

Development of Composite Fan System

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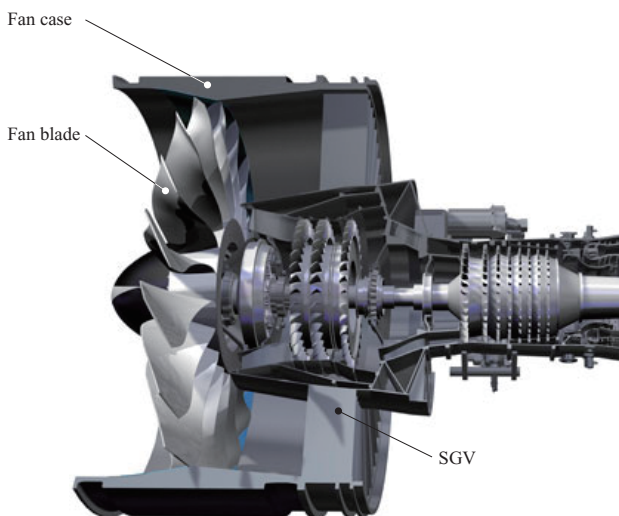
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The Composite Fan System R&D Project was created to develop composite structural parts for the fans used in next-generation commercial aero-engines. The technology developed for the composite fan case and composite structural guide vane has been completed and demonstrated. These two parts will be applied to the PW1100G-JM, which powers the Airbus A320neo. This paper gives an outline of the development of the composite fan case and composite SGV.

1. Introduction

In recent years, the demand for higher efficiency in aircraft engines has been increasing in intensity, and newly developed engines have been designed to have a higher bypass ratio, which makes the diameters of engine fans larger than those of their conventional counterparts. This further increases the weight of fan parts, which intrinsically accounts for a large proportion of engine weight, and therefore there is high demand for lighter weight fans.

We have been researching and developing a composite fan system since 2007. The purpose of the R&D is to apply composite materials to ① fan cases, ② Structural Guide Vanes (SGV), and ③ fan blades, which are typical structural parts that increase in size along with an increase in bypass ratio, and thereby achieve a reduction in weight. **Figure 1** illustrates the composite fan parts.



(Photo credit : Pratt & Whitney)

Fig. 1 Composite fan parts

In this paper, of these three parts, we will introduce an outline of the development of the fan case and SGV, which have been adopted for the PW1100G-JM engine mounted on the Airbus A320neo.

2. Outline of research and development

The greatest challenge in applying a composite material to structural parts of an aircraft fan is obtaining sufficient impact resistance. Generally, composites have low impact resistance; however, since a fan blade or SGV is expected to encounter bird strikes during flight, the material used for these parts is required to have impact strength high enough to maintain the soundness of the structural parts even after a bird strike. Meanwhile, a fan case requires containment capability such that even if a fan blade breaks off (Fan Blade Off: FBO), it prevents the fan blade from breaking through the fan case. Therefore, the material used for the fan case is required to have high energy absorption performance and non-penetrability against high velocity impact. Such characteristics are similar to bullet-proofing.

This R&D has been conducted on the basis of a building block approach. **Figure 2** illustrates the building block

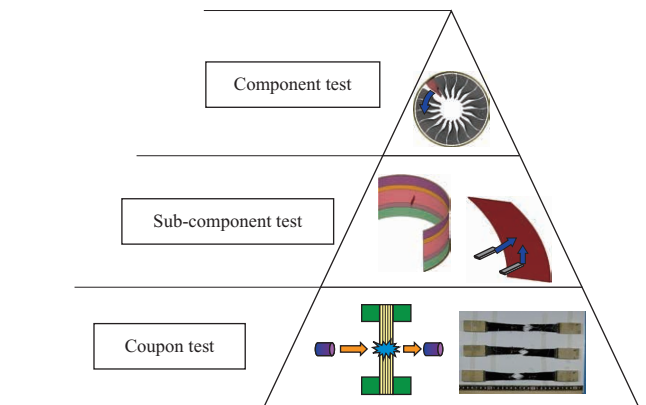


Fig. 2 Building block

approach for the fan case. For the coupon test, a high speed impact test was conducted on a flat plate to select a material; for the sub-component test, a high velocity impact test was conducted on a curved panel and also on a half ring that were cut out of an actual size ring; and for the component test, an FBO test was conducted such that a rotating fan blade was cut off to cause it to fly outward and strike against the inner wall of an actual scale fan case.

