Application of an effective description procedure for interpreting 3D flow fields past a helicopter fuselage


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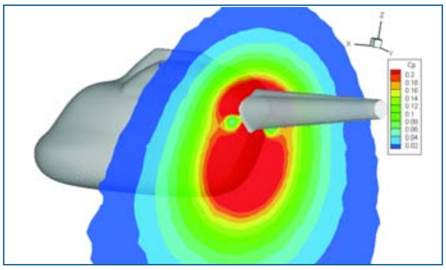
This paper discusses the use of advanced flow field structure extraction methods for a comprehensive understanding of the flow field structure presented on a case of a simplified helicopter fuselage.

The turbulent flow is modeled via RANS (Reynolds-averaged Navier-Stokes) approach solved by means of Finite Volume Method on an unstructured type hybrid grid using the commercial software FLUENT 6. Two flight scenarios are presented here: cruise flight at a negative angle of attack with low influence of the induced velocity field of the rotor; and hovering flight when only the velocity field of the rotor plays a role. In cruise flight the flow field was found to be steady, thus non-linear RANS approach was reliably applied, however in the case of hovering, large scale unsteadiness was expected and the flow field was traced by means of URANS (Unsteady RANS) method. Post-processing of the results is based on the simultaneous observation of streamlines, wall-streak lines, vortex cores and the iso-surfaces of the second invariant of the velocity gradient tensor (usually denoted by *Q*). Applying these methods, one can not only show the structure of separated flow regions but can determine which of these structures are relevant regarding the aerodynamic characteristics of an aerospace vehicle or its components. The gathered additional information may extend the support of design engineers in making conceptual or optimization decisions.

This article is edited from a paper the authors presented, with detailed diagrams of results, at the International Aerospace CFD Conference in Paris organised by ANSYS, Inc. Founded in 1970, ANSYS, Inc., develops and globally markets engineering simulation software and technologies widely used by engineers and designers across a broad spectrum of industries. It also organises conferences across a range of industries including the aircraft and aerospace sectors.


Charting the high pressure vortex.

Introduction

A Hungarian company has been developing a helicopter powered by diesel engines designed to carry five people. The estimated weight is going to be around 1,700kg and the essence of the concept is to decrease the fuel consumption and the pollutant emission by powering the aircraft by means of diesel engines instead of the gas turbines almost invariably used at the present weight category.

The design and construction process posed many difficult problems. Development of the main and tail rotor, and construction of the fuselage together with different equipment and systems, posed huge challenges. The power transmission system design proved to be a remarkably difficult and challenging area because of the application of two diesel engines. A main area of development involved aeromechanical design. This required determining the forces acting on the helicopter during different angles of attacks and flight situations. The rotor of the helicopter was modeled by standalone software developed by Tamás Gausz, of the department of Aircraft and Ships at Budapest University of Technology and Economics.

The software used to compute the induced velocity field of the rotor took into account the direction of rotation, the estimated drag coefficient of the fuselage, the flight conditions, the airfoils, the flapping characteristics of the rotor blades and the formation of the well known cone-shaped resultant setup of the rotor "plane" due to the aerodynamic forces. As well as the aerodynamic analysis of the fuselage another challenging task was to determine the correct way of inlet and outlet of cooling and combustion air to and from the diesel engines.

This paper discusses the flow field around the baseline model of the fuselage by using advanced flow field analysis concepts that have already been successfully performed on other areas of fluid mechanics. Flow field analysis techniques for plotting streamlines, visualising wall-streak lines and representing iso-surfaces of the second invariant of the velocity gradient tensor (the second one proposed by Jeong and Hussain 1995[6]) can be applied to understand the phenomena determining the aerodynamic characteristics of the fuselage.

