Development of PW1100G-JM Turbofan Engine

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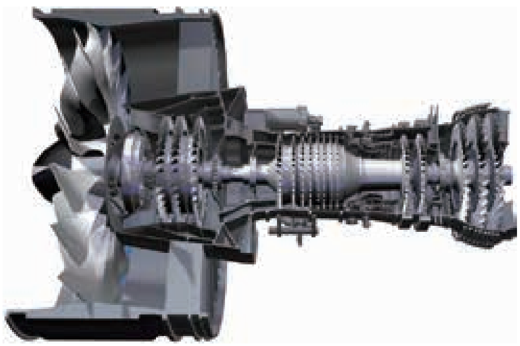
The PW1100G-JM is one of the next-generation turbofan engines selected to power the Airbus A320neo (New Engine Option). IHI participated in the PW1100G-JM program as a member company of the Japanese Aero Engines Corporation (JAEC). The PW1100G-JM adopts the Geared Turbo Fan (GTF) system and delivers improvements in fuel efficiency, emissions, and noise by applying state-of-the-art composite materials and component technologies. This paper presents an overview of the PW1100G-JM.

1. Introduction

Airbus (France: Airbus SAS) is currently developing the A320neo (New Engine Option), and is aiming to achieve a 15% higher fuel efficiency, a double-digit reduction in NO_x emissions, and a 50% reduction in airframe noise by replacing the engine of the A320 currently in service with that of a state-of-the-art design and keeping the airframe converting cost to a minimum. **Figure 1** illustrates a next-generation narrow-body commercial aircraft Airbus A320neo. The PW1100G-JM (**Fig. 2**) has been selected as one of the engines to be installed on the A320neo. Development of this engine began as an international collaborative project under IAE, LLC, a consortium of Pratt & Whitney (P&W, USA), the Japanese Aero Engines Corporation (JAEC), and MTU Aero Engines Holdings AG (MTU, Germany). IHI participated in the project as a member company of JAEC. In addition, JAEC is developing this engine with financial assistance from the International Aircraft Development Fund (IADF).

(Image credit : Airbus)

Fig. 1 Airbus A320neo aircraft



(Image credit : P&W)

Fig. 2 PW1100G-JM cutaway view (1)

The PW1100G-JM adopts a Geared Turbo Fan (GTF) system with an advanced gear system, and the bypass ratio has been increased to approximately 12 to achieve high propulsion efficiency. Furthermore, state-of-the-art composite materials and component technologies have been combined to deliver improvements in fuel efficiency, emissions, and noise.

This paper presents an overview of the PW1100G-JM development program, as well as the engineering features of the components being developed by IHI.

2. Overview of PW1100G-JM development

2.1 Development history

The A320neo family of narrow-body aircraft being developed by Airbus provides great improvements in cost effectiveness and environmental friendliness by replacing the engines of the existing A320 aircraft family (the V2500 and the CFM56) with state-of-the-art engines. A320neo aircraft are scheduled to enter into service in the fourth quarter of 2015. Meanwhile, major American and European engine manufacturers proposed their own new engine designs, and in December 2010, the PW1100G-JM by P&W and the LEAP-1A by CFM International (a joint venture between Snecma of France and General Electric of the United States) were selected.

Creating these new engines requires the latest technologies in order to meet stringent demands while ensuring safety. In light of the position given to PW1100G-JM as a V2500 successor engine, P&W asked JAEC and MTU, co-partners in the V2500 international collaborative project, to participate in the development work, based on their past achievements and latest technologies. After detailed discussions with P&W and MTU, JAEC decided to participate in the development work, and the companies signed a joint agreement in September 2011.

JAEC is contributing 23% of the PW1100G-JM (the same share as with the V2500), and is responsible for the fan, low pressure compressor, low pressure shaft, and part of the combustor. MTU has an 18% share, and is responsible for the low pressure turbine and part of the high pressure compressor, while P&W is responsible for all other components. IHI is responsible for the main fan module parts in the V2500 program, and has a 60% share of the Japanese contribution. For the new engine, IHI is responsible for the main fan module parts as was the case for the V2500, and has a 65% share of the Japanese contribution.