The coupon test was also conducted on the fan blade and SGV to select a material and a molding method, and the sub-component and component tests were conducted for verification of the parts and the material.

3. Fan case development

3.1 Coupon test (Flat plate impact test)

In order to select a high-energy absorbing material suitable for the fan case, high speed impact tests were conducted on relatively small, flat test plates as test pieces. Three types of material systems were chosen as candidate materials by reinforcement system and molding method. The three types of material systems include ① combinations of a 3D preform and RTM (Resin Transfer Molding) (3D-RTM), ② autoclave molding of tough matrix prepreg (tough matrix prepreg materials), and ③ combinations of a modified epoxy matrix and Filament Winding (FW). Among these, the epoxy matrix used in FW was modified in the course of this development. The high speed impact test was conducted such that a projectile (steel cylinder) was shot from an air gun toward the center of each of the test pieces with the outer circumference of the test piece fixed in place. Evaluation was made on the basis of absorbed energy calculated from the speeds before and after the projectile penetrated through the test piece. **Figure 3** illustrates the test piece impact test.

Figure 4 illustrates the test results of the energies absorbed by the three types of materials. The dashed line represents the result obtained from a titanium alloy test piece of equivalent weight. As shown in **Fig. 4**, energies absorbed by the 3D-RTMs and the tough matrix prepreg materials are less than or equal to that of the titanium alloy; however, the absorbed energies of D2 and D3 among the three types of FW modified epoxy matrices are higher than those of the titanium alloy, especially D2 which is at least 1.5 times that of the titanium alloy. Whereas all the other test pieces are only deformed in a small area around impact spot, D2 deformed with a larger area bulging out, and the difference

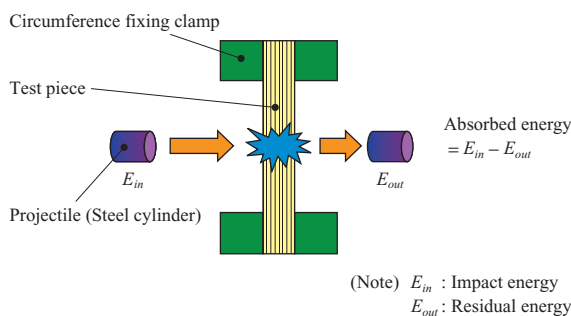


Fig. 3 Coupon impact test

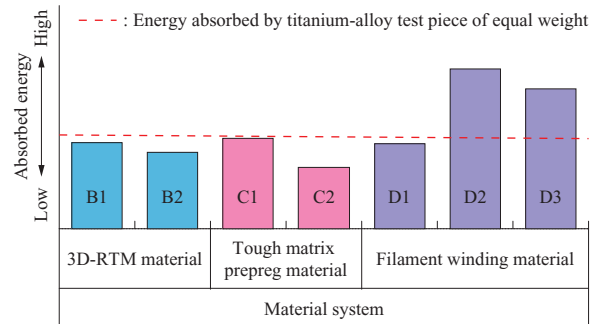


Fig. 4 Coupon impact test, screening result

is considered to explain the difference in absorbed energy.

From the results of the series of coupon tests, FW using the D2 modified epoxy matrix was selected as the fan case material including a molding method, and this material system was used to conduct the sub-component and component tests at the upper stages of the building block.

3.2 Sub-component test

(1) Curved panel impact test

The first stage sub-component test is a curved panel impact test. In this test, a 1/8 ring was cut out of an actual size ring as a test piece, and a titanium alloy flat plate was shot with an air gun into the test piece.

In FBO, the behavior exhibited by a broken fan blade colliding with a fan case is very complicated, unlike a head-on collision as in the flat plate test. It collides with the inner surface of the fan case with a certain orientation, and the inclination determines the collision angle. This is the first collision. If the broken fan blade does not penetrate through the fan case, the fan blade rolls and then collides with the inner surface with its engine shaft (hub) end. This is called the second collision. The sub-component test for evaluating such behavior and damage to the fan case is the curved panel impact test. **Figure 5** schematically illustrates the curved panel impact test. We also conducted impact analysis regarding the behavior of the projectile and the damage to the panel, and verified that the behavior and damage were analytically estimable. **Figure 6** illustrates an example of the curved panel impact test and analysis result.