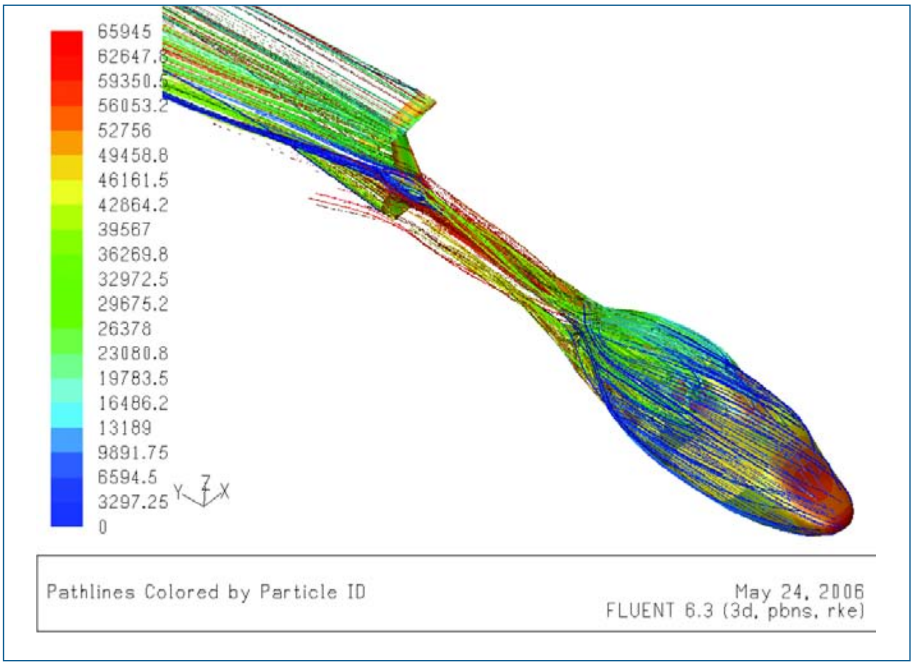
The flow around the helicopter fuselage was found to be characterized by regions of boundary layer separation that introduced favorable conditions in terms of the force and moment coefficients.

The determination of the flow field characteristics and the forces and moments acting on the fuselage were determined by means of RANS modeling.

RANS modeling of the flow around the fuselage

To obtain forces and moments at an acceptable accuracy, several considerations and numerical tests were conducted to correctly chart the characteristics of the flow problem. As this helicopter is basically a low-speed vehicle, the density of the air was taken to be constant. This ensured that the solution of the 3D Navier-Stokes equations for momentum and the continuity equation described the aerodynamic phenomena correctly. However, at that time the Reynolds number range and the mixing property of the rotor meant the flow had to be handled as turbulent. During cruising conditions, though, there can be a portion of the front of the fuselage where the boundary layer is laminar, although during these investigations the transition was not modeled.

Second order upwind scheme was applied to the convective and diffusion terms in all the solved transport equations and to increase the robustness and accuracy of the solver the node-based gradient formulation was used. The pressure-velocity coupling was solved by the SIMPLE method. The helicopter



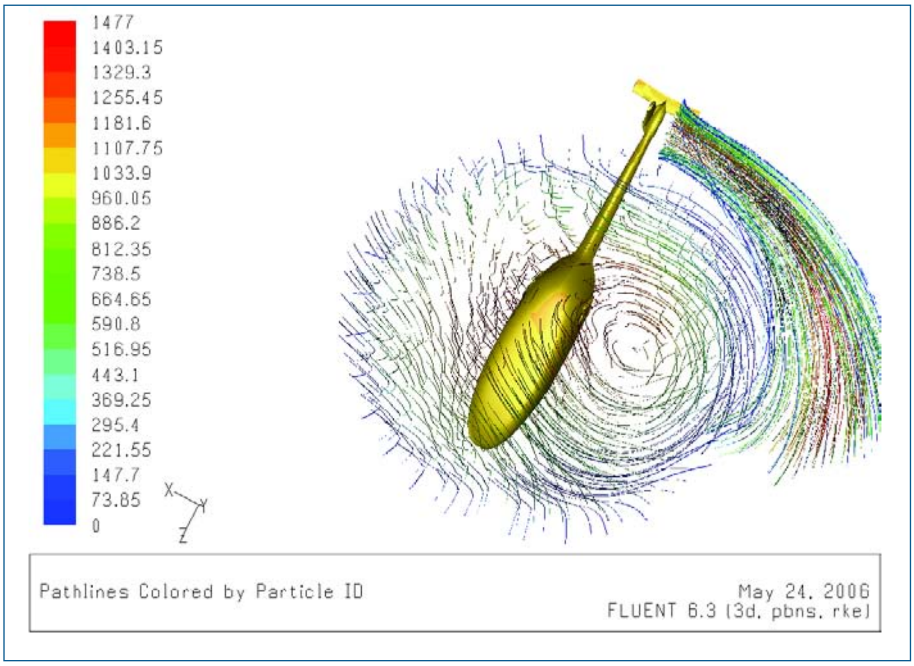
Pathlines shed light on trends.

