Simple Low Noise Technology

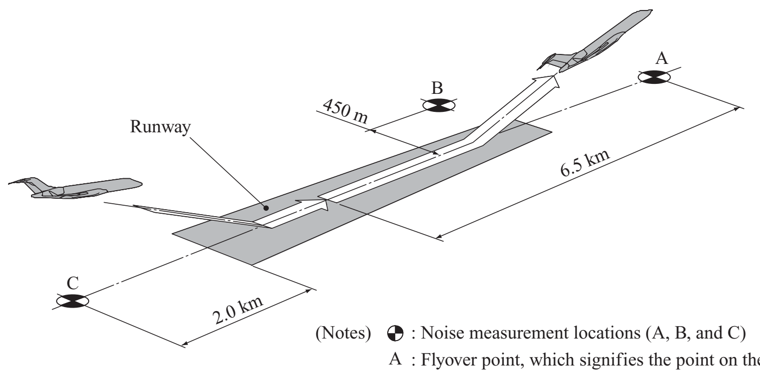
OISHI Tsutomu : Manager, Advanced Technology Department, Research & Development Division, Aero-Engine & Space Operations
OBA Yoshinori : Manager, Advanced Technology Department, Research & Development Division, Aero-Engine & Space Operations

The objectives of the ECO engine project are improvement of engine system integration capability and establishment of advanced technologies required for the next-generation of small aircraft engines that are environmentally friendly and economically viable. Technologies for low noise engines in the ECO engine project are described. The aircraft noise reduction is targeted to achieve the new chapter 4 standard with 20 dB cumulative margin in ICAO Annex 16. Research and development of low noise technology was conducted for fan noise reduction and exhaust jet noise reduction, which are the major noise sources of jet engines. In the fan noise research targeting 3 dB reduction, a swept blade and integrated outlet guide vanes were investigated under weight limit and structural restrictions. In the jet noise research targeting 2 dB reduction, the notched nozzle as a new concept was investigated for simple nozzle design. 3.8 dB reduction for fan noise and 2.2 dB reduction for jet noise were demonstrated through several model rig tests.

1. Introduction

The noise standards currently in effect for major civil aircraft are based on the ICAO (International Civil Aviation Organization) Annex 16, Volume I, Chapter 3 (hereinafter called Chapter 3) established by the ICAO in 1976. Under Chapter 3, the three points to be evaluated, as shown in **Fig. 1**, are as follows: (A) the flyover reference noise measurement point, (B) the lateral reference noise measurement point, and (C) the approach reference noise measurement point. A regulated noise level is assigned to each of these three points as a function of the aircraft maximum take-off gross weight.

Because Chapter 4 was established in 2001 in the wake of the resolution to tighten noise standards, it has been in effect for new models of aircraft applying for model certification since January of 2006. Chapter 4 follows Chapter 3 in terms of the regulated noise levels for the three points shown in **Fig. 1**; in addition to these noise levels, though, the noise margin (the difference between the noise level of an aircraft and the regulated noise level under Chapter 3) at each point is taken into account. More specifically, the requirements are as



(Notes) : Noise measurement locations (A, B, and C)
A : Flyover point, which signifies the point on the extended center line of the runway at a distance of 6.5 km from the start of roll
B : Lateral point, which signifies the point on a line parallel to and 450 m from the runway center line, where the noise level is at its maximum during take-off
C : Approach point, which signifies the point on the extended center line of the runway 2.0 km from the threshold

Fig. 1 Noise measurement locations (three points) for ICAO Annex 16, Volume I, Chapter 3 regulation follows: 1) The cumulative noise margin at the three points is more than 10 EPNdB (Effective Perceived Noise in decibels), 2) The sum of the noise margins at not less than two points is more than 2 EPNdB. For example, if the noise margins at the flyover point, lateral point, and approach point corresponding to the regulated noise levels under Chapter 3 are 5, 4, and 3 EPNdB respectively, the cumulative margin comes to 12 EPNdB, which satisfies Chapter 4. EPNdB is the unit of sound used for aircraft noise certification, where adjustments are made in accordance with the way a sound is heard by the human ear and the length of time a disturbing sound is heard while an aircraft is flying overhead.

