Turboprop Inlets for High-Lift Aircraft

Investigation of Highly Loaded, Over-the-Wing Installed Turboprop Inlets for High-Lift Aircraft

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In Short

- Unsteady RANS simulations for analysis of interaction between turboprop S-duct intake, propeller, and wing
- Design of turboprop diffuser intake, including Integrated Particle Separator, for a high-lift aircraft with channel wing installation

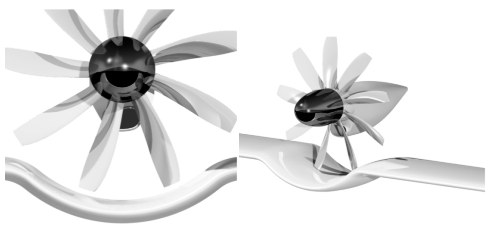

Figure 1: *Analysis model of integrated S-duct installed on channel wing.*

The progress of civil aviation is challenged by the limitation of physical capacities of the major hubs. High density around the major hubs of air transport adds to delay times and eventually limits the market growth. Guidelines defined in Flightpath 2050 [1] by the Advisory Council for Aeronautics in Europe (ACARE) consider faster connections and point-to-point connections for the future commercial aviation. Small airports within the air transportation network can be used for this objective, but their short runways and locations to close population centres should be considered for the aircraft design. In this context, Coordinated Research Centre 880 (CRC 880) develops single-aisle civil commuter within the project "Fundamentals of High-Lift for Future Civil Aircraft", that can take-off and land on such small airports with short runways [2]. The aircraft uses an active high-lift system for augmenting the lift generated during take-offs and landings. As the system power is supplied by the engines, Institute of Jet Propulsion and Turbomachinery investigates the integration and the interaction of the propulsion system within the CRC 880 in the subproject "B6 - Investigation of Highly Loaded Turboprop Inlets for High-Lift Aircraft" (Fig. [1]).

The CRC 880 aircraft is powered with two turboprop engines in its first research period. It has a flight mission of $Ma = 0.74$ cruise at $10.6km$ altitude, and uses active high-lift system for boundary layer control (BLC). The BLC system contains electric-powered small compressors embedded in the wings, with their power supplied by the turboprops. Under these conditions, the maximum power demand was estimated as $10MW$ for each turboprop, including the high-lift system power of $1.5MW$ at sea-level in the first research period. The high power rate of CRC 880 turboprop increases the importance of its intake design, especially when installed on a channel wing. The highlight, throat and aerodynamic interface plane (AIP) areas of the diffuser intake were determined by the corresponding air mass flow rate requirement.

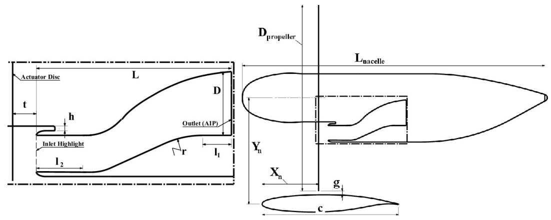

Figure 2: *Integrated S-duct dimensional analysis parameters.*

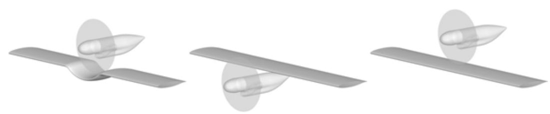

Figure 3: *Installation types for the investigation of integrated S-duct intake with actuator disc.*

In order to capture the required air mass flow around the spinner and the gearbox within, turboprop intakes have a default S-duct shape with large curvature angles that introduce secondary flows, in addition to the propeller downstream effects. Isolated and uninstalled single scoop intake models were investigated for internal flow aerodynamics using steady-state RANS equations in the previous phases [3] [4]. According to the results, wrap-around S-ducts with $L/D = 3$ were chosen for the next phases of the subproject.

CRC 880 aircraft design uses also unconventional engine-nacelle integration types such as channel wing for passive high-lift effects and for possible reduction in noise emission. Therefore the S-duct design requires the analysis of external flow interaction effects. In this case, even though the main influence is expected from the propeller, the wing and the nacelle shape have also critical importance due to the channel wing. For the analysis of the component interaction effects, the scoop type wrap-around S-ducts were integrated into a representative nacelle with $L_{nacelle}/D_{propeller} = 1.6$ for the predicted turboprop size, installed on a wing model (Fig. [2]). Steady-state RANS simulations were run to compare three different installations, varying intake proximity to the propeller and the nacelle hub, and varying azimuth angle of the intake with respect to the rotation axis. Intake aerodynamic performance was evaluated on the AIP.

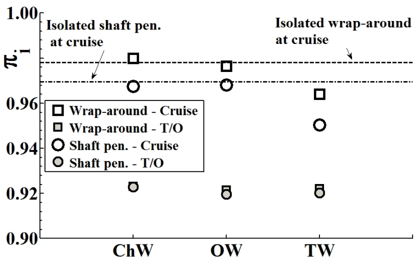

Figure 4: *Total pressure recovery of channel wing (ChW); over-the-wing (OW); tractor wing (TW).*

The integrated intake was installed on an unswept wing with DLR F15 transonic airfoil. The propeller of the turboprop has a diameter of $5m$ with a centre to hub ratio of 0.26. It was approximated as an actuator disc for the steady-state RANS simulations. The analysis intake models were of both wrap-around and shaft penetration types. Computational grids were generated using CENTAUR software. Steady-state simulations were done using DLR's TAU flow solver, with Spalart-Allmaras of negative type for the turbulence model. The simulations were run for take-off and cruise conditions. Farfield freestream was adjusted to $Ma = 0.6$ for cruise, due to the local sonic flow on actuator disc tips when the actual cruise speed $Ma = 0.74$ for CRC 880 aircraft was used. $Ma = 0.172$ was used considering the end of the take-off run of the aircraft.