fuselage was placed within a spherical shaped sub-domain. This was attached to a brick shaped outer and much larger domain that represented the infinite airspace via a non-conformal interface. This way the different angles of attack could then be set without re-meshing any of the domains. The grid in the inner spherical sub-domain was one million unstructured tetrahedral and prism cells, while the outer domain was a structured, hexahedral grid with 0.5 million cells. The influence of the occasional vortices in the internal domain was investigated by means of local grid adaption by the hanging-node method. The aspect ratio of the near-wall cell layer was in the order of 50 and 300, when wall function approach was used and when two-layer approach was applied for the near wall treatment, respectively. These high aspect ratios were found to be of negligible error due to the mostly surface-parallel flow on the fuselage. In case of wall function approach there were six layers of prism cells to provide appropriate resolution of the near wall region and also to provide smooth transition of the grid from prismatic cells to the outer tetrahedral cells (volume change was kept below 1.3 at the cell-type transition region). In case of the computations using the two-layer wall treatment approach, 15 prism layers were applied due to the necessary resolution of the logarithmic region of the boundary layer and also due to the smooth transition from prisms to tetrahedrons.

The last and the most significant concept was near-wall handling. Modeling the anisotropic turbulent boundary layer with the presence of pressure gradient in both a favorable and adverse way was a crucial point in determining the forces acting on the fuselage. This is because a large portion of the drag originates from the wall shear stress exerted on the surface of the body by the boundary layer, and another large portion is due to the separation of boundary layer.

The point of separation depends on the characteristics of the boundary layer so different near-wall concepts were tested. In all cases boundary layer transition was omitted as, in the case of a helicopter, the rotor introduces high amplitude disturbances into the flow and thus it is most likely that bypass transition will take place causing a negligible area of laminar boundary layer domain in the low speed cruising case. However, in case of high speed cruise flight (51m/s), the Reynolds number based on the momentum thickness of the boundary layer exceeds its critical value after the first 200mm distance from the stagnation point on the nose of the fuselage towards the sides of the body, based on flat plate boundary layer theory. As the boundary layer was handled to be turbulent on the whole surface of the helicopter, the wall handling approaches valid for turbulent boundary layers were applied for the present investigation.

One approach was the non-equilibrium wall function by Kim et al, 1995[2] that takes the effect of pressure



Challenging design problems.

gradient into account but contains the whole physics of the boundary layer in a simple empirical model. In this case the first layer of prismatic shaped cells were tuned to have constant y^+ values between 30 and 300. As a result of the series of grid tests the final results that are presented contained the first layer of cells between y^+ values of 50 and 170.

The other approach was the more sophisticated two-layer based enhanced wall treatment in Fluent software that is capable of resolving the low Reynolds number anisotropic domain in the lower portion of the turbulent boundary layer. Thus, the velocity profiles are computed and not modeled. However, this latter solution requires a much higher number of cells than the former one.

The substitution of the transport equation for ε with an algebraic equation[10] does not necessarily reflect the anisotropic nature of turbulence in this region. In this case the values of y^+ were tuned to be below 1 everywhere on the model. Both approaches were applied on the present case to investigate their doubtless influence on the location of separation **of** the turbulent boundary layer. The results of the tests showed very small changes in the location of boundary layer separation on the surface of the helicopter fuselage that lead to only 5% and 10% change in the force and moment coefficients, respectively that might be due to the similarity of this flow situation to the benchmark tests used for tuning these near wall handling models during the validation of Fluent software.