(2) Half ring impact test

In the curved panel impact test, the weight of the projectile is a few dozen grams, which is significantly lighter than the weight of an actual fan blade. Therefore, in order to evaluate the containment performance using a projectile with a weight equivalent to that of an actual fan blade, the high velocity impact test was conducted using half of a ring that is same shape as that of the engine. This is called a half ring impact test (**Fig. 7**). **Figure 7** illustrates a schematic view of the half ring impact test and the moment when the projectile collides with the half ring. In this test, the projectile was shot parallel to the shot direction and it collided perpendicular to the inner surface of the test piece.

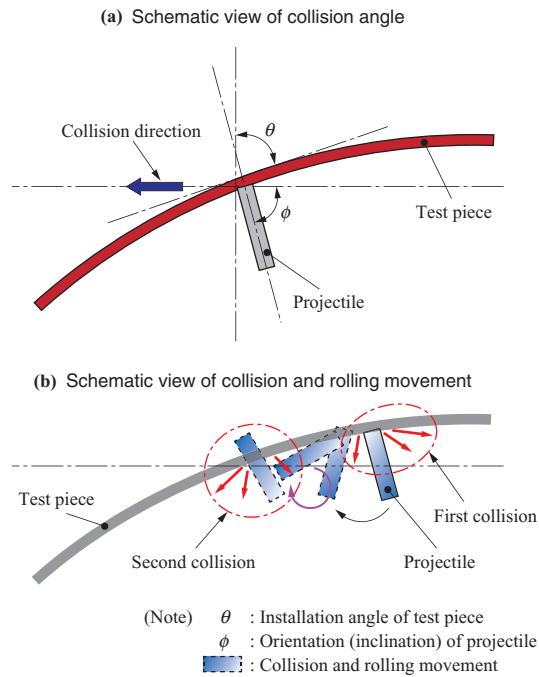


Fig. 5 Schematic of curved panel impact test

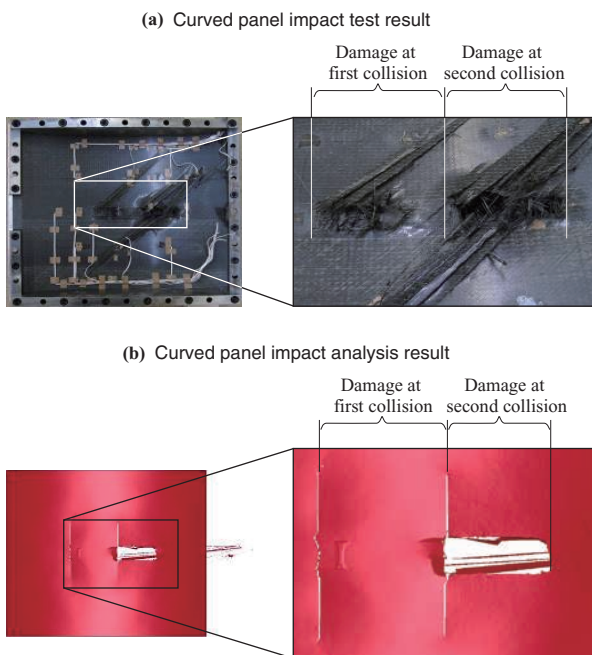


Fig. 6 Damage mode correlation between test and analysis

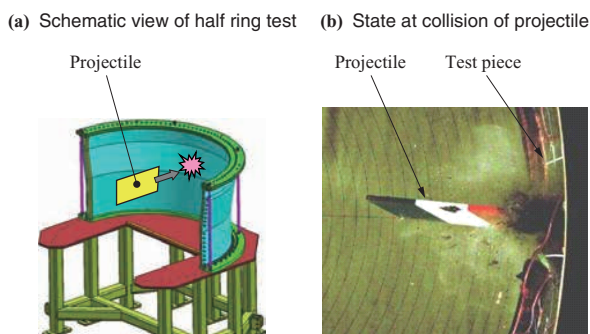


Fig. 7 Half ring impact test

The scale effect of the containment performance in the high velocity impact test was evaluated by combining the results of the flat plate impact test, curved panel impact test, and half ring impact test.