2.2 Predicted market volume

In the present market for narrow-body aircraft in the 120-220 seat class, approximately 12 000 existing models such as the Boeing 737 and the Airbus A320 are in service. When the ages of these aircraft are taken into account, it is believed that the market volume over the next 20 years for this class will show a replacement demand of approximately 6 000 of the 12 000 aircraft currently in service. Furthermore, new demand due to market growth in this class is anticipated, and the volume of the overall demand is expected to reach 15 000 aircraft or more. Currently, Airbus is conducting development of the A320neo as an aircraft for this market. In the future, in addition to existing aircraft such as the Boeing 737, new models such as the 737 MAX are expected to enter the market, and new competing designs may also be developed.

Airbus is also considering putting an A320 successor with a redesigned airframe on the market around 2025. Assuming a 14-year sales period (from 2015 to 2028) for the A320neo, even a conservative estimate of the market volume for narrow-body aircraft during this period is approximately 7 000 aircraft. If the A320neo receives orders for approximately half of this market, orders for approximately 3 500 aircraft would be acquired, and assuming that the PW1100G-JM is selected as the engine for half of those, demand for approximately 3 500 engines is envisioned.

2.3 Engine specifications

Table 1 illustrates the major specifications of the PW1100G-JM as compared to the V2500. By raising the bypass ratio above the V2500, the PW1100G-JM achieves a large fuel efficiency improvement with less noise. Raising the bypass ratio results in a fan diameter larger than that of the V2500, but the application of IHI's own advanced composite materials technology makes a large contribution to engine weight reduction.

2.4 Development milestones

Figure 3 illustrates PW1100G-JM development milestones. Development of the PW1100G-JM began in 2011, and after design, prototype engine production, and various development tests, the PW1100G-JM is projected to acquire engine type certification in the third quarter of 2014, and enter into service in the fourth quarter of 2015. The development tests consist of running tests using a total of eight prototype engines and various component tests. The development of eight prototype engines is divided into two phases (Block-1 and Block-2), and are planned so that the lessons learned via design/testing of Block-1 can be applied to the design in Block-2, which is to receive type certification. This setup helps reduce development risks.

At present, production of the four prototype engines

Table 1 PW1100G-JM & V2500 specifications

Feature	Units	Specification	
Engine		PW1133G-JM	V2533-A5
Aircraft		A321neo	A321
Takeoff thrust	lbf (tf)	33 000 (Approx. 15)	33 000 (Approx. 15)
Fan diameter	m (in)	Approx. 2.06 (81.0)	Approx. 1.61 (63.5)
Bypass ratio *1	—	Approx. 12	Approx. 4.5
Thrust specific fuel consumption	%	−16	Reference value
Noise *2	dB	−15 to 20	−5

(Notes) *1 : Indicates the ratio between the mass flow rate of air bypassing through the fan only and passing the compressor/combustor to the mass flow rate drawn through the compressor/combustor.
*2 : Indicates the value with reference to FAR 36 Stage 4 (U.S. Federal Aviation Noise Regulations).

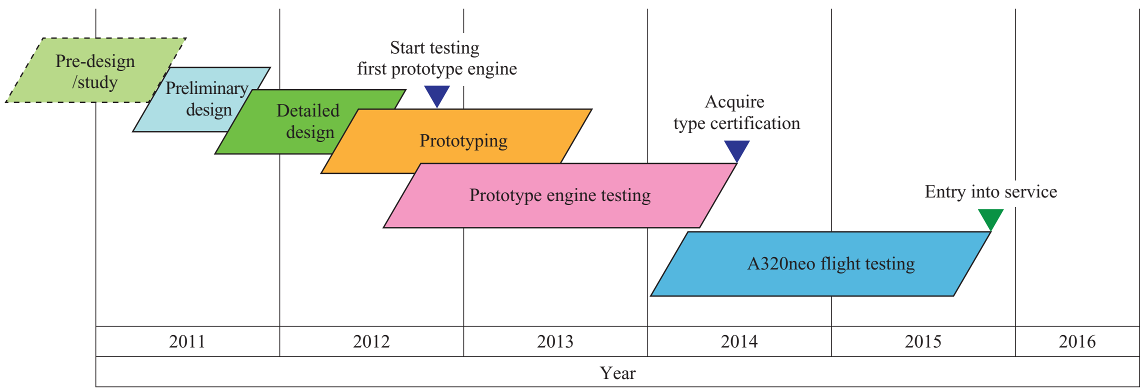
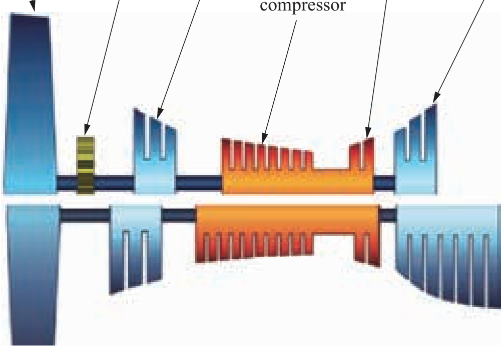


