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A Fan Concept to Meet the 2017 Noise Goals

James H. Dittmar
Lewis Research Center, Cleveland, Ohio

November 1998

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A FAN CONCEPT TO MEET THE 2017 NOISE GOALS

James H. Dittmar
National Aeronautics and Space Administration
Lewis Research Center
Cleveland, Ohio 44135

SUMMARY

The National Aeronautics and Space Administration has established a goal of a 20 EPNdB reduction of aircraft noise by the year 2017. This paper proposes a fan concept for an engine that may meet this noise goal. The concept builds upon technology established during the Advanced Subsonic Technology Program which should show a 10 dB reduction potential. The new concept uses a two stage fan which allows low tip speed while still maintaining a reasonable total pressure rise across the two stages. The concept also incorporates many other noise reduction techniques in addition to low tip speed including a low number of exit guide vanes, swept and leaned guide vanes, a high subsonic Mach number inlet and syncrophased rotors to obtain active noise cancellation. The fan proposed in this paper is calculated to be able to achieve the 2017 noise goal.

INTRODUCTION

In 1997, NASA released its three pillars for Success in Aeronautics and Space Transportation; Global Civil Aviation, Revolutionary Technology Leaps and Access to Space. As part of the Global Civil Aviation Pillar one of the technology goals is the reduction of aircraft noise. Specifically, the goal is to “Reduce the perceived noise levels of future aircraft by a factor of two from today’s subsonic aircraft within 10 years and by a factor of four within 20 years.” A factor of two reduction is about 10 Effective Perceived Noise Decibels (EPNdB) and four is 20 EPNdB.

As part of the ongoing Advanced Subsonic Technology Program, the noise effort should show a 10 decibel (dB) noise reduction by its completion in the year 2001. This reduction is a combination of reduced engine noise and aircraft improvements. The engine part of the noise reduction comes primarily by going to a lower pressure ratio, slower turning fan on a high bypass ratio engine. This leaves an additional 10 dB of noise reduction to be obtained before the year 2017 goals can be met. Further reductions in the aircraft noise will require equivalent reductions in engine noise. To bring the engine noise down will require the reduction of the fan components, both internal and jet noise, by at least the same 10 dB. The purpose of this report is to propose a new fan concept that could result in an additional 10 dB reduction from the Advanced Subsonic Technology Fan thereby enabling the goal of a 20 dB reduction by 2017 to be reached.

BASE FAN

A combination of technologies developed under the Advanced Subsonic Technologies (AST) program is used to arrive at a base fan that, when installed in an engine, results in approximately a 10 dB reduction from the airplanes presently flying. The primary fan characteristics are from the Pratt & Whitney Advanced Ducted Propulsor Fan 1 tested during the AST program and reported in reference 1. Characteristics of this fan are shown in table 1 and a photograph of the fan being tested in the NASA Lewis 9×15 wind tunnel is shown in figure 1. Calculations using this fan, with an acoustically treated nacelle, on an engine for an 850 000 lb maximum takeoff weight airplane showed significant noise reductions. When compared with the present airplanes that were constructed with 1992 technology, reference 2, noise reductions of 9.3, 7.1, and 4.3 EPNdB were shown at the approach, cutback and sideline rating points. A 10 dB reduction at each of these points would give a sum of 30 dB. This fan yields a 20.7 EPNdB reduction.

Another AST fan test using an Allison Engine Company fan showed that the incorporation of lean and sweep in the fan exit guide vanes resulted in a further noise reduction of approximately 3dB at all of the rating speeds for-both tone and broadband noise. A photograph of these exit guide vanes is shown in figure 2. If this 3dB is added to the P&W ADP reductions at each of the rating locations the results are 12.3, 10.1, and 7.3 EPNdB at the approach, cutback, and sideline rating locations. This yields a total of 29.7 dB compared with the desired 30 dB. For the purposes of this concept development, the P&W ADP fan having leaned and swept stators is assumed to be 10 dB below the noise of existing airplanes. This fan will therefore be used as the base fan from which the new fan concept will attempt to show an additional 10 dB reduction and meet the 2017 noise goals.

