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COMMERCIAL AIRCRAFT COMPOSITE THRUST REVERSER BLOCKER DOOR MANUFACTURED USING THE RESIN TRANSFER MOLDING TECHNIQUE

Kurt R. Kraft
Boeing Commercial Airplane Group
Seattle, Washington

Abstract

This paper presents an account of the first use of a nacelle resin transfer molded (RTM) graphic composite part by the Boeing Commercial Airplane Group. The Propulsion Systems Division of the Boeing Commercial Airplane Group is working with an outside vendor to develop and apply the RTM process to manufacture an acoustically-treated carbon fiber thrust reverser blocker door. An overall view of an engine nacelle thrust reverser is provided as well as an explanation of the function of the blocker door. Previous methods of block door construction and overall design conditions are summarized; advantages and disadvantages of the RTM process explained; and the new RTM composite blocker door design is reviewed. The paper concludes with a summary of point design allowable generated for design use and the overall status of today's blocker door program.

Introduction

A modern turbine-powered commercial aircraft engine nacelle is a complex, multifunction structure that surrounds the engine. The nacelle's functions are to act as a simple aerodynamic fairing in minimizing drag effects of airflow around the engine; to enhance overall engine efficiency by providing proper inlet and exhaust airflows, which in turn relates to the performance of the aircraft; and to help control the engine noise footprint in the vicinity of airports. As with all aircraft design, an efficient structure at the minimum weight is also a prime requirement. A general view of a typical nacelle is shown in Figure 1.

The thrust reverser is a portion of the nacelle that performs the additional task of reversing the engine thrust during the landing role of the aircraft. The thrust reverser works by redirecting the engine airflow (thrust) from the normal aft direction to the forward direction, thereby applying a significant contribution to the slowing of the aircraft.

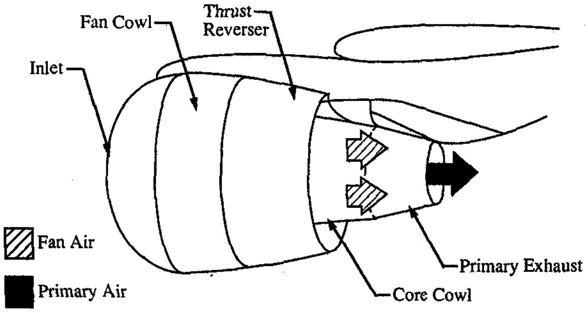


Fig. 1 General view of a typical nacelle.

The 767 and 747 aircraft installed with the Pratt & Whitney PW4000 engine use a fan thrust reverser configuration known as a translating sleeve-cascade type. In this configuration during reverse thrust, only the fan flow is redirected forward. Fan flow reversing is accomplished by a series of fixed turning vanes, known as cascades, that are exposed when a translating sleeve slides aft. Attached to the translating sleeve on the fan duct wall are a series of blocker doors which are pulled down via a drag link. This action blocks the fan duct and forces the fan flow through the cascades. A general view of this thrust reverser both in forward and reverse modes is shown in Figures 2 and 3.

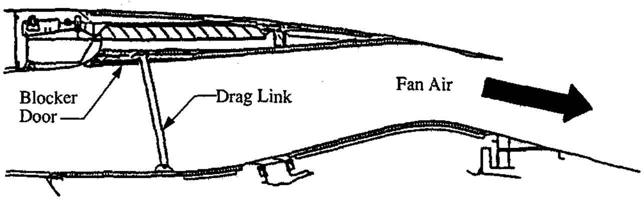


Fig. 2 Thrust reverser stowed.

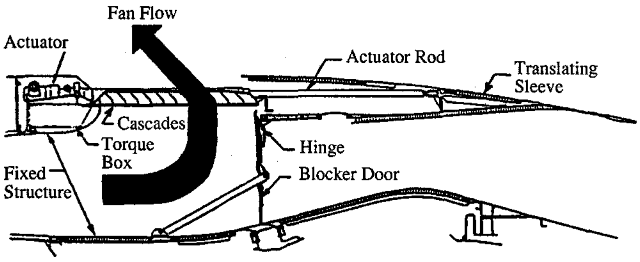


Fig. 3 Thrust reverser deployed.