Fig. 3 PW1100G-JM development milestones

in Block-1 has been completed, with the running tests on the first prototype engine being performed in 2012. The design is now being checked and evaluated through running tests performed using these prototypes. In addition, Block-2 design has also been completed, incorporating the performance improvements, weight reductions, cost reductions, and maintenance cost reductions obtained by applying lessons learned through Block-1 design and testing. Currently, trial production and running test preparations for the four Block-2 prototype engines are in progress. **Figure 4** illustrates various running test conditions with the first prototype engine.

3. PW1100G-JM features

Figure 5 illustrates a comparison of the PW1100G-JM and conventional engine configurations. In contrast to the conventional engine configuration on the bottom, the PW1100G-JM on the top drives the fan slowly at a smaller number of revolutions per minute than the low pressure compressor and the low pressure turbine thanks to the advanced gear system, thereby achieving a high bypass ratio, high propulsion efficiency, and low noise with a larger fan. By placing the advanced gear system between the fan and the low pressure compressor, it is possible to make the diameter smaller and reduce the number of stages of the fast-spinning low pressure turbine compared to a conventional engine configuration.



(Image credit : P&W)

Fig. 5 Comparison of PW1100G-JM and conventional engine configurations [1]

Figure 6 illustrates the appearance of the PW1100G-JM engine. As **Fig. 6** depicts, the fan section is larger than the core section that drives the fan. In order to reduce the weight of this large fan section, hollow aluminum fan blades derived from P&W technology are adopted, along with a fan case and fan exit guide vanes featuring IHI's composite materials technology. These composite material parts are being manufactured by IHI Aerospace.

(a) Ground test

(b) FTB test

(Image credit : P&W)

Fig. 4 PW1100G-JM first engine ground test and FTB test [1]

(Image credit : P&W)

Fig. 6 PW1100G-JM engine overview

3.1 Fan section

Figure 7 illustrates a composite fan case cross-section. When a composite fan case having a small thermal expansion rate is used in combination with aluminum alloy fan blades having a large thermal expansion rate, the tip clearance of the fan increases under high-altitude, low-temperature conditions, causing degraded fan efficiency. In order to prevent this phenomenon, a structure is adopted in which a Thermal Conforming Liner (TCL) with an aluminum alloy honeycomb is laid on the inner side of the composite bare case of the outer shell. Since this TCL is supported so as not to have its thermal expansion limited by the composite bare case, the liner closely surrounding the tips of the fan blades exhibits a magnitude of thermal expansion that is equal to the fan blades under high-altitude (low-temperature) conditions, making it possible to minimize tip clearance during flight. Containment is also demanded of the fan case (keeping broken fan blades inside the fan case). This fan case has already been confirmed by component testing as having the desired containment capacity.

Next, **Fig. 8** illustrates the composite fan exit guide vane structure. The fan exit guide vanes have the function of maintaining high efficiency of the bypass flow compressed by the fan blades by rectifying it with low loss. In order to minimize interference with the pylons placed downstream, the fan exit guide vanes of the PW1100G-JM consist of optimally positioned vanes with five different camber

