Numerical analysis of integration of nacelle to a high lift aircraft configuration

Installed adVAnced Nacelle uHbr Optimisation and Evaluation

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In Short

- Multi-point optimization of installed nacelles for UHBR engines,
- Transonic wind tunnel tests,
- Validation of optimized installed nacelle performance.

Since the operation of turbofan engines for commercial airplanes, both the air traffic as well as the efficiency of aircraft engines have linearly increased. An efficient aircraft operation model is highly important and it leads to sustainable aviation by reducing the carbon footprint. Fuel prices are steadily increasing and industries are looking at alternative options to reduce the dependency on fossil fuels. Nevertheless, airlines can get better at managing operational costs by reducing the fuel consumption resulting in reduced burden on the passengers as well as the industry. It has been prognosed that the yearly increase of air travel will be around 4 - 6% [1] and strategies to reduce emissions should be strongly pursued more so than ever, given the adverse effects of global warming for all life forms. Most of the modern turbofan engines operating currently have a ByPass Ratio(BPR) of around 12:1 and it is forseen that the future Ultra High ByPass Ratio(UHBR) would be in the region of around 12-20:1 [1]. This results in larger and efficient aircraft engines. These engines are housed in the nacelles and attached to the aircraft wings at suitable positions. The design and development of advanced nacelles should also keep up in pace, parallel with the development of UHBR engines. European Union (EU) has always placed high emphasize on working towards stopping the human induced climate change. Through the efforts of clean sky program, various programs in diverse domains are supported towards climate friendly aviation. The combined european project "Installed adVAnced Nacelle uHbr Optimisation and Evaluation"(Project ID: 863415, Call ID: H2020-CS2-CFP09-2018-02) is a joint effort towards the design and development of an advanced nacelle configuration for the future UHBR turbofan engines. The project partners are from university as well as industry, resulting in a close co operation between numerical design and development leading to testing in the wind tunnel as well as validation with high fidelity CFD tools.

The IVANHOE concept provides a methodology to optimise nacelle location and geometry. Ultimately, the methodology will be able to support a concurrent design process of wing, engine and nacelle which will allow to reach a global optimum in thrust/drag/lift performance. The project concept is based on three major streams of activities as listed in the bullet points.

The first and third streams need reliable numerical flow simulations to achieve their objectives. The numerical simulation approach of the IVANHOE project takes advantage of carefully selected and qualified numerical methods with models of turbulence beyond the state of the art. For reasons of computational efficiency, the partners employ the robust and numerically efficient commercial code Fluent during automated optimization processes, however with a careful checkout of its numerical accuracy by using cross comparisons against the aeronautical flow solver DLR-TAU. The DLR-TAU flow solver offers the opportunity to use advanced simulation models beyond the state of the art in comprehensive CFD analyses. These are Reynolds-stress models of turbulence (RSM)[2] that have been validated for aircraft applications at high-Reynolds numbers during previous works by the German Aerospace Center, DLR, and TU Braunschweig. These models will be employed to represent the effects of secondary flows in nacelle and pylon junctions in transonic flow, and they aim at resolving longitudinal vortices at take-off flow conditions much better than with eddy-viscosity models. The IVANHOE project will build on these technology advancements to bring CFD evaluation of installed UHBR nacelles to a new level. To achieve these project objectives, dedicated flow simulations were performed during the project. The project partners perform initial validation computations on a range of well-known and publicly available test cases that represent the installation effects of bypass ratio engines on commercial aircraft. The existing public data bases of previous AIAA Workshops on drag prediction and high lift prediction serve these needs. The results of the computations by the IVANHOE partners will provide the needed evidence, that numerical simulation data are not biased by significant numerical errors or by employing unsuited or improperly implemented models of turbulence.

The Common Research Model High-Lift (CRM-

HL) configuration is derived from the CRM high-speed configuration to serve for studies involving take-off and landing flight phases [4]. Notable differences between the two variants is the inclusion of slats and flaps in the high-lift configuration. Slats are supported by the slat brackets and flaps are attached to the wing with three flap support fairings. Out of the three available high-lift device settings, the nominal settings for the landing configuration from the high-lift prediction workshop is chosen. Both the inboard and outboard slat angles are set at 30 deg whereas the inboard flap angle is 40 deg and outboard flap angle is set at 37 deg.