Three installation types were compared to assess the effect of channel wing installation on the intake performance, in comparison to conventional tractor and standard over-the-wing installations (Fig. [3]). It was observed that the intakes on channel wing installations have 1.7% higher total pressure recovery than the ones with conventional tractor wing (Fig. [4]). The results of the corresponding total pressure recovery, as well as the distortion were presented at the International Society of Air-Breathing Engines (ISABE) conference in September 2017, and published in The Aeronautical Journal in 2017 [5].

The S-duct intake proximity to the propeller midplane (approximated as the actuator disc) and the nacelle hub was varied for the analysis of the interaction effects of the integration. Wrap-around intake was used for the analysis, and it was simulated at

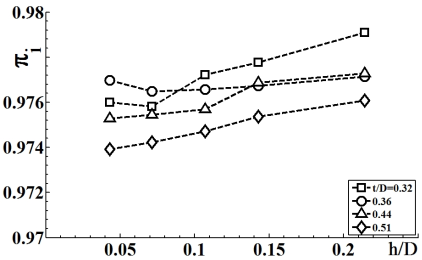

Figure 5: *Intake proximity effects on the total pressure recovery; on channel wing at cruise ($Re = 18 \times 10^6$).*

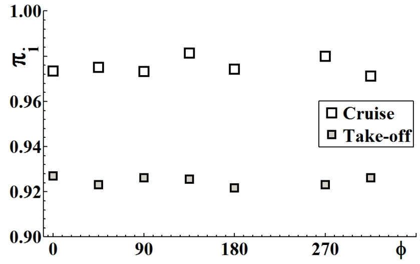

Figure 6: *Intake azimuthal position effects on the total pressure recovery; channel wing installation.*

cruise conditions. As the S-duct intake proximity was varied on the channel wing installation, the results showed that the change in total pressure recovery remained below 1% (Fig. [5]). Increasing the intake proximity to the actuator disc and the nacelle hub rise the recovery, although in smaller effect. All results for the comparison of total pressure recovery, as well as the distortion against the changes in proximity to the actuator disc and in boundary layer diverter height were presented at the American Society of Mechanical Engineers (ASME) turbomachinery conference in July 2017 [6].

The S-duct intake azimuth angle with respect to the actuator disc rotation axis was varied to investigate the interaction effects of the integration position. Wrap-around intake was used for the analysis, and it was simulated at both take-off and cruise conditions. The reference azimuth position at $\phi = 270^o$ showed higher π_i than the rest at cruise condition (Fig. [6]). The exception was observed with the intake at $\phi = 135^o$; however, its high performance over the reference remained below 1%, which requires further verification. On the other hand, $\phi = 90^o$ position of the intake showed favourable distortion characteristics. All results for the comparison of total pressure recovery, as well as the distortion against the change in intake azimuth position were presented at the 12. European Turbomachinery Conference (ETC) in March 2017 [7].

The wrap-around S-duct design is further improved for the experimental test campaign model considering the internal flow aerodynamics and the results of the analysis of the interaction effects. The reference design was based on the diffuser of [8] (Fig. [8]), with a mild curvature that allows diffusion in the first 40% and with a height aspect ratio of $H/L = 0.2$, slightly lower than the simplified wrap-around model of the previous cases $(H/L = 0.26)$. The design improvement was based on the cross-sectional shape of the basis duct. Altering this guideline as in Fig. [7] revealed that when the height aspect ratio is doubled, all the pressure gain by diffusion is lost due to the secondary flows produced by the curvature. Therefore a wrap-around S-duct with lower height aspect ratio $(H/L = 0.26$ was used again for the experimental test campaign.

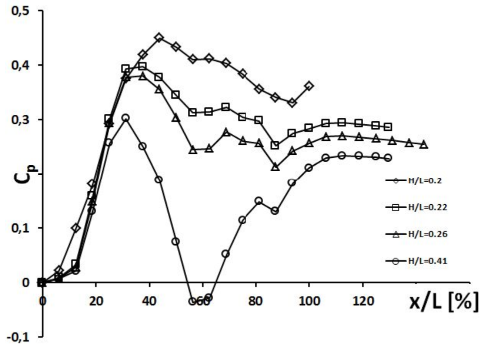

Figure 7: *Pressure distributions along the flow direction in the S-ducts with increasing height aspect ratio at T/O condition.*

The investigation of interaction effects will continue with the analysis of the intake performance combined with the lip profile effects of the nacelle integration and the integrated particle separator (IPS). The developing boundary layer in the propeller downstream will be again critical for the diverter height of the intake from the hub, as the installation height of the channel wing is important for the IPS. After the design objectives for the highest total pressure recovery with minimum distortion on AIP are achieved, the best case will be analysed with full-scale propeller applying unsteady RANS simulations. In this phase, real propeller effects on integrated intake will be investigated, in addition to the flow over the nacelle in channel wing configuration.

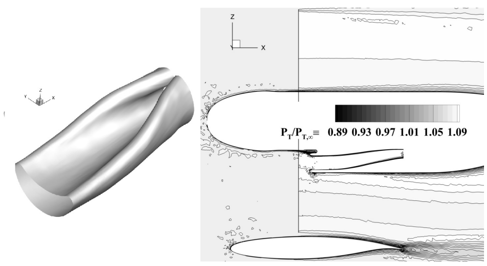

Figure 8: *Wrap-around S-duct reference model on channel wing at cruise* $(Re = 18 \times 10^6)$.

WWW

https://www.sfb880.tu-braunschweig.de

More Information

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