BASIC NOISE TREND APPROXIMATIONS

General noise trend approximations will be used to evaluate the noise reduction potential of the concept. These approximations will not yield exact numbers but will show, in general, if the concept has the potential for the 10 decibels reduction. Detailed designs could follow this concept definition paper allowing more accurate predictions to be calculated. However, in this concept paper the following noise trend predictions will be used.

The noise from a fan stage can be considered as consisting of the fan jet noise and the fan internal noise. For the purposes of this paper future references to jet noise will mean fan jet noise and references to fan noise will mean fan internal noise. The jet noise for this paper will be assumed to vary as the fan jet velocity to the eighth power. So to compare the difference in jet noise between two fans the following would be used

$$\Delta dB_{\substack{jet \\ noise}} = 10 \log\left(\frac{V_{J_2}}{V_{J_1}}\right)^8 \tag{1}$$

where V_{J_1} is the jet velocity of the first fan and V_{J_2} is the jet velocity of the second fan. If V_{J_2} is greater than V_{J_1} then the ΔdB would be positive indicating a noise increase.

Fan internal noise varies with velocity also at either the fifth or sixth power. Here, because it is conservative in the sense that if you meet the noise goals with the fifth power exponent you will more than meet them with the sixth power exponent, the fifth power of velocity is used. For the fan , the noise comes from various internal sources. Some of the sources create tones and others create broadband noise. The noise contribution of these sources will typically be related to different velocities. For example, the broadband noise generated by the rotor might depend on the flow velocity relative to the rotor while the broadband noise generated by the exit guide vanes might depend on the flow velocity relative to those guide vanes.

When comparing fans that have the same blade aerodynamic loading (the same section lift coefficients) but at different rotative speeds, the velocity triangles for the flow fields are approximately similar. Then velocity ratios comparisons between two fans would be approximately the same for all of the velocities. So under the assumption that the blade aerodynamic loading for a new fan would be approximately the same as for the base fan, the rotor tip velocity is chosen here as the velocity to be used for the noise comparisons. Further discussions of how this blade aerodynamic loading will be held constant will be included in the development of the new fan concept later in this report.

The fan noise difference between two fans is then to be approximated by

$$\Delta dB_{\substack{fan \\ noise}} = 10 \log\left(\frac{V_{T_2}}{V_{T_1}}\right)^5 \tag{2}$$

where V_{T_1} is the fan tip speed for fan 1 and V_{T_2} is the fan tip speed for fan 2. If V_{T_2} is greater than V_{T_1} the ΔdB would be positive indicating a noise increase.

Equations 1 and 2 are then the noise trend approximations that will be used to evaluate the noise reduction potential of the new fan concept.

FAN CONCEPT DEVELOPMENT

Jet Noise Reduction

The base fan has an 840 ft/sec tip speed with a 1.28 pressure ratio. The velocity ratio necessary to achieve a 10 decibel jet noise reduction can be determined from equation 1. Where V_{J_N} is the new fan jet velocity and V_{J_B} is the base fan jet velocity.

$$-10\text{dB} = 10\log\left(\frac{V_{J_N}}{V_{J_B}}\right)^8$$

$$V_{J_N} = 0.7498$$

This lower jet velocity corresponds to a reduced fan pressure ratio. Using the Ames Tables, reference 4 , the new pressure ratio can be calculated. Starting with some static condition upstream of the fan, the static to total pressure ratio $\frac{P_S}{P_{T_{IN}}}$ would be 1. (Other conditions could be used that would correspond to some fixed velocity upstream of the engine but since the airplane velocity would be low, M = 0.1 to M= 0.3 for the noise measurement locations, the resulting velocity ratio and pressure ratio for the new fan would be the same as calculated using a static to total pressure ratio of 1) The base fan produces a 1.28 pressure ratio or $\frac{P_{T\,exit}}{P_{T_{IN}}} = 1.28$.

Dividing one by the other gives $\frac{P_S}{P_{T_{exit}}} = 0.781$, which corresponds to an exit Mach number of 0.6 for the base fan. The desired velocity ratio to obtain a 10 dB noise reduction is 0.7498 which yields a Mach number of 0.45 for the new fan. To obtain this Mach number a $\frac{P_S}{P_{T_{exit}}}$ of 0.8703 is indicated which is a pressure ratio of approximately 1.15.