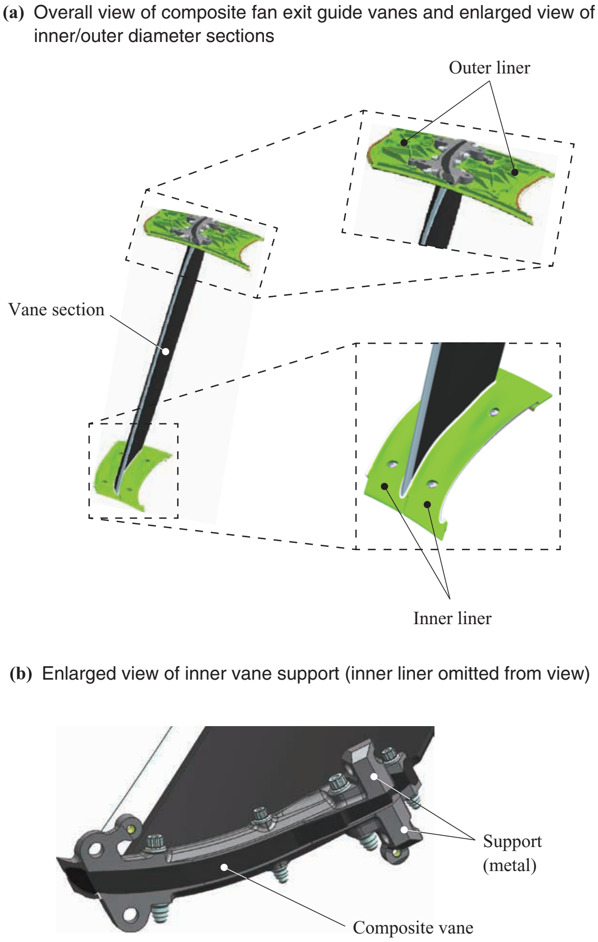


Fig. 8 Structure of composite fan exit guide vane

angles. From a structural perspective, the fan exit guide vanes are Structural Guide Vanes (SGVs) that support the fan case, and are able to withstand a large flight load as well as fan blade off load. Moreover, in order to satisfy the rigidity demanded of the overall engine, a structure is adopted in which both ends (inner and outer diameter) of the composite vanes are held between sets of metal supports.

3.2 Low pressure compressor

In order to make the fan and the low pressure system rotors rotate at different speeds, the low pressure compressor section of the PW1100G-JM engine primarily consists of: ① a Fan Drive Gear System (FDGS), ② main bearings for the fan and the low pressure system rotors, ③ a frame supporting the FDGS (front center body), ④ variable inlet guide vanes, ⑤ a three-stage low pressure compressor, and ⑥ a frame having mounts that supports the main bearing of

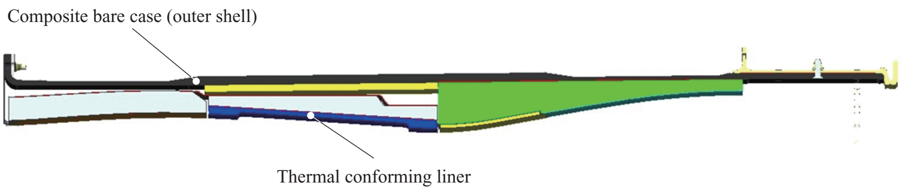


Fig. 7 Composite fan case cross-section

the high pressure system rotor (intermediate case). In a typical high-bypass ratio engine, the low pressure compressor section and the high pressure compressor section have a frame that supports the main bearings for both the low pressure system and high pressure system rotors as well as the engine mount. Conversely, the PW1100G-JM engine features a front center body for supporting the FDGS and the respective main bearings of the fan and the low pressure system rotors, placed between the fan and the low pressure compressor section. Furthermore, this front center body supports the fan case via the fan exit guide vanes.

The low pressure compressor in which the rotors spin faster than in a conventional engine consists of three stages having variable inlet guide vanes. The low pressure compressor implements a three-dimensional vane design developed using Computational Fluid Dynamics (CFD). In order to withstand high centrifugal forces, the rotary section has a structure that resembles the rotary section of high pressure compressor, and all stages adopt an Integrated Bladed Rotor (IBR) combining the blade section and the inner disk section. **Figure 9** illustrates a low pressure compressor stage-2 IBR.

In addition, in order to ensure the required surge margin, the low pressure compressor exit includes a variable bleed valve. **Figure 10** illustrates the cross-section of a variable bleed valve. As **Fig. 10** illustrates, the outer diameter exit of the bleed duct provided in the intermediate case can be fully opened or closed by the valve moving in the axial direction of the engine. Although the structure has basically been proven in engines such as the V2500, Block-1 running tests revealed that strong acoustic vibrations were being produced in this duct, and so a number of candidate configurations were formulated with the cooperation of P&W, and CFD as well as rig testing confirmed that shortening the duct length yields the required effect with the least risk. From these results, the Block-1 parts were immediately reworked, and later running tests were carried out safely. In addition, further improvements were made to the Block-2 and type design.