Blocker Doors

Any new or replacement blocker doors must meet all of the geometric constraints of the existing PW4000 thrust reverser blocker doors. The blocker door hinge points, drag links attach points, and kinematics of motion must remain the same in order to be incorporated into the production installations. In addition to these constraints, there are several design improvements in the existing hinges and link attachments that were the result of extensive development work that must be included in any new composite replacement blocker door.

The thrust reverser on the 767 and 747 with the PW4000 engine was derived from the 767 Pratt & Whitney JT9D-7R4 engine thrust reverser. The engine power levels in reverse thrust on the PW4000 engine are limited to a corrected fan speed (N_{1C}) of 89%, so as to match the reverse thrust levels of the JT9D-7R4 engine. Table 1 shows the approximate ultimate loads (in pounds) and load points that are applied to both blocker door designs.

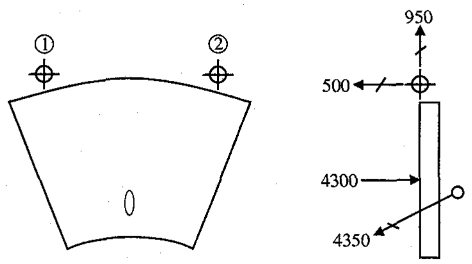


Table 1 Blocker door loads and reactions.

The blocker doors have a fatigue durability requirement at the typical reverse thrust load levels. In order to meet the fatigue requirement with 95% confidence of 95% reliability of survival, the blocker doors need to be designed for 200,000 load cycles at 1.6 times the typical reverse thrust load as shown in Table 2.

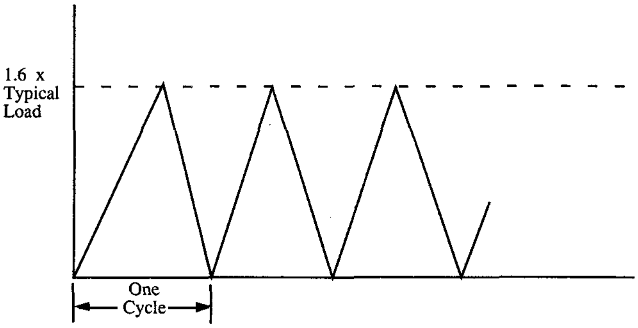
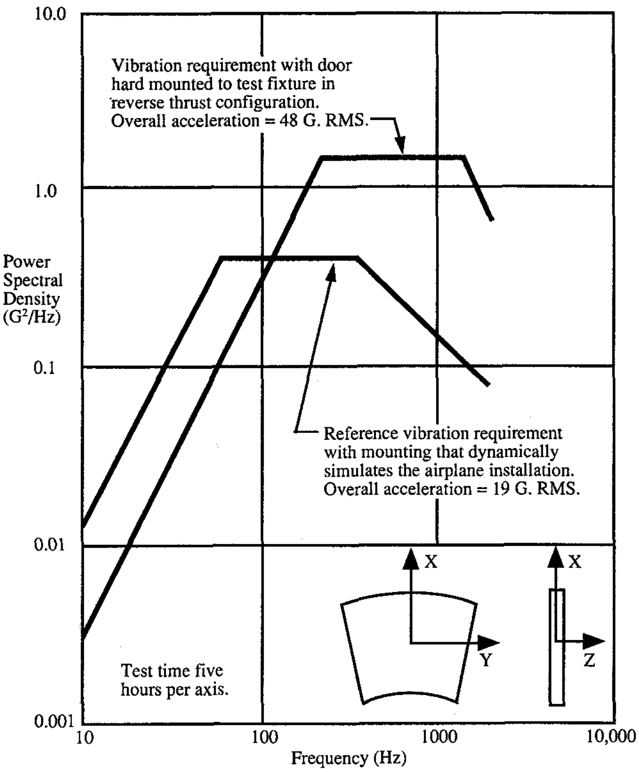


Table 2 Load cycles.

