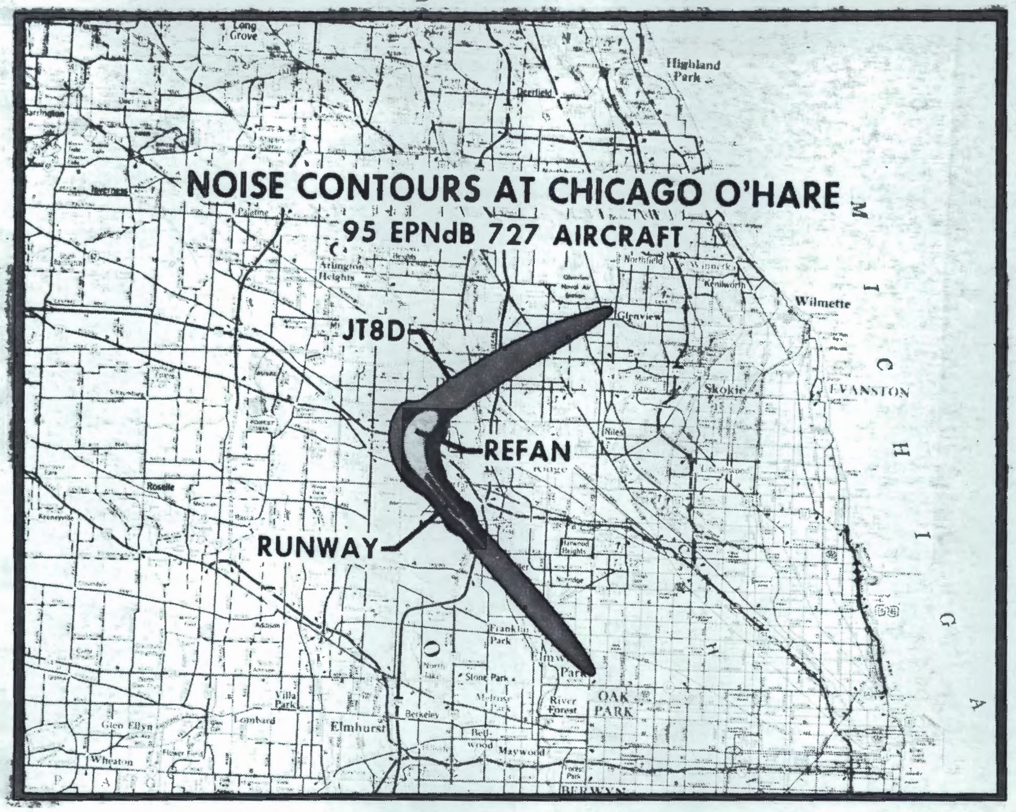
SLIDE ~~#~~13 CS-67558

CURRENT JT8D

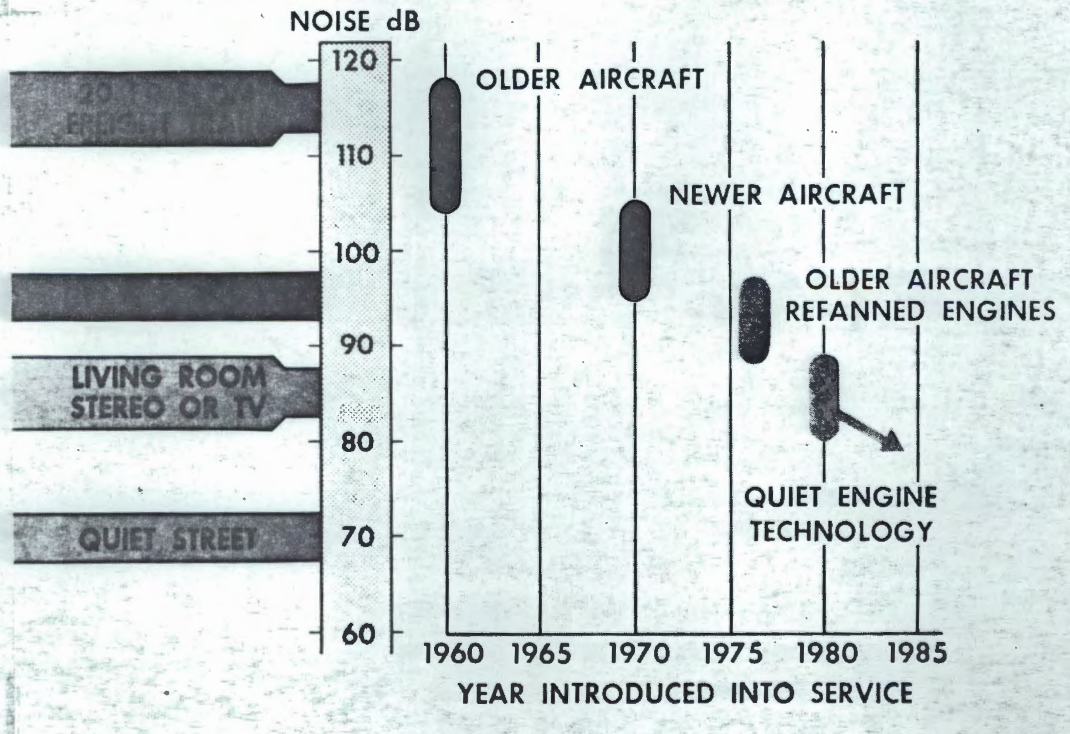


REFAN JT8D