A pressure ratio of 1.15 is then the pressure ratio desired for the new fan concept to obtain the 10 dB reduction in fan jet noise. This is a mixed flow engine and the core jet noise component is assumed to be lower than the fan jet component. A lower fan pressure ratio would give a lower velocity and an even larger jet noise reduction but as the pressure ratio is reduced, the engine has to grow in size to provide the thrust required to propel the airplane. Fan size and its effect on the airplane configuration will be discussed later but the desire to keep the engine to a reasonable size drives the pressure ratio to be as high as possible while still obtaining the noise reduction. For this reason the desired fan pressure ratio for the concept fan is 1.15.

Fan Noise Reduction

To obtain the ten decibel fan noise reduction

$$-10\text{dB} = 10\log\left(\frac{V_{T_N}}{V_{T_B}}\right)^5,$$

where V_{T_N} is the new fan tip speed

and V_{T_B} is the base fan tip speed.

This yields a ratio of 0.63 for $\frac{V_{T_N}}{V_{T_B}}$. This results in a new fan tip speed of 530 ft/sec given the base fan tip speed of 840 ft/sec. This is a low tip speed to produce a pressure ratio of 1.15 and even if it were possible to design a fan to give this pressure ratio at 530 ft/sec, it would have the blade aerodynamic loading significantly higher than the base fan. This would then violate the basic noise assumption of having the new fan retain approximately the same loading as the base fan.

A calculation for the pressure ratio that a 530 ft/sec tip speed fan would yield with the same blade aerodynamic loading as the base fan is now undertaken. The adiabatic efficiency of a fan can be represented by

$$\eta = \frac{P_r^{\frac{\gamma-1}{\gamma}} - 1}{T_r - 1} \text{ (equation 3.1 of ref. 5)} \tag{3}$$

where P_r is the fan pressure ratio, T_r is the temperature ratio and γ is the ratio of specific heats which is taken as 1.4 for air. For a given geometry of the flow, i.e. constant blade aerodynamic loading, the stagnation temperature rise of the stage varies as the square of the tip speed when the speed of sound is assumed constant.

$$T_r - 1 \quad \alpha \quad V_{Tip}^2 \text{ (rewritten from page 195, ref. 5)} \tag{4}$$

So to maintain the same blade aerodynamic loading for the new fan, with equal efficiencies, the temperature rise of the new fan must have the same ratio to the base temperature rise as the ratio of the squares of the fan tip speeds. The following calculations show the pressure ratio that the 530 ft/sec tip speed will achieve with the fixed loading.

$$\frac{(T_r - 1)_{\text{base fan}}}{(T_r - 1)_{\text{new fan}}} = \left(\frac{V_{T_{base}}{}^2}{V_{T_{new}}{}^2}\right) = \left(\frac{840}{530}\right)^2$$

$$\frac{\left(P_r^{\frac{\gamma-1}{\gamma}} - 1\right)_{\text{base fan}}}{\left(P_r^{\frac{\gamma-1}{\gamma}} - 1\right)_{\text{new fan}}} = \left(\frac{840}{530}\right)^2 = 2.512$$

$$\frac{\gamma - 1}{\gamma} = \frac{1.4 - 1}{1.4} = 0.2857$$

$$\left(P_r^{0.2857} - 1\right)_{\text{base fan}} = (1.28)^{0.2857} - 1 = 1.073 - 1 = 0.073$$

$$\frac{0.073}{\left(P_r^{\frac{\gamma-1}{\gamma}} - 1\right)_{\text{new fan}}} = 2.512$$

$$\left(P_r^{\frac{\gamma-1}{\gamma}} - 1\right)_{\text{new fan}} = \frac{0.073}{2.512} = 0.029$$

$$\left(P_r^{\frac{\gamma-1}{\gamma}}\right)_{\text{new fan}} = 1.029$$

$$P_r^{0.2857} = 1.029$$

$$P_{r\ \text{new fan}} = 1.1$$

At the same level of blade aerodynamic loading, the 530 ft/sec tip speed, which is needed to obtain the 10 dB of noise reduction, could only support a pressure ratio of 1.1. This is significantly lower than the 1.15 pressure ratio that would be needed for the jet noise reduction and brings the engine size issue into discussion.