Since the requirements for an aircraft to be considered environmentally friendly in terms of the noise it generates are becoming tougher, it is vital to incorporate noise reduction technology into the development of next-generation aircraft so as to have ample margins against Chapter 4 regulated noise levels.

2. Objective of research and development

The objective of the research and development of the environmentally compatible engine (hereinafter called the ECO engine) for small aircraft is to increase the cumulative noise margin at the three points with regard to Chapter 4 regulated noise levels to 20 EPNdB for aircraft with ECO engines.

Figure 2 indicates the target noise level of the ECO engine project against the ICAO regulated noise levels and cumulative noise levels of civil aircraft together with the Chapter 4 regulated noise levels. The x-axis represents the maximum take-off weight, while the y-axis represents the cumulative noise levels at the three points targeted by Chapter 3 regulation. Aircraft with nearly the same take-off weight (CRJ-200, ERJ145, ERJ135) are currently in service with a cumulative noise margin of approximately 12 to 18 EPNdB against Chapter 4 as shown in **Fig. 2**. The quietest of the three aircraft is the CRJ-200, which retains a cumulative noise margin of 17.8 EPNdB against Chapter 4. The CRJ-200 is equipped with a CF34-3B1 engine.

The present research is, while keeping in mind lower weight and costs, intended to develop technology to realize the target noise margin of 20 EPNdB against Chapter 4 through efforts to further reduce noise by more than 2.2 EPNdB, with the technology of the CF34-3B1 engine as the starting point. Since the major noise sources for the ECO engine are the fan and jet noise, efforts to lower these noises will certainly lead to a reduction in noise levels overall.

Thus, the present research set out to develop a technology to reduce fan and jet noise. The necessary noise reduction was set at 3 EPNdB for the fan noise and 2 EPNdB for the jet noise in order to realize a noise reduction of at least 2.2 EPNdB for the ECO engine.

3. Fan noise reduction technology

Fig. 3 illustrates the requirements and technological issues involved in realizing both the structuring of the fan (to reduce cost and weight) and noise reduction. Typically, the fan of an engine is made up of a rotor blade, outlet guide vanes, and a frame strut. For the ECO engine, however, a structure where the outlet guide vanes and frame strut are incorporated (hereinafter called the integrated OGV) is adopted; subsequently, it is desirable to shorten the spacing between the rotor blade and the integrated OGV axes as well as to cut down on the number of parts. It is also desirable to do so from an aerodynamic point of view.

However, it is considered appropriate to add to the number of integrated OGVs and to widen the

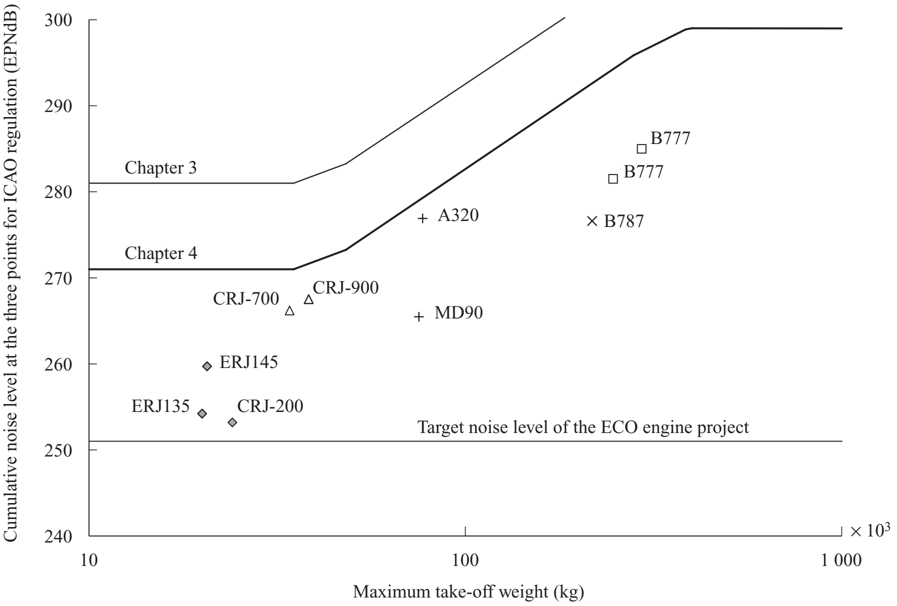


Fig. 2 Target of research and development and cumulative noise level under ICAO Annex 16, Volume I, Chapter 3 regulation