During the flight envelope, the blocker doors are subjected to severe random vibration from both sonic effects and gas turbulence effects. To meet the flight sonic durability requirement, the blocker doors must be able to endure, without failure, the vibration spectrum shown in Table 3 along the X, Y, and Z axis for 5 hours each. The vibration spectrum combines the effects of both sonic and gas turbulence effects.



Vibration requirement with door hard mounted to test fixture in reverse thrust configuration. Overall acceleration = 48 G. RMS.

Reference vibration requirement with mounting that dynamically simulates the airplane installation. Overall acceleration = 19 G. RMS.

Test time five hours per axis.

Table 3. Vibration test requirements.

The temperature profile of a PW4000 blocker door generally ranges from -65°F to 280°F. In addition, they must endure exposures to almost all aircraft/ engine fluids such as jet fuels, skydrol, engine oil, water, ethylene glycol, and salt spray without any significant degradation in performance. The blocker door also forms a portion of the nacelle acoustic treatment and any new design must match the acoustic impedance and reactance of the existing design so as not to impact the certified community noise levels.

To meet all of the engineering requirements, the original 767 JT9D-7R4 blocker doors were designed using traditional forms of aluminum aircraft acoustic structures, i.e., bonded aluminum sandwich construction. The doors are made by first adding a buried plastic septum to the aluminum honeycomb core. The honeycomb core is then shaped and formed to the proper contour, and dense core is added at hinge and drag link fitting locations. At this point, a formed and perforated aluminum face skin along with a solid aluminum backskin is adhesively bonded to the honeycomb core assembly. After bonding, the door is trimmed and edge potting is added along all exposed door edges. The blocker door assembly is finished with the addition of the hinge fittings and drag link fittings. The basic existing door structure is shown in Figure 4.

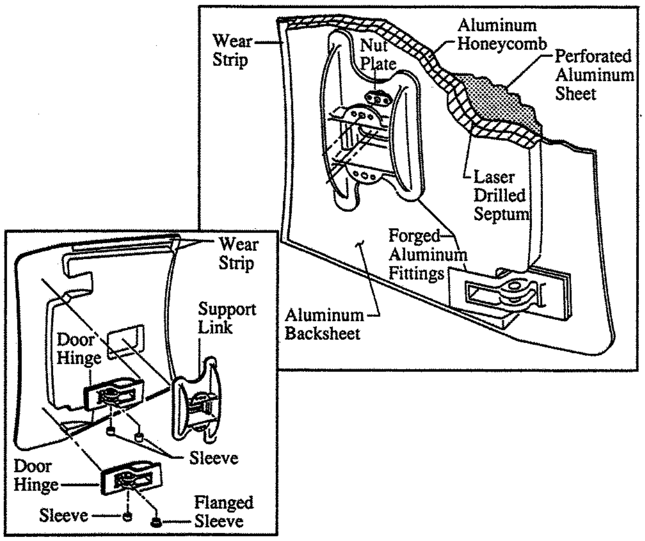


Fig. 4 Existing door configuration.

Although the existing blocker doors have now had satisfactory inservice experience for over 10 years, an effort was begun in 1988 to improve both the weight and cost of the blocker doors by replacing the existing aluminum doors with doors made from newer technology materials and processes. Inputs were solicited from several vendors for replacement design concepts. The concept that best matched the overall goals of the blocker door program utilized a carbon fiber/epoxy system manufactured using the resin transfer molding technique.