Engine Size

The pressure ratio has a direct relationship on the size of the engine required to yield a given thrust. The thrust relationship is as follows.

$$F \ \alpha \ (P_r - 1)\, PA$$

Where F is the thrust, P_r is the pressure ratio, P is the pressure upstream of the engine and A is the fan area. The exhaust is assumed circular so $A = \pi R^2$ with R being the fan radius. Therefore a fan with a pressure ratio of 1.15 has an area compared with the base fan of .28/.15 or 1.867 times the base fan. This yields a fan radius 1.36 times as large as the base fan. At a pressure ratio of 1.1 the area is 2.8 times as large with a radius ratio of 1.67. Because of the available clearance between the airplane wing and the ground an engine 1.67 times the radius, as would be the case with the 1.1 pressure ratio fan, would be unacceptable. The 1.15 pressure ratio fan with a radius 1.36 times the base fan is also too large. To make an airplane with acceptable ground clearance with a 1.15 pressure ratio would require the use of more engines each having a smaller diameter. If one base engine at a pressure ratio of 1.28 were replaced with two engines at 1.15 pressure ratio, the 1.15 pressure ratio engines would each have a diameter of 0.97 the base fan diameter. This would be an acceptable configuration from the ground clearance perspective. In other words, a two engine airplane would become a four engine airplane with the new 1.15 pressure ratio engines. This, although presenting a cost penalty, could be acceptable. However, the fan noise reduction calls for an even lower 1.1 pressure ratio to obtain the 10 decibels noise reduction. Here even replacing the base fan with two 1.1 pressure ratio fans means that the fans would be 20 percent larger in diameter, which would not be acceptable from a ground clearance perspective.

New Fan Concept

So then, how can an acceptable size fan be achieved with a tip speed low enough to obtain the 10 dB fan noise reduction? The proposed concept uses a two stage fan. Each of the fan stages would turn at the lower tip speed and when put together would achieve the desired 1.15 pressure ratio. Then two of these new 1.15 pressure ratio, two stage fan engines, would replace each of the base engines.

This two stage fan concept, on initial inspection, would appear to meet the desired 10 decibel noise reduction from the base fan (20 dB from current airplanes). However, the two stage fan concept has some additional noise sources over that of a single stage fan. These additional noise sources and methods to reduce or counterbalance their effects, so that the noise goal can be obtained, are the subject of the following discussion.

Additional Noise Sources and Solutions

The use of two fan stages brings in the additional noise of the second stage. If the two noise sources are assumed to add in a random nature, a 3 decibel noise increase will be observed. The new two stage concept would then have a 7 decibel noise reduction instead of the desired 10 decibels. To achieve the 10 decibel noise goal then each stage would have to be 13 decibels below the base fan. When this calculation is performed then each fan would have a tip speed of 460 ft/sec. With the same blade aerodynamic loading as the base fan, each 460 ft/sec fan could support a pressure ratio of 1.08. In order to obtain a total pressure ratio across the two stages of 1.15, each of the stages would need to produce a pressure ratio of 1.072. This then becomes a viable design. So the two stage fan concept then consists of two 1.072 pressure ratio fans turning at 460 ft/sec tip speed.

The presence of the two fan stages, one behind the other, has an additional interaction noise source that is not present in a single stage fan. This is the interaction of the first fan’s exit guide vane wake with the second fan’s rotor. To minimize this effect, the distance between the first and second stages should be maximized. To do this it is proposed that one of the fans be driven off the front of the engine while the other fan be driven from the aft. This would allow larger spacing between the two fans and potentially eliminate this extra noise source. It would also allow larger spacing between the rotor and exit guide vane in each stage for more potential noise reduction.