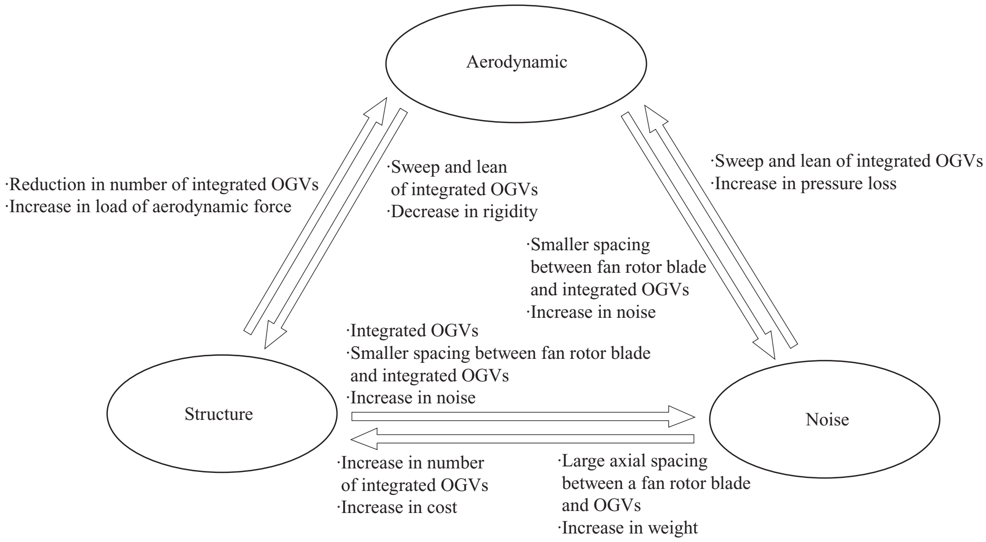


Fig. 3 Requirements and technical issues to achieve low noise maintaining low cost and low weight

in-between-axes spacing in order to reduce noise, so giving priority to the requirements from an aerodynamic and structural point of view will result in an increase in noise level. For this reason, it is critical to redesign the fan rotor blade and integrated OGVs so that the reduction in noise can be realized. In the case of integrated OGVs, the application of the sweep-lean design, where they are inclined in the direction of the circumference (lean) and radius (sweep), is one option. However, this option might result in an inability to maintain its rigidity as a reinforcing material, accompanied by a functionally increased loss. Hence, the development of an integration technology to contribute to the realization of the objective of fan noise reduction was carried out with a trade-off between the requirements for the structure and for noise reduction.

Figure 4 indicates a fan noise test rig (with the duct at the fan entrance having been removed). The scale model test was conducted with the use of the present fan noise test rig at the anechoic fan noise test facility of the IHI Mizuho plant in order to verify the noise reduction effect due to differences in, among other things, the following: 1) the geometry of fan rotor blade, 2) the number of integrated outlet guide vanes, 3) the axial spacing between fan rotor blade and integrated outlet guide vanes, and 4) the sweep and lean of integrated OGV.

Fig. 4 Fan noise test rig

First, the reduction in noise from the fan rotor blade is explained below. The fan rotor blade shown in **Fig. 4**, known as a swept rotor blade, was designed through the utilization of CFD (Computational Fluid Dynamics) so that both a high aerodynamic performance and lower noise could be demonstrated. A base rotor blade (the shape adopted for the CF34-3B1, taken as standard here, and others) was also designed for the purpose of comparison. **Figure 5** shows a comparison between the shock wave (mach distribution) in the vicinity of the leading edge of the swept rotor blade and the base rotor blade. The swept rotor blade (shown in **Fig. 5-(a)**) retains such a contour that its frontal portion is slanted as compared to the base rotor blade (**Fig. 5-(b)**), thereby enabling the bow shock generated around the leading edge of the rotor blade to weaken as shown in **Fig. 5-(a)**. Thus, it could be expected that fan noise would be reduced in the high rpm zone.