RTM Process

In the RTM process, a relatively fluid resin is injected into a closed die containing a porous fiber preform in the shape of the intended component. In some cases, a vacuum assist is used to help purge the mold of air and help draw the resin through the mold. The process is as shown in Figure 5. For most engineering applications, the resin and catalyst are usually heated individually and mixed before injection, since a catalyzed resin would have a short pot life. This is normally accomplished using a static mixer located near the injection nozzle. After injection, excess resin in the mixer is purged with a solvent. The resultant parts are mold-controlled on all surfaces. Since the RTM process requires a closed-mold tool, it does not involve bagging labor or bagging material waste and, in addition, ribs, bosses, inserts and cores can be molded in place. The RTM process allows the use of continuous fiber layups with high fiber volume values (V_f). Because of this, RTM is applicable to high-performance components. The high V_f values are achieved by the use of fabrics and tapes that contain a small percentage (about 4%) of a thermoplastic agent or binder that is softened by using heat or a solvent. By laminating the material, activating the thermoplastic binder and compressing the laminate, a rigid fiber preform (with up to 70% V_f) is obtained having an appropriate size and shape. The fiber preforms are necessary for complex shaped parts because they are mechanically rigid and can be handled, which significantly reduces tool loading times; are easily shaped to the dimensions of final part; have repeatable fiber volumes that can be as high as 70%; have fiber alignments that are accurate; and contain adequate porosity for easy resin flow during the injection process.

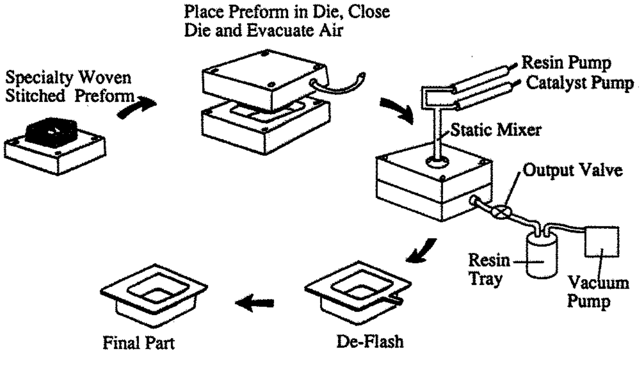


Fig. 5 Fabrication sequence.

Composite Door Design

An exploded view of the new composite blocker door design is shown in Figure 6. It consists of three major sub-assemblies – the honeycomb core assembly, the facesheet assembly, and the back pan assembly. The honeycomb core assembly utilizes a fiberglass honeycomb with a buried plastic acoustic septum that is laser drilled after insertion into the core. After septum insertion, the core is trimmed net for insertion into the backpan assembly.

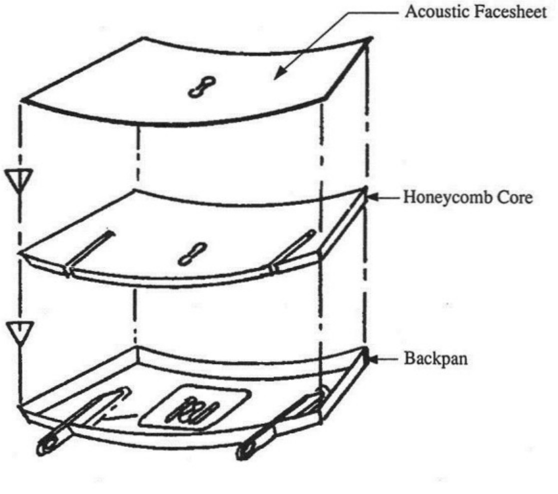


Fig. 6 Boeing blocker door fiber assembly.

For the facesheet, the cloth fabric preforms are cut with a knife cutting tool to the exact size required. The fiber preforms are loaded into the mold tool and forced over a "bed of nails" to form the acoustic hole pattern. The mold die is then closed, and a vacuum is applied to evacuate the mold cavity. The epoxy resin is then injected at 200°F for 40 minutes with approximately 1/2 gallon of resin purged (wasted) through the mold cavity to thoroughly purge the part of air. The tool is then plugged and sent off for partial cure. All mold tools are made from cast iron and use oil heating. The use of cast iron assists in the effectiveness of the parting agent and is significantly cheaper than alternative tooling materials.