Some drawbacks may exist for this type of engine layout. For example, an engine performance penalty may result from the large axial stage separation and a core booster stage might be required for proper airflow to the core engine. However, these details would be part of a detailed engine design and will not be specifically addressed in this concept paper since they do not seem to be insurmountable.

The third added noise source results from a higher through flow velocity in the fan stages. One initial assumption was that all of the velocities vary in relationship to the fan tip speed. A 1.072 pressure ratio fan would therefore have all of the velocities in proportion to its 460 ft/sec tip speed. However, when the two fans are placed axially one behind the other within the duct (yielding a combined pressure ratio of 1.15), the axial velocity flowing through the duct corresponds to that for a 1.15 pressure ratio fan. The higher duct velocity would result in a noise level higher than that of a 1.072 pressure ratio fan.

To estimate the additional noise, the interaction of the rotor flow field with the downstream exit guide vane was chosen as a representative source because it usually represents the dominant noise source for both the tone and broadband fan noise. The relative velocity entering the exit guide vanes, raised to the fifth power was used to approximate the impact on this noise source. The velocity diagrams from the Pratt & Whitney ADP Fan 1, Appendix A of reference 7, were used to construct the relative velocities for the base fan, the 1.072 pressure ratio fan with normal through flow and the 1.072 pressure ratio fan with the through flow representative of the 1.15 pressure ratio fan. Noise reductions calculated for the 1.072 pressure ratio fan with its nominal through flow velocity showed a predicted noise reduction of 13 decibels as expected. The 1.072 pressure ratio fan, with the higher 1.15 pressure ratio fan through-flow velocity, showed only an 8.5 dB reduction. This is almost 5 decibels less than needed to obtain the combined reduction of 10 decibels (13 decibels needed per fan). Therefore, additional methods of fan noise reduction will be necessary to reach the goal. The rotor wake-exit guide vane interaction is assumed the dominant noise source for both tone and broadband noise so methods of reducing this source will be considered.

One method to reduce the perceived noise of this type of low speed fan was presented in reference 8. In this paper, a predicted noise reduction was achieved by abandoning the cutoff number of exit guide vanes. This was based on the long chord exit guide vane noise reduction work of references 9 and 10 and the newer broadband noise reduction work of reference 11. A smaller number of long chord exit guide vanes was used to replace the existing vane set. This gave a broadband noise reduction of about 5 decibels but increased the tone noise. A net noise reduction of 2 EPNdB was observed. If the tone noise was not present in the spectra, the reduction would have been on the order of the 5 dB broadband noise reduction. Therefore, to achieve the needed noise reduction using fewer exit guide vanes, a method for tone noise reduction will also be required. The low fan tip speed and the leaned and swept fan exit guide vanes will provide some tone noise reduction. In addition, the large axial spacing built into this fan will reduce tone noise. These reductions may be such that the tones do not present a problem here. However, in case additional tone noise reduction is needed, another tone noise reduction method will be discussed. This discussion will occur after an evaluation is made of how much broadband noise reduction can be achieved with a small number of long chord exit guide vanes for this new concept fan.

The noise reduction expected from a small number of long chord vanes has been approximated in reference 11 to be 10 times the log of the vane number. The base fan has 45 vanes. If these are replaced with 12 long chord vanes the resulting vane number ratio is 3.75 which yields a predicted broadband noise reduction of 5.7 decibels. This is slightly more than needed to bring the noise of each stage down by 13 dB which gives the desired reduction of the two fan stages to meet the 10 dB goal. This assumes that the rotor wake-exit guide vane interaction is the dominant broadband noise source, which is a good assumption. This also assumes that all the other broadband sources are at least 5 decibels lower than the rotor wake-exit guide vane source so that they don't limit the amount of noise reduction achievable. If some other broadband noise source becomes dominant then some other method may be required to lower that source and obtain the desired broadband noise reduction. If, for example, the inlet boundary layer - rotor source were to become important some method of decreasing the boundary layer thickness, like blowing or suction, would be required.