Description of the flow field

The investigation of the flow field structure included examining the effect of two flight situations on the simplified helicopter fuselage: cruising at 51m/s velocity in the corresponding angle of attack computed from the rotor software and the mounting characteristics of the rotor axis; and hovering far above the ground in order to be able to neglect ground proximity effects. For both cases the conventional streamline and streak line plots are shown but for both cases also the *Q*-condition[6] is applied for the time-averaged flow field.

Cruise flight case

The helicopter had a negative angle of attack during cruise flight that was computed to be -10° with respect of the construction plane in case of 51m/s velocity. But the fuselage was not completely streamlined. There was a flow separation region at the rear part of the body in the vicinity of the junction between the empennage lever and the body. The separation zone was, however, not closed but could be characterised by the formation of two longitudinal vortices. The special character of these vortices is that they include fluid that has a static pressure slightly above the ambient pressure (Cp = 0.04-0.05). This is possible only if the separation itself takes place at a location where the pressure was higher than that of the undisturbed free flow. In these circumstances the pressure inside these vortices is lower than that in the vicinity of them but higher than the ambient value.

The wall-streak lines showed that the junction point of the fore-body of the helicopter fuselage and the tail beam is a stagnation point of the flow. These results indicate that there is no recirculating flow in the base region, but air is pulled from underneath the body upwards by the induced velocity field of the two longitudinal vortices. In the rear stagnation point the pressure coefficient increases to a value between 0.4-0.5 which is an overpressure above the ambient value. The over pressure in the rear part of the fuselage prohibited a design that placed the exhaust of the cooling air and exhaust gases in this area. The exhaust sections were thus placed on the sides of the body that also slightly modified the flow field in the rear region. There was an interesting combination of the visualisation methods: streak lines and iso-surfaces of *Q* with the addition of lines of separation (negative bifurcation[8]) and reattachment (positive bifurcation) and the vortex core extraction. The vortex core method, which is based on the critical point theory[8] detects the core of the two longitudinal vortices. But the reattachment and separation lines on the surface of the fuselage indicated the presence of some smaller not resolved vortices.

The junction type vortex would be not visible through an analysis of just the wall-streak lines and the streamlines. In several other cases the authors had to analyze the meaning of the extracted flow features with scepticism as the real physical ones could only be distinguished from numerical errors via experiences.

Hovering flight

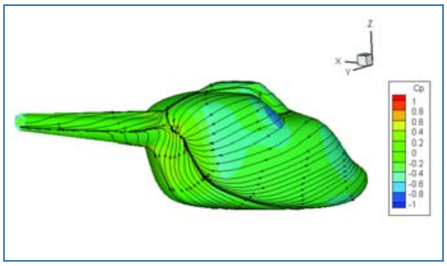
In case of hovering flight the fuselage behaves like a bluff body. The average velocity induced by the rotor was obtained from the rotor modeling software to be around 10m/s. The rotor model did not induce swirl velocity, only a non-axial-symmetric axial velocity distribution. It was established that large scale vortices formed underneath the fuselage with an irregular pattern.

The study showed that one can also expect periodic vortex shedding in this case as the iso-surfaces of Q enclose also the vortices represented by the streamlines. However in this case the simplified fuselage is not realistic as during hovering flight the engines are running on almost maximum power, thus the highest amount of cooling air is going in and coming out from the fuselage, influencing the flow field.

Conclusions

This paper discusses the flow field around a simplified helicopter fuselage by applying the advanced visualisation techniques like the second invariant of the velocity gradient tensor denoted by Q, wall-streak lines, vortex cores and characteristic negative and positive bifurcation lines that indicate separation and reattachment of the boundary layer. The flow field structures were discussed in case of two flight situations: cruising and hovering. The helicopter fuselage was found to be a bluff body due to the separation of boundary layer at the very rear part of the fuselage. However, due to the presence of the body-tail junction, the pressure in this region is relatively high that contributes significantly to drag reduction. On this aspect the rear part of the helicopter fuselage behaves like a vortex generator that prevents backflow and provides the presence of only longitudinal vortices.

In case of hovering flight the



Charting streak lines.

helicopter becomes a classical bluff body with a complicated vortex system originating from boundary layer separation along the lower part of the fuselage, however, the shedding vortices were found to be dynamically not so significant as those longitudinal ones forming in case of cruise flight.

The formation of intake and outlet sections for the