3.3 Component test (FBO test)

The FBO test was conducted as the final stage of the building block. This test was conducted such that titanium alloy fan blades were fit into an actual size fan case, which was designed on the basis of the results of previous tests, in the same way as in an actual airplane, then one of the rotating fan blades was released using gunpowder at its dovetail end (the part for fixing the airfoil to the hub), and then whether the fan case could contain the released fan blade was verified. **Figure 8** illustrates the FBO test, in which a state immediately after the fan blade was released is illustrated. As a result of the FBO test, although the fan case was damaged, the fan blade was contained, and therefore the validity of the design has been verified.

4. Development of composite SGV

4.1 Coupon test (Gelatin impact test)

In order to develop a high impact resistant material suitable for the fan blade and SGV, a gelatin high speed impact test on a flat plate was conducted. The test was conducted such that a gelatin ball, which simulated a bird, was shot with an air gun into the center of the flat plate, which simulated the vane. The impact causes wavelike deformations on the edges of the flat plate of the composite material, and as a damage mode, delamination occurs in the material. Evaluation of the material was made on the basis of delamination area with respect to gelatin impact energy.

Figure 9 illustrates the gelatin impact test and results. As a result of repeatedly improving the fiber-matrix interface with the use of a tough epoxy composite proven to be an impact-resistant composite (composite E) and a thermoplastic composite (composite F) as benchmarks, we were able to develop a thermoplastic composite (composite C) that suffers less delamination damage.

From the results of this test, we selected composite C as the material and press molding as the molding method for



Fig. 8 Containment rig test

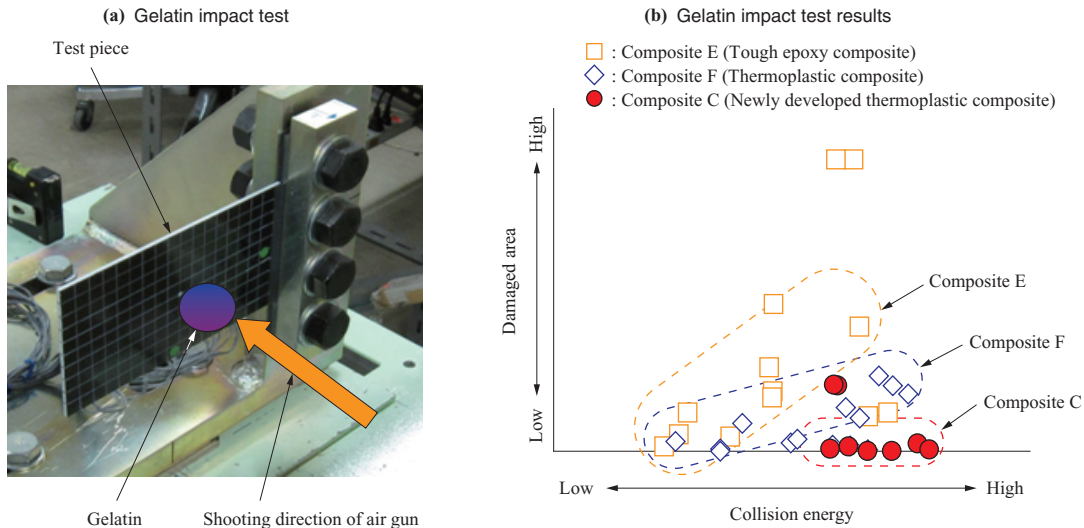


Fig. 9 Gelatin impact test and results

the fan blade and SGV. Using this material system, the sub-component and component tests at the upper stages of the building block were conducted.

4.2 SGV sub-component test (Single vane test)

Figure 10 illustrates the SGV sub-component test.

(1) SGV single vane strength test

An SGV single vane test was conducted using an actual size SGV that employed a wedge bonding configuration selected in the coupon test as a test piece, and with one end of the SGV fixed, a load equivalent to that experienced at the time of engine operation applied to the other end. The results of the test confirmed the soundness of the SGV in both a cyclic load condition at the time of normal operation and a maximum load condition applied to the SGV at the time of FBO.