The new concept fan will then have 12 exit guide vanes. If these guide vanes were to have the same solidity as the original set, then they would be 3.75 times as long with an equivalent thickness increase. With larger exit guide vanes situated near the front and near the aft of the engine, it will be assumed that they can carry the load of the core and any service to the core. This implies that no other struts or pylons will pass through the fan flow path. This would eliminate the noise generated by these struts or pylons as a consideration and possibly result in further noise reductions.

Previously, lower tip speed, swept and leaned fan exit guide vanes and increased axial spacing were included to reduce fan tone noise. An additional technique proposed here to provide tone noise reduction could be classified as a form of active noise control. When two equal noise signals are introduced into a duct a noise reduction can be realized by phasing the two sound sources so that they cancel each other out. An example of such an experiment can be found in reference 6 where this type of cancellation was demonstrated using advanced turboprop noise. To reduce the tone noise in this two fan concept device it is proposed that the noise from the two fans be used to cancel each other. This would be accomplished by means of active synchrophasing of the fans to provide the cancellation. This synchrophasing technique has been applied to airplane propellers in the past and has been shown to be effective. Here it would have to be tailored to remove the specific duct modes that carried the most tone energy. This synchrophasing technique would require that the two fan stages be on different spools of a multi-spool engine so that their phase could be independently varied. This technique of synchrophasing the two fan stages has the potential of not only reducing the tone noise so that the noise goal can be achieved but could even provide some additional broadband noise reduction.

In addition to the methods discussed which should bring the noise of this fan down to the 2017 noise goal, an additional noise reduction technique could bring the noise even lower. In reference 12, the noise reduction achievable by a high subsonic Mach number inlet was discussed. This paper, using previous references, indicated that with inlet centerline Mach numbers as low as M=0.7 or 0.8, noise reductions of 15 dB or more were possible and this reduction occurred for both tones and broadband. In addition the high subsonic inlet Mach number changed the directivity of the sound away from the side of the engine and pointed it more directly out the inlet. For a hypothetical airplane takeoff flight path, this change in directivity resulted in another 16 dB of noise reduction for the dominant tone noise. The real advantages of the high subsonic inlet have not been fully realized on presently flying commercial subsonic aircraft and the high subsonic Mach number inlet is included in this new fan concept because of its high potential noise reduction.

Fan Concept Configuration

The new fan concept proposed in this paper is illustrated in figure 3. The concept has two fan stages turning at a 460 ft/sec tip speed with 1.072 pressure ratio per stage resulting in an overall pressure ratio of 1.15. The two fan stages are placed far apart, one being driven by the front of the engine and the other by the aft. The stages are driven by two separate spools of the engine so they can be synchrophased. The rotor blade number was kept at the 18 blades of the base fan but the exit guide vane number was reduced to 12 to obtain broadband noise reduction. A high subsonic Mach number inlet was included for reduced inlet noise. The noise approximations used in this report indicate that this fan has the potential to be 10 decibels quieter than the base fan and should be able to meet the noise reduction goal of 20 decibels below existing aircraft by the year 2017.

CONCLUDING REMARKS

In this paper a fan concept is proposed to meet the 2017 noise goal of a 20 EPNdB reduction from existing aircraft. The new fan concept builds on technology from the Advanced Subsonic Technology program that already shows the potential of a 10 dB reduction. This AST technology fan consists of the basic characteristics of the Pratt & Whitney ADP Fan 1 combined with the swept and leaned exit guide vanes of an Allison Engine Company Fan. The new fan concept uses this AST fan as a base fan and is configured to give 10 dB additional noise reduction resulting in the 20 dB noise reduction goal.

The new fan concept is illustrated in figure 3 and a summary of the noise reduction steps is found in table II. The fan consists of two stages having a 1.072 pressure ratio per stage for a total fan pressure ratio of 1.15. The overall pressure ratio of 1.15 was chosen to achieve a jet velocity that would yield the 10 dB reduction from the base fan. The fan stages have a rotative tip speed of 460 ft/sec with 18 rotor and 12 exit guide vanes in each stage. The 460 ft/sec tip speed was determined from a calculation to reduce the fan noise by the desired 10 dB from the base fan. The low number of long chord exit guide vanes are provided to obtain a broadband noise reduction. The use of a small number of relatively thick long chord vanes enables the core to be supported by these vanes. This eliminates the need for an internal pylon and removes it as a possible noise source. These exit guide vanes are also swept and leaned to reduce blade interaction noise. The fan stages are also placed far apart in the duct, one driven from the