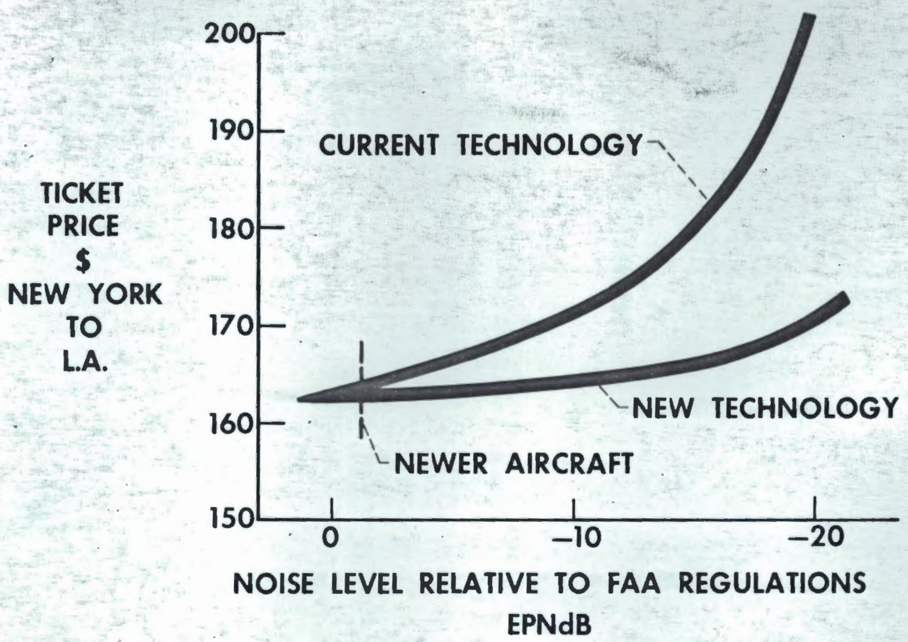
SLIDE 14 CS-67559



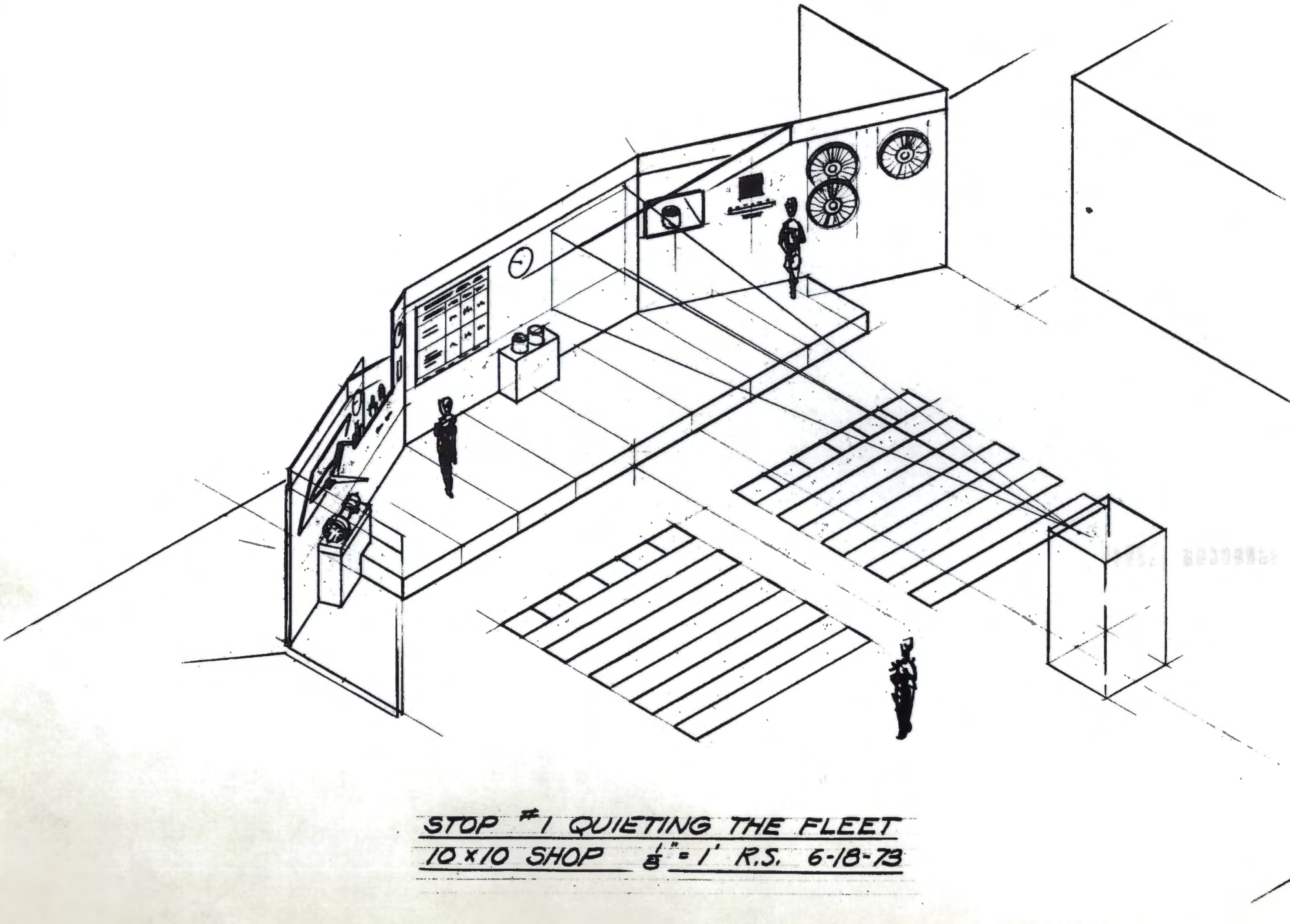
SLIDE 15 CS-67560