(2) Gelatin impact test

A gelatin impact test simulating the collision of a bird weighing 2.5 lbs. was conducted using an actual size SGV as a test piece. Since an actual bird collides with the fan blades before colliding with an SGV, the

state of the bird after the collision with the fan blades was estimated by analysis, and gelatin having the estimated weight and shape was used. No damage was found in the SGV after both the appearance test and nondestructive inspection. Thus the impact resistance of the SGV was confirmed.

4.3 SGV component test (SGV full-ring test)

A full-ring test was conducted such that a full set of 48 actual size SGVs corresponding to one engine was attached to a jig simulating a fan case and a fan frame, and an actuator was used to apply the load at the time of engine operation. Figure 11 illustrates the SGV full-ring test. The test was conducted under two different conditions, i.e., the maximum load condition applied to SGV at the time of FBO (FBO test), and a cyclic load condition based on vibration occurring during the period after FBO until arrival at an airport (Fly Home test: 200 000 cycles). In both conditions, the SGVs maintained rigidity until completion of the test. Thus the soundness of the SGVs was verified.

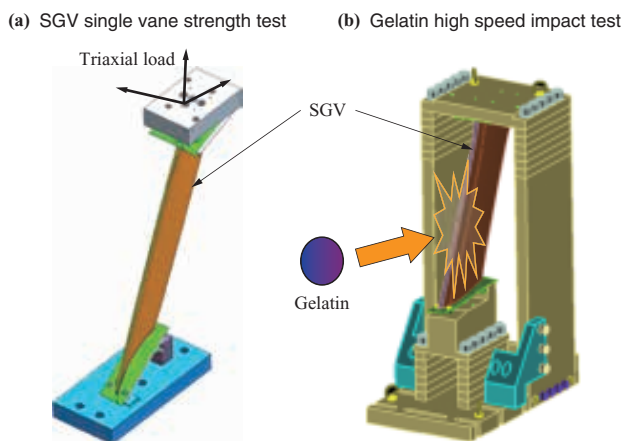


Fig. 10 SGV sub-component test

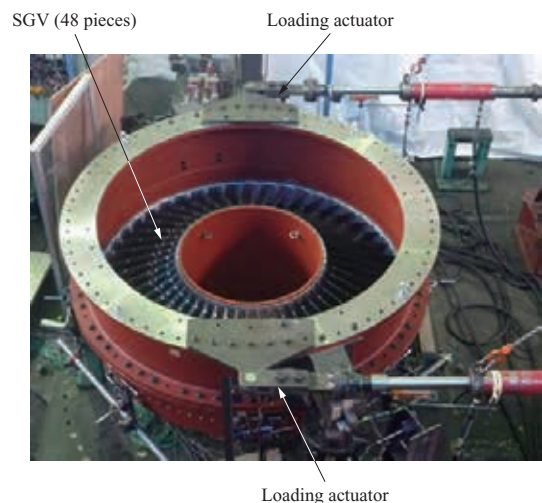


Fig. 11 SGV full ring test



(Photo credit : Pratt & Whitney)

Fig. 12 PW1100G-JM and composite fan case

5. Adoption for PW1100G-JM

The composite fan case and composite SGV developed in this R&D were adopted for the PW1100G-JM, and an engine test was underway as of August 2013. **Figure 12** illustrates the PW1100G-JM and the composite fan case, and **Fig. 13** illustrates an external view of the composite SGV for the PW1100G-JM.

6. Conclusion

Technologies of the composite fan case and composite SGV have been developed, demonstrated, and adopted for application to the PW1100G-JM, a next-generation civil aircraft engine. A practical use lighter weight fan, which is essential for realizing a high-efficiency high-bypass fan,



Fig. 13 PW1100G-JM composite SGV

fulfills the main need of customer airlines, i.e., a reduction in operational cost. The lighter weight fan is also expected to be widely adopted engines that will be developed in the future. Furthermore, we are going on to develop the composite fan blades toward their application to an actual aircraft, and we are also working to further reduce the fan case and SVG in weight.

— Acknowledgements —

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