front of the engine and the other from the aft, to reduce this interaction noise. The fan stages are driven from separate spools of the engine and are syncrophased to provide active noise cancellation in the duct. Acoustic treatment is provided on both the inner and outer fan duct walls. This treatment is also present on the walls internal to the long chord vane passages. A high subsonic Mach number inlet is provided to further reduce the noise of this concept. The resulting two stage fan, as described in this report, has the potential of meeting the 2017 noise goal of a 20 dB reduction.

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TABLE I.—PRATT & WHITNEY ADP FAN 1

Takeoff tip speed	840 ft/sec
Takeoff pressure ratio	1.28
Rotor blade number	18
Stator vane number	45
Rotor stator spacing in axial Fan chords at mid span	1.8

TABLE II.—SUMMARY OF NOISE REDUCTION STEPS

The base fan (P&W ADP with 18 rotor blades and 45 leaned and swept stator vanes having a 1.28 Pressure ratio and 840 ft/sec tip speed) should give 10 EPNdB reduction from 1992 technology. An additional 10 dB reduction in both fan jet and fan internal noise is required to meet the 2017 goal.

JET NOISE REDUCTION

A pressure ratio reduction to 1.15 lowers the jet velocity and should give a 10 dB reduction.

FAN NOISE REDUCTION

1. A tip speed reduction to 530 ft/sec should give a 10 dB noise reduction for a fan with equivalent blade aerodynamic loading to the base fan.
2. A 530 ft/sec tip speed will not, however, support a 1.15 pressure ratio fan with equivalent blade aerodynamic loading . The equivalently loaded fan at a 530 ft/sec tip speed would have a 1.10 pressure ratio.
3. Since a 1.10 pressure ratio fan would be too large, a two stage 1.15 pressure ratio fan was proposed. Each stage would give a 1.072 pressure ratio.
4. Two fan stages added together would give 3 dB more noise, so the tip speed was further lowered to 460 ft/sec to give 13 dB reduction per stage for the total reduction of 10 dB.
5. Additional noise would be created with the two stage fan since the through flow velocity is the velocity that would be present for a 1.15 pressure ratio fan.
6. The extra broadband noise would be reduced by going to less stators (12).
7. Extra tone noise would be reduced by synchrophazing the two rotors to get active noise cancellation.
8. Additional noise reduction would be obtained by using a high subsonic Mach number inlet.

The final result is a two stage fan with 1.072 pressure ratio per stage for an overall pressure ratio of 1.15. The fan would have a 460 ft/sec tip speed with 18 rotors and 12 stators using synchrophazing for active noise control and employing a high subsonic Mach number inlet. This fan should be 10 EPNdB below the base fan and 20 EPNdB below 1992 technology.

Figure 1.—Pratt and Whitney ADP Fan 1.