A noise element known as a "buzz saw noise," which is attributed to the bow shock generated at the leading edge of a rotor blade, is dominant in the high rpm zone

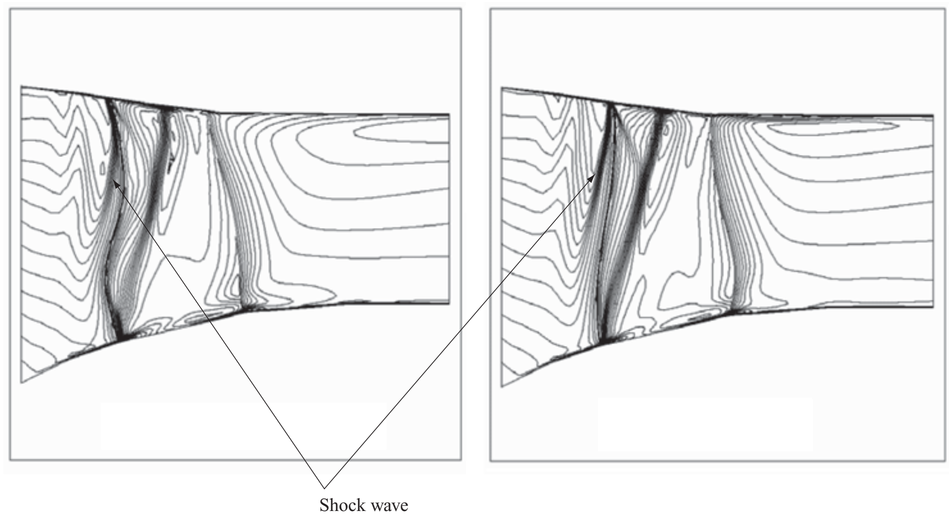


Fig. 5 Comparison of bow shock at rotor leading edge between swept rotor blade and base rotor blade (Mach contour)

(with the fan operating zone at lateral point (B) shown in **Fig. 1**). In short, it is possible to reduce the buzz saw noise by weakening this shock wave. The model test in which a swept rotor blade and base rotor blade are used for the fan noise test rig was conducted in order to verify the noise reduction effect of the swept rotor blade. **Figure 6** gives a comparison between fan noises generated by a swept rotor blade and a base rotor blade. The x-axis represents the operating speed of the fan rotor blade, while the y-axis represents the fan noise level. An evaluation based on the results made it possible to verify that the swept rotor blade contributes to a noise reduction of 1.3 EPNdB.

Figure 7 illustrates the results of the cumulative noise evaluation taking into consideration the noise reduction effect resulting from the integrated OGV as well, as compared to the fan noise reduction target. The x-axis represents the ratio of spacing between the trailing edge of the rotor blade and the leading edge of the integrated OGV to the length of the rotor blade axial cord, while the y-axis represents the cumulative noise level reflecting the noise reduction effect and its breakdown in EPNdB. A reduction in noise of 2.5 EPNdB owing to the integrated OGV is the sum of the noise reduction effects at the approach and flyover points shown in **Fig. 1**, while the noise reduction owing to the swept rotor blade is the effect at the lateral point shown in **Fig. 1**. The breakdown of 2.5 EPNdB is as follows : 1.3 EPNdB resulting from the sweep and lean integrated OGV and 1.2 EPNdB resulting from the normalization of spacing between the rotor blade and the guide vane. A total reduction in noise of 3.8 EPNdB at the three points was achieved within the range of structural requirements.