The process for the backpan assembly is similar to the facesheet assembly, except several preforms are involved. The backpan assembly consists of two hinge arm preforms, a drag link clevis preform, and a backpan structure preform. For each preform, the cloth fabric pieces are cut with a knife cutting tool to the exact size required. The precut pieces are then loaded into a preform tool where heat and pressure are applied to activate the thermoplastic binder and shape the preforms. Once formed, the fiber preforms are loaded into the backpan mold tool. The mold die is then closed and the RTM injection process is applied the same as with the facesheet sub-assembly. Once the facesheet and backpan components have completed their partial cure cycle, they are removed from the mold tools and deflashed to remove any excess resin at the mold parting line. The sub-assemblies are now ready for final bonding.

All blocker door bonding is conducted in a clean room facility. After hole machining, titanium bushings are inserted into the proper locations at the drag link clevis and hinge lug locations in the backpan assembly with an adhesive. The backpan is loaded into the bond tool and held in position by locator pins in the hinge and drag link bushings. A film adhesive is applied to the core side of the back pan and the core assembly is then loaded into position. The facesheet has a film adhesive applied to the core side that is reticulated to free the acoustic hole pattern of adhesive material. The facesheet is them loaded into the tool. Once loaded, the tool is closed and sent to an oven. Pressure is applied during the final cure/bonding cycle through a silicon pad within the bonding tool. The final cure is conducted for 3 hours at 350°F. After cooling, the blocker door is removed from the bonding tool and again deflashed. It is then sent to final assembly where it is painted and finished with the addition of spherical bearing and a drag link spring assembly. A finished blocker door assembly is shown on Figure 7.

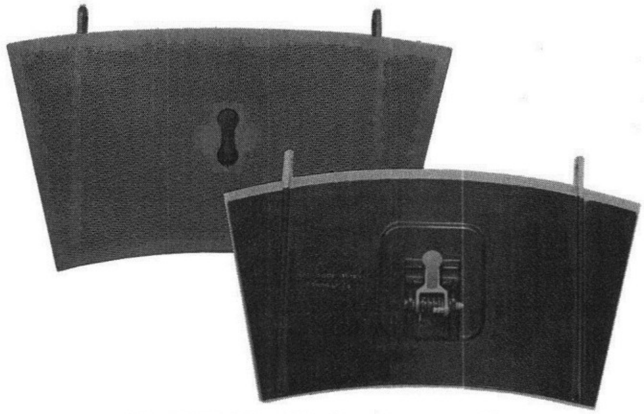


Fig. 7 Finished blocker door assembly.

Coupon Test Program

Since the MIL-HDBK series does not contain design allowable for RTM graphite composites, a point design allowable program was initiated using coupons of the anticipated RTM materials. The tested materials included resin transfer molded graphite fabric (T300-3K to BMS9-8) and graphite tape T300-6K to BMS9-8) both resin transfer molded with a Hysol resin system. Also tested were a variety of film and paste adhesives. The tests were performed for unconditioned and conditioned specimens at -65°F, 70°F, and 220°F. Conditioning was for 30 days at 140°F and 80% to 85% RH. Tests were also performed after contamination in the six fluid environments as listed below:

1. 14 days at 70°F in anti-ice fluid
2. 14 days at 70°F in cleaning agent
3. 14 days at 70°F in hydraulic fluid
4. 14 days at 160°F in hydraulic fluid
5. 14 days at 70°F in jet fuel
6. 14 days at 70°F in urea solution

Table 4 provides the point design allowables test matrix.

Inter-Laminar Shear Strength (ILSS) tests were performed to specification GRAG 2.1. Tensile Strength (TS) tests were performed to specification ASTM D 3039-76. Compression Strength (CS) tests were performed to specification ASTM D 3410-75. Table 5 summarizes carbon fabric and tape material allowable strengths determined for the different tests and test conditions. The allowable strength is given in pounds per square inch (PSI) units and is based on a "B" allowable, which is the mean strength minus three times the standard deviation.

The test results were lower than expected values and averaged approximately 15% less than the equivalent prepreg/hand layup BMS8-212 system. The lower values were the result of two factors both of which created a high standard deviation – high scatter in the test samples and low population sample sizes.