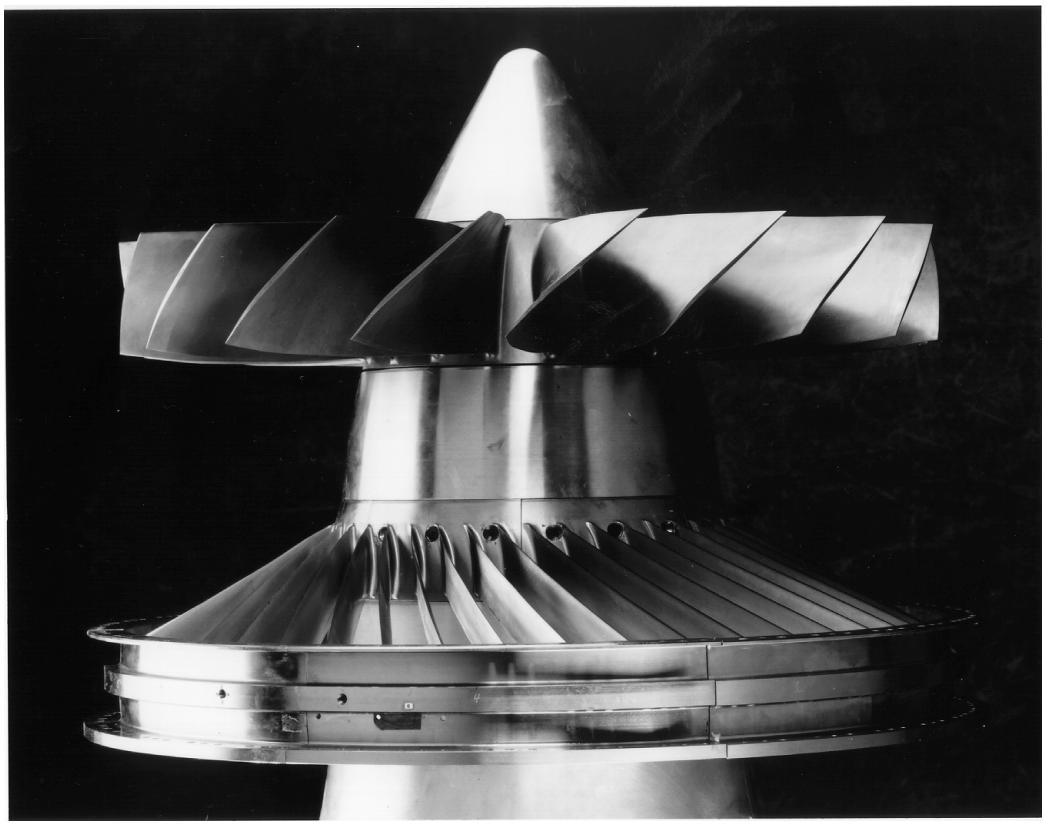

Figure 2.—Swept and leaned exit guide vanes.

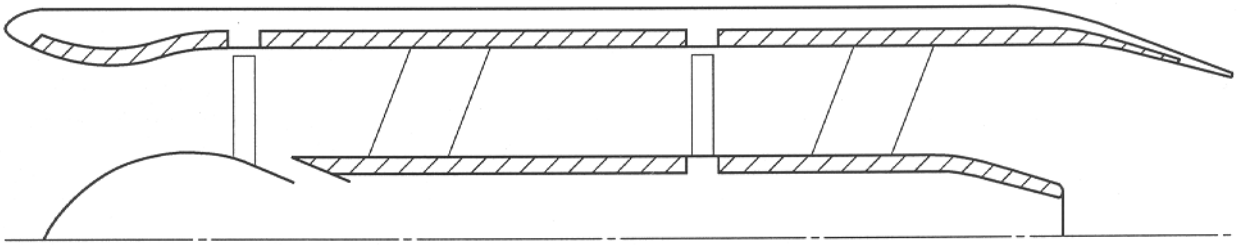

Figure 3.—New fan concept characteristics

1. Two fan stages with 460 ft/sec tip speeds
2. Pressure ratio equal 1.072 per stage
3. Overall pressure ratio equal 1.15
4. Large spacing between fans and between blade rows inside each fan
5. Fan stages driven from opposite ends of engine on different spools
6. Rotors synchrophased
7. 18 rotor blades
8. 12 long chord, swept and leaned stator vanes
9. No pylon
10. Acoustic treatment on inner and outer flow path walls including area between exit guide vanes
11. High subsonic Mach number inlet

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James H. Dittmar

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The National Aeronautics and Space Administration has established a goal of a 20 EPNdB reduction of aircraft noise by the year 2017. This paper proposes a fan concept for an engine that may meet this noise goal. The concept builds upon technology established during the Advanced Subsonic Technology Program which should show a 10 dB reduction potential. The new concept uses a two stage fan which allows low tip speed while still maintaining a reasonable total pressure rise across the two stages. The concept also incorporates many other noise reduction techniques in addition to low tip speed including a low number of exit guide vanes, swept and leaned guide vanes, a high subsonic Mach number inlet and syncrophased rotors to obtain active noise cancellation. The fan proposed in this paper is calculated to be able to achieve the 2017 noise goal.

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