The CRM-HL configuration includes a through flow nacelle and pylon. These parts were removed to perform the powered nacelle and pylon integration. The baseline nacelle and pylon geometry which was optimized for the CRM cruise configuration, is integrated to the lower surface of the CRM-HL geometry. The positioning of the leading edge of the pylon under the wing is retained as well as the vertical distance in between the wing lower surface and nacelle upper surface. The nacelle geometry conceived for high-speed has been a little adapted to avoid interference with appendices in the high-lift configuration.

The role played by the vortices from wing pylon juncture in the onset of stall has been observed and documented [3]. Figure 1 shows the surface pressure distribution over the top surface of the wing in the stall region. Between the coarse and refined mesh with IVANHOE baseline nacelle with the same flow conditions, predicted pressure distribution and separation are similar as seen in fig. 1(a) and (b). The large flow separation over the suction side of the wing, upstream of the inboard flap appears to initiate wing stall.

For the case of nominal landing configuration with flow through nacelle at wind tunnel Reynolds number, surface pressure distribution is shown in fig. 1(c) for 20.55 deg angle of attack. In the simulation, major separation are observed only in the outboard wing section and mid span of outboard flap. However, larger separation could be observed in the inboard wing section near to the wing body junction towards the trailing edge region, as well as pockets of separation in the outboard wing between outboard flap end and wing tip, in the experiments. These differences appear to be the origin of over prediction of the maximum lift coefficient by the SA model. Figure 1(d) provides the vortical flow over the wing in the stall region, showing vortex breakdown at the pylon wing junction with SA model contributing to the flow separation over the wing surface.

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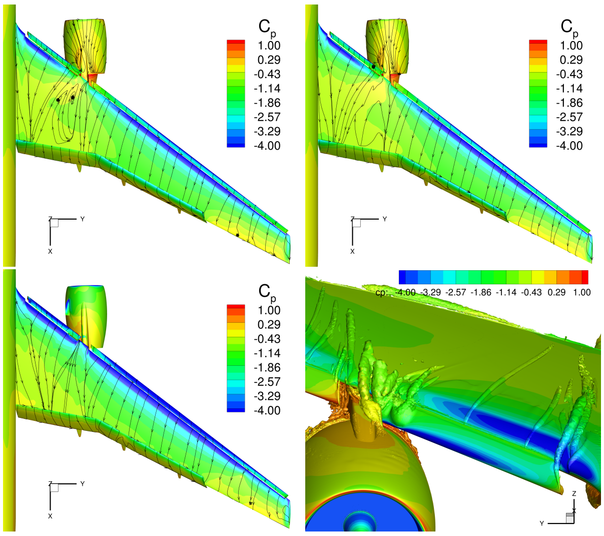

Figure 1: *Surface pressure distribution, flight Reynolds number at $\alpha = 16$ deg(top): Coarse mesh(left); Refined mesh(right); Level-D workshop mesh at wind tunnel Reynolds number at $\alpha = 20.55$ deg(bottom left); Vortical flow in the stall region, non dimensional Q-criterion iso surfaces ($Q * MAC^2/U^2_\infty = 50$) with c_p contour at $\alpha = 16$ deg, SA model, refined mesh and flight Reynolds number(bottom right)*

More Information

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[2] **Eisfeld, B.***Implementation of Reynolds Stress Models into the DLR-FLOWer Code, Institutsbericht, DLR-IB 124-2004/31, Report of the Institute of Aerodynamics and Flow Technology, Braunschweig, ISSN 1614-7790, 2004.*

[3] **Gokul Subbian and Andrea Magrini and Denis Buosi and Rolf Radespiel and Rita Ponza and Ernesto Benini.***Investigation of HL-CRM Aerodynamics With a UHBPR Nacelle in Powered-on Condition, AIAA Propulsion and Energy 2021 Forum, doi = 10.2514/6.2021-3547.*

[4] **Doug S. Lacy and Adam M. Clark.***Definition of Initial Landing and Takeoff Reference Configurations for the High Lift Common Research Model (CRM-HL), AIAA AVIATION 2020 FORUM, doi = 10.2514/6.2020-2771.*

Project Partners

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