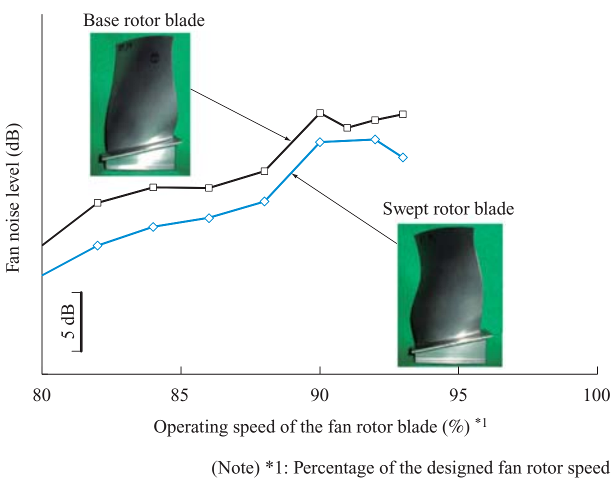


Fig. 6 Comparison of fan noise between swept rotor blade and base rotor blade

4. Jet noise reduction technology

The method considered effective in reducing jet noise is as follows: high-temperature, high-pressure gas from the turbine and compressed air are mixed inside the exhaust nozzle with a mixture promotion device provided upstream flow conditions of exhaust nozzle for engine. However, since the structure becomes complicated, it is difficult to realize a reduction in both cost and weight.

Although a chevron nozzle has begun to be used in commercial flights recently, in order to promote jet mixture by making the contour of the exit portion of the exhaust nozzle saw-edged, the issue of the reduction in thrust during flight has yet to be addressed. The present research contributed to the development of technology to reduce jet noise without thrust being adversely affected by further simplifying the contour of the exit portion of the exhaust nozzle as opposed to a chevron nozzle.

Figure 8-(a) shows a jet noise test rig, while **Fig. 8-(b)**, **-(c)**, and **-(d)** show the contours of a notched