	Unconditioned	Conditioned	Anti-Ice Fluid MIL-A-8243	Cleaning Agent BMS 11-6	Hydraulic Fluid BMS 3-11	Hydraulic Fluid BMS 3-11 (140 F)	Jet Fuel A-1	Runway De-Ice Fluid DOD-U-10866
ILSS								
Carbon Cloth (0/90)								
-65° F	5	5						
70° F	20	10	5	5	5	5	5	5
220° F	10	10	5	5	5	5	5	5
Perforate	5	5	5	5	5	5	5	5
Film Adhesive	15	15	5	5	5	5	5	5
Paste Adhesive	15	15	5	5	5	5	5	5
Carbon Roving 70° F	5							
CS/CM								
Carbon Cloth								
-65° F	5	5						
70° F	20	10	5	5	5	5	5	5
220° F	10	10						
Carbon Roving 70° F	5							
TS/TM								
Carbon Cloth (0/90)								
-65° F	5	5						
70° F	20	10	5	5	5	5	5	5
220° F	10	10						
Carbon Roving 70° F	5	5	5	5	5	5	5	5

Table 4 RTM point allowable test matrix.

The moisture conditioning samples showed a weight gain of approximately 1% after 28 days and then leveled off.

Current Status

The composite blocker doors have successfully completed a comprehensive series of qualification tests, which simulated the full life and inservice environment of the blocker doors. These test have validated, as much as current testing procedures allow, their acceptability for production use. To further reduce the level of risk for a full production program, a set of thrust reverser blocker doors were installed on an inservice 767 with PW4000 engines in 1989. The

Material Type	Test Type	Static Strength (psi)											
		Unconditioned			Conditioned			Fluid Resistance					
		-65°F	72°F	220°F	-65°F	72°F	220°F	1 72°F	2 72°F	3 72°F	4 72°F	5 72°F	6 72°F
Woven Cloth	ILSS	6279	7352	3872	6525	5162	3089	6656	6653	6757	6569	6902	7308
	@ 220°F	-	-	-	-	-	-	2813	3263	2509	4162	4829	3509
0°/90° Alignment	TS	-	46270	60740	-	51520	52300	-	-	41770	-	-	51550
	CS	34580	27490	43600	57810	28900	36060	36630	33840	47080	53290	45110	45360
Uni-Directional	ILSS	-	12920	-	-	-	-	-	-	-	-	-	-
Fiber	TS	-	162,060	-	-	-	-	-	-	-	-	-	-
0° Alignment	CS	-	87,002	-	-	-	-	-	-	-	-	-	-
Perforated Skin 0° Alignment	TS	-	23540	-	-	-	-	-	-	-	-	-	-

Table 5 Composite blocker door - materials allowables, static strength summary.

inservice test articles are to be flown through early 1991, during which time they are to be inspected on a regular basis. At the time of this writing (April 1990), the inservice blocker doors have experienced over 2,000 hours of flight time and over 420 reverser deployments without any serious deterioration or wear.

Some problems have arisen in the production program that are currently under investigation. The problems include fiber breakout of the facesheet upon removal from the "bed of nails" tool; fiber distortion of the lug plies; and resin rich areas with microcracking around the lug fittings. The fiber breakout problem should be resolved by a refinement to the "bed of nails" tool geometry and a possible change to the RTM epoxy system. The fiber distortion and resin rich problems are a result of designing the composite part to look like the aluminum part. Several design changes are underway to eliminate multiple ply drop-offs and tight corner radii. These changes along with the possible epoxy system changes are expected to correct these problems. Future RTM parts must be designed using good composite design practices without trying to duplicate existing metallic part geometry.

Summary

The specific goals of the PW4000 RTM composite blocker door program were to exploit the RTM manufacturing process to achieve a weight and cost reduction without compromising the performance of the blocker doors or the thrust reverser system. Even though there are some problems yet to be totally resolved, the program has been considered a success because it has met all of these goals. The program was able to maintain traditional weight trades for converting metallic components to carbon fiber composites while realizing significant cost improvements. The new composite doors have successfully demonstrated that they will be equivalent to, or better in performance than, the doors that they replace. Based on this programs outcome, RTM appears to be a viable manufacturing production method for aircraft structural composite parts.