Fig. 9 Low pressure compressor stage-2 IBR

3.3 Low pressure turbine shaft

Besides the fan and the low pressure compressor section, IHI is also responsible for the low pressure turbine shaft, which has established a solid record in prior engine development and mass production. The current shaft adopts materials that have been proven in prior models, but differs from these prior models in that it spins faster, which demands high speed balance during manufacturing from the perspective of rotor dynamics.

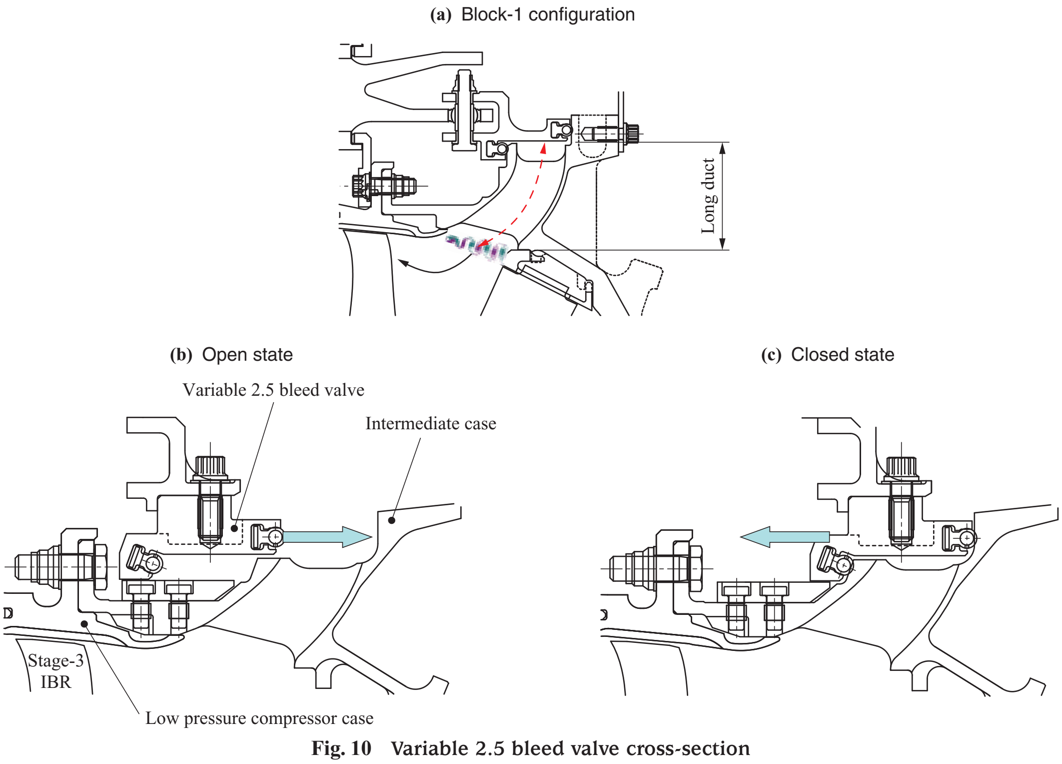


Fig. 10 Variable 2.5 bleed valve cross-section

4. Conclusion

This paper introduces an overview of the PW1100G-JM development program, as well as the engineering features of the components being developed by IHI. Approximately one year remains until the scheduled engine type certification in the third quarter of 2014, and so far development is proceeding smoothly.

This development work is an international collaborative project by P&W, MTU, and JAEC. As this is the second time since the V2500 that our companies have participated as equal partners in a joint venture, the program is being driven forward with renewed focus while tapping the potential of our high-level design and manufacturing expertise, such as IHI's own composite materials technology. For the first time in the world, composite materials are being adopted for use as SGVs in the fan exit guide vanes, and we believe that such adoption of IHI's original materials and designs after a variety of engineering tests present a great opportunity to demonstrate IHI's impact on and presence in the world.

— Acknowledgements —

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