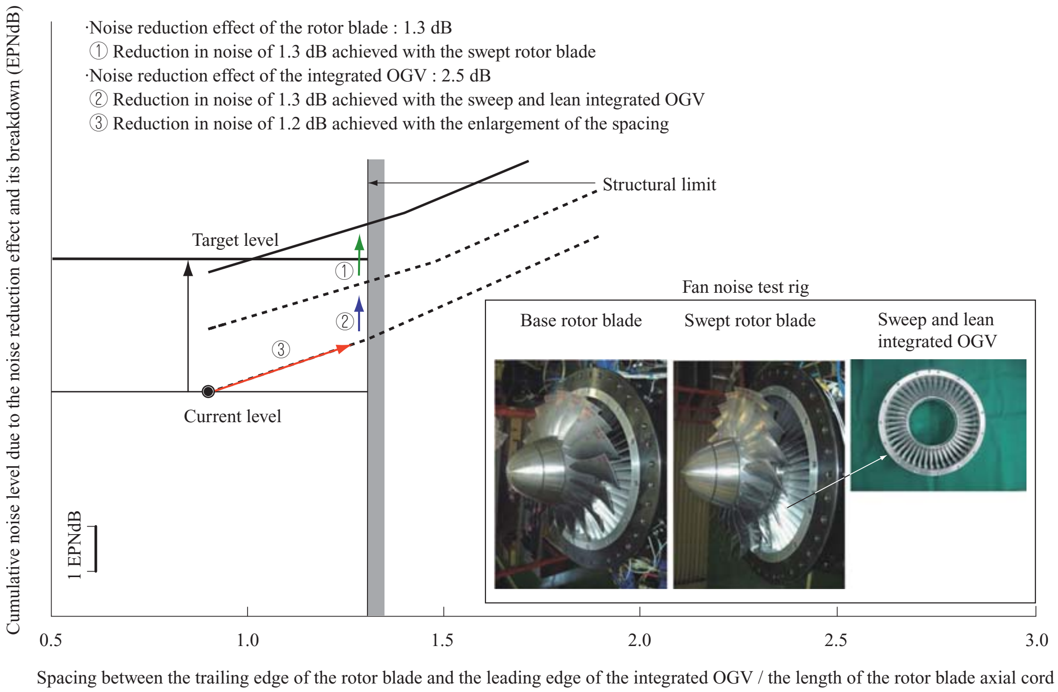


Fig. 7 Evaluation toward the fan noise reduction target

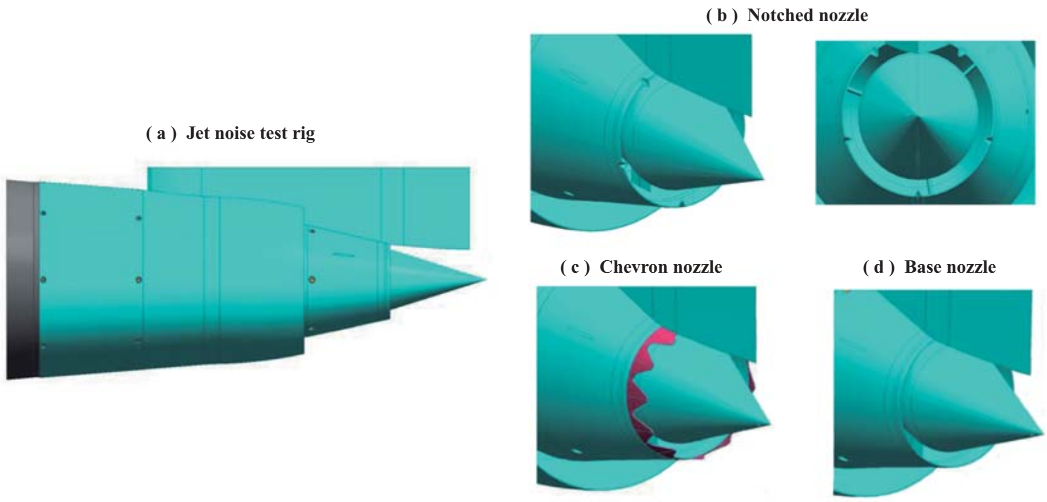


Fig. 8 Jet noise test rig with notched nozzle, chevron nozzle and base nozzle

nozzle originally designed for noise reduction, a chevron nozzle and a base nozzle for comparison. For a notched nozzle, triangle-shaped small-size mixers are positioned at five locations in a circumferential direction. The chevron nozzle has 12 triangular cuts in a circumferential direction. As a result of CFD analysis of a mixture promotion effect for exhaust jet resulting from these nozzles, it was learned that a notched nozzle contributes to almost the same mixture promotion as a chevron nozzle despite being extremely small and simple. Thrust went down with a chevron nozzle, whereas it remained the same with a notched nozzle. Furthermore, the CFD analysis mentioned above was performed in conjunction with the JAXA (Japan Aerospace Exploration Agency) and IHI (ECO engine project); details are provided in the references (1).

Following this, the model test was conducted at the anechoic wind tunnel, which is a jet noise test facility (Noise Test Facility of QinetiQ: hereinafter called NTF [(2)]), shown in **Fig. 9**. Since jet noise is affected by flight, it is necessary to conduct a noise test in a wind tunnel where flight speed during take-off and landing can be simulated. Flight speed can be simulated at 70 to 80 m/s with the jet noise test rig on a scale of approximately 1:5 with simulated core and bypass nozzles of a small-size engine set up inside a wind

Fig. 9 Anechoic wind tunnel noise test facility at QinetiQ

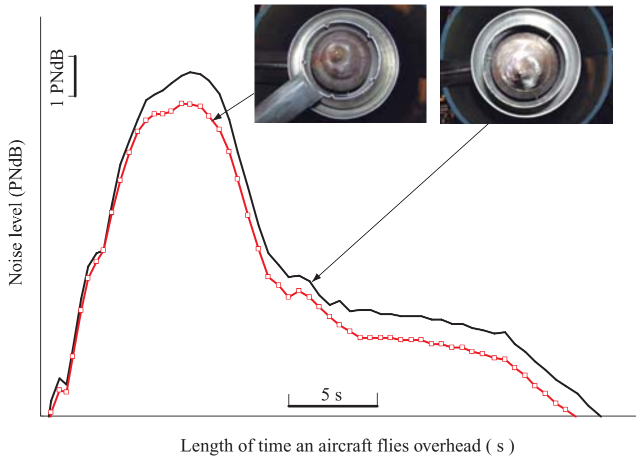


Fig. 11 Comparison of sideline noise during take-off between notched nozzle and base nozzle

tunnel of 1.8-meter diameter at the NTF. The upstream temperature of an exhaust nozzle and the pressure of the ECO engine can also be simulated. **Figure 10** is a picture taken from behind the nozzle of a jet noise test rig with a notched nozzle installed.

