DEVELOPMENT AND APPLICATION OF A FLUID-BASED NACELLE ICE PROTECTION SYSTEM

2022-11-29

Koji Shimoi, CAV Systems

ABSTRACT

A nacelle ice protection system on a turbofan engine is one of the critical components of an aircraft. Ice on the nacelle inlet surface is undesirable because the ice reduces engine operating performance due to the adverse effect on air flow into the engine, damages fan blades and engine core components when it sheds, and adds weight. In order to keep ice from forming on the nacelle inlet surface, most aircrafts with turbofan engines are protected with a hot bleed air Nacelle Anti-Ice System (NAIS). However, the hot bleed air NAIS has several drawbacks including high power consumption, high complexity, and an undesirable impact on the engine performance due to operational coupling. Moreover, aircraft electrification has been the important subjects of research and development in recent years to reduce carbon footprints. As hybrid or fully electric aircrafts are developed it is unlikely hot bleed air or surplus electrical power will be available for the NAIS. Thus, an alternative method of the NAIS will be required.

This presentation will provide an overview of the development of the TKS Ice Protection System (IPS) for a nacelle inlet to address these issues. The TKS IPS is a fluid-based system whereby a fluid that acts as a freezing point depressant is delivered to the leading edges of the surfaces to be protected. The fluid reduces the freezing point of impinging supercooled water droplets to prevent ice formation. A typical TKS IPS consists of porous, laser drilled titanium panels that form the leading edges of the wing and empennage. However, CAV's technological research and advancement over the past several years have enabled the production of TKS leading edge panels from carbon fiber reinforced polymer (CFRP) composite materials with complex geometries.

Figure 1 illustrates a cross-section view of a portion of the inlet assembly fitted with TKS IPS. A typical nacelle inlet with a hot bleed air NAIS uses aluminum as lipskin material so that the external surface can be heated for anti-icing. On the other hand, TKS IPS works at ambient temperatures and enables the lipskin to be built with CFRP composite materials for weight reduction and improved manufacturability. The external surface of the composite lipskin has an electroplated metallic coating. The metallic coating provides an erosion shield that protects the composite skin from leading edge damage. The inlet assembly has perforations of micron-sized holes along a leading edge section of an inlet cowl to allow freezing point depressant fluid (FPDF) to weep through the perforations onto the exterior surface of the inlet cowl. The perforations are laser drilled through the entire thickness of the inlet lipskin, penetrating both the composite panel and the metallic coating.Behind the perforated area of the lipskin, there is a backplate bonded to the interior surface of the lipskin to form a plenum. The FPDF is supplied to the plenum by an electric pump through conduits that extend from a reservoir. Inside the plenum, there is a membrane that absorbs and uniformly distributes the FPDF to the perforations.

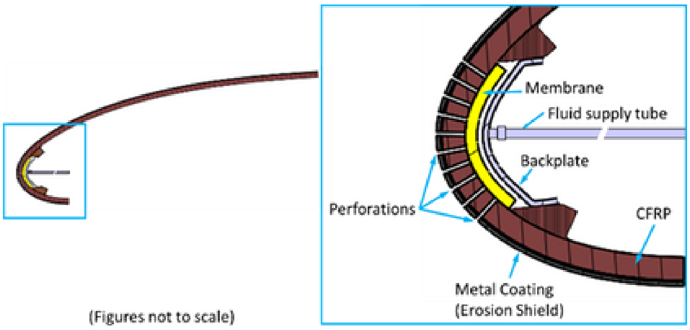

Figure 1. Cross-section view of a portion of Inlet cowl assembly and a close-up schematic of TKS IPS.

Both a hot bleed air NAIS and a TKS nacelle IPS were modelled and designed for a Boeing 767-400ER-size aircraft with two 100-inch (254 cm) fan diameter turbofan engines. A generic nacelle geometry was used for the analysis model as shown in Figure 2. Table 1 lists the assumed engine parameters used for the analysis.

The design and performance studies were conducted over severe icing conditions found in 14 CFR Part 25 Appendix C during the various flight phases. The analysis results show the hot bleed air NAIS would not be able to provide fully evaporative anti-icing for some of the severe icing conditions. It would result in running wet anti-icing and be expected to form an ice shape due to the lack of heat provided by the engine settings at certain flight phases. (Data will be provided during oral-presentation). This can also be problematic for the engine operation. Extracting more bleed air to power the NAIS could stall the engine. Another scenario is that when propulsion is not needed such as a descent or slowing of the aircraft, the power demand of the NAIS forces the engine to continue generating thrust. That not only increases fuel consumption but also increases difficulty in meeting air traffic control speed restrictions during approach. On the other hand, the TKS IPS can operate independently with a fraction of the power required for the bleed air NAIS. It can be designed to provide fully anti-icing performance for all the Continuous Maximum (CM) icing conditions without a concern of the engine operation. The TKS IPS is normally designed to operate as a de-icing during Intermittent Maximum icing conditions and it can provide a completely clean nacelle surface upon exiting the encounter.

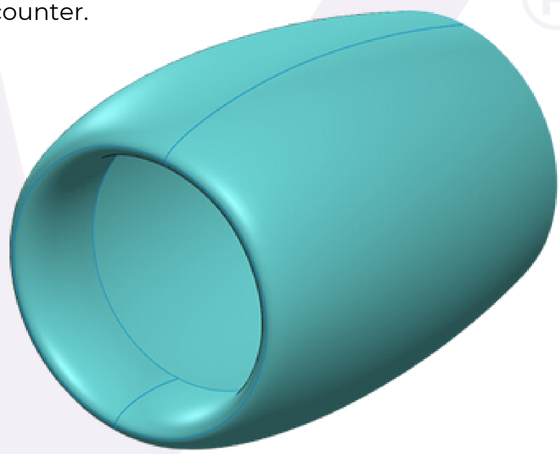

Figure 2. Generic nacelle geometry.