SLIDE 16 CS-67561



SLIDE 17 CS-67562



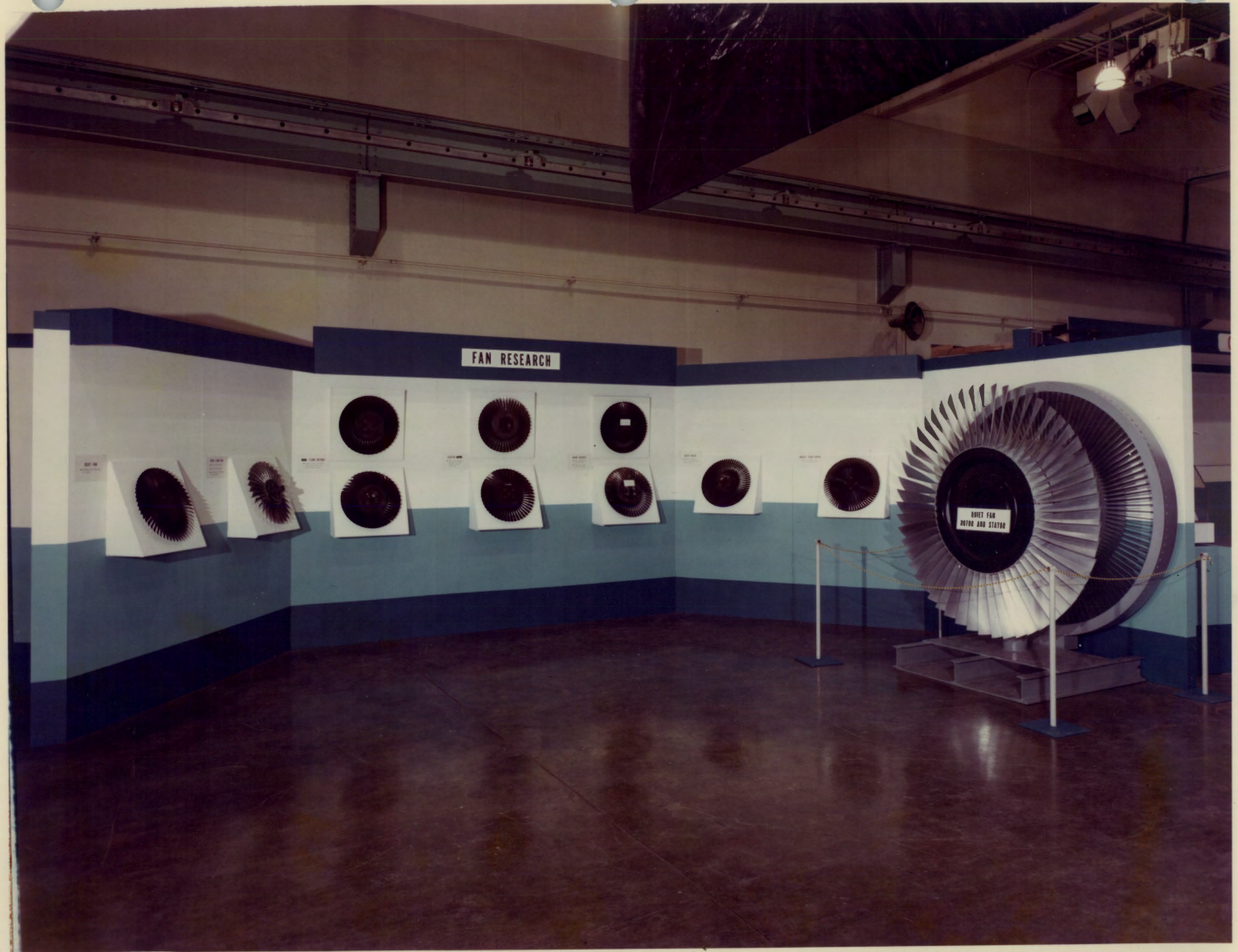
STOP #1 QUIETING THE FLEET
10 x 10 SHOP $\frac{1}{8}$" = 1' R.S. 6-18-73

NASA
C-73-1568

10' x 10' SUPERSONIC WIND TUNNEL

NASA
C-73-3381

NASA
C-73-3375



NASA
C-73-3377

NASA
C-73-3378