Jet noises were measured through a microphone attached to the circumference of a circle with a radius of 12 meters from the center of each nozzle. Then, the measured jet noises were evaluated against Chapter 4 regulated noise levels pursuant to the ICAO provision. **Figure 11** indicates a comparison between the characteristics of noises from notched and base nozzles at a lateral point. The x-axis represents the length of time an aircraft flies overhead (in seconds), while the y-axis represents the noise level (PNdB: Perceived Noise in decibels). **Figure 12** illustrates the evaluation results in EPNdB of noise reduction effects achieved with notched and chevron nozzles based on **Fig. 11**.

The noise reduction effects for a notched nozzle were 1.2 and 1 EPNdB at the lateral point and the take-

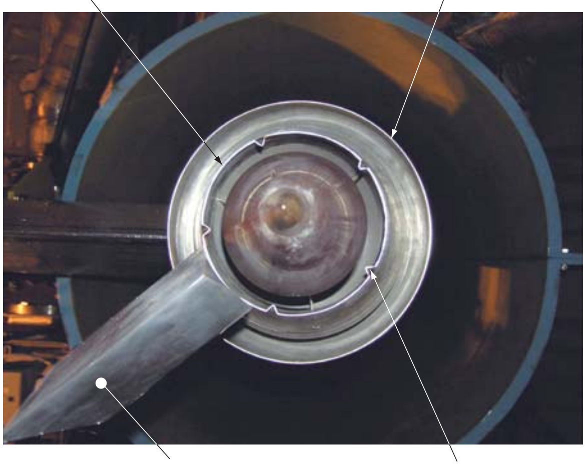


Fig. 10 Notched nozzle installed in the jet noise test rig

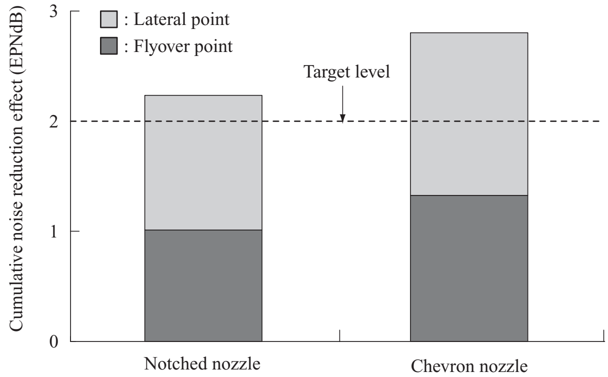


Fig. 12 Noise reduction of notched nozzle and chevron nozzle

off point respectively, making a total of 2.2 EPNdB during take-off. Thus, it was verified that the targeted noise reduction level of 2 EPNdB was attained. The jet noise reduction effect during landing was not taken into account because it had no influence on overall engine noise. As seen in **Fig. 12**, the cumulative noise reduction effect arising from the use of a chevron nozzle was 2.8 EPNdB during take-off. It turned out that a notched nozzle was not as effective as a chevron nozzle in terms of noise reduction. However, it could be predicted through CFD analysis that a notched nozzle is superior to a chevron nozzle in terms of thrust capability; the present research verified the effectiveness of a notched nozzle.

5. Conclusion

We have executed the development of noise reduction technology for the ECO engine. We have realized reductions in cost and weight for such engines by cutting down on the number of parts, which was achieved by minimizing the number of vanes through the adoption of an integrated OGV, and by minimizing the spacing between the rotor blade and the integrated OGV. At the same time, we have developed technology to reduce fan noise without a decline in efficiency, while allowing for interference between the swept rotor blade and the integrated OGV. To achieve a reduction in jet noise, we have developed a notched nozzle as a new concept to reduce noise without a decline in thrust.

As a result of the tests, we have reached the targeted noise reduction levels at the three test points, providing us with a chance to achieve the noise level of 20 EPNdB from Chapter 4 for ECO engines.

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REFERENCES

(1) Y. Oba et al.: Low Noise Research and Development In Japanese Environmentally Compatible Engine for Small Aircraft Project, ISABE2007-1123 (2007.9)

(2) R. A. Pinker : The Enhancement of the QinetiQ Noise Test Facility for Larger-scale Exhaust Systems, AIAA2004-3019 (2004.5)