Table 1. Engine parameters.

Compressor	1 fan, 3-stage LP, 10-stage HP
Fan diameter	100 inches (254 cm)
Takeoff thrust	62,000 lbf (276 kN)
Bypass ratio	11
Overall Pressure ratio	45:1
NAI Bleed Air Source	7th stage HPC
Available Beed Air Mass flow (%W26)	≤1%

In addition to eliminating operational coupling of the engine and IPS, thereby improving both engine and IPS performance, the application of the TKS system to the nacelle has several other benefits to the aircraft performance.

Another study was performed to compare the effect of FPDF usage for the TKS IPS and fuel usage for the hot bleed air NAIS if the aircrafts have the following flight schedule as an example:

- Aircrafts operate daily between JFK airport in New York and Heathrow airport in London.
- 3 trips (one way), per 24 hours, 90 trips per month, year-round (1,080 trips per year).
- 10% of flights will be considered for icing conditions, 9 encounters per month.
- Two icing encounters will be considered on climb.
- Two icing encounters will be considered on descent.
- All encounters will be considered a 50th percentile liquid water content CM icing encounter with 15-mm median volume diameters for the horizontal extent of a standard 14 CFR Part 25 Appendix C cloud [1].
- Flight airspeeds were derived from actual flight data of 767-400ER.
- Icing encounter flight times will be derived from actual flight data of 767-400ER.

The total fuel usage for the aircraft due to the hot bleed air NAIS was 671 US gallons (2,540 liters) while the total FPDF usage for aircraft with the TKS IPS was calculated to be 277 US gallons (1,048 liters). Therefore, the TKS IPS can also reduce the aircraft fuel consumption and carbon footprints.

Besides using the composite materials for the inlet lipskin instead of aluminum, the weight can be further reduced by replacing all the heavy conduits and pressure valves for the hot bleed air NAIS with lighter and smaller diameter tubes and electric pump for the TKS IPS. Also, the forward bulkheads to form a D-duct (or cavity) in the hot bleed air NAIS will be no longer required in the TKS IPS.

Another benefit of the TKS IPS is that the inlet assembly can have a continuous material system in which the metallic coating of the lipskin seamlessly extends along the leading edge of the inlet cowl and the entire length of the outer surface of the inlet cowl as illustrated in Figure 3. The smooth and uniform surface promotes laminar flow and results in improved aerodynamics performance for better fuel efficiency. Conventional inlet cowls may include seams at interfaces between the lipskin and the outer barrel. The seams cause turbulent flow along the exterior surface, which is detrimental to flight and engine performance.

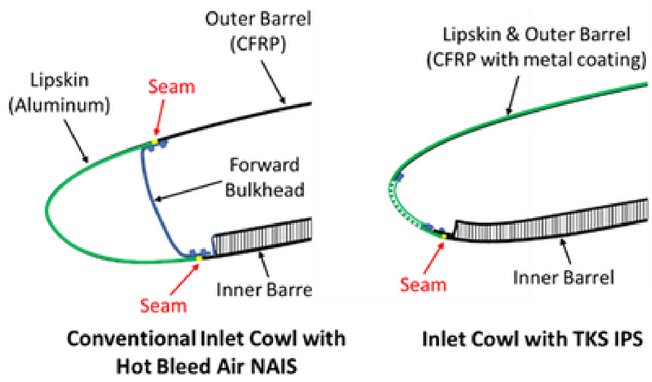

Figure 3. Comparison of inlet cowl structures.

Lastly, the acoustic panel on the inlet cowl with the TKS IPS can be possibly extended forward for improved acoustic attenuation or maintaining similar acoustic performance to the conventional inlet for a shorter inlet without sacrificing ice protection performance. Figure 4 shows the perforated area of the lipskin for the TKS IPS is smaller than the protected area for the hot bleed air NAIS. Thus, TKS IPS can accommodate a larger acoustic panel.

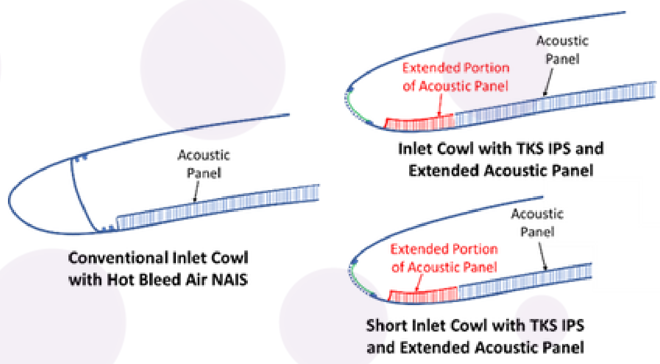

Figure 4. Comparison of acoustic panel size between inlet with hot bleed air NAIS and inlet with TKS IPS.

TKS IPS can provide a reliable and low-energy ice protection solution for nacelles while improving both engine and IPS performance. The application of the TKS IPS to the nacelle also enables a reduction in both weight and carbon footprints as well as improved laminar flow and acoustic attenuation.

References:

1. R. K. Jeck, "Advances in the Characterization of Supercooled Clouds for Aircraft Icing Applications," FAA Technical Report DOT/FAA/AR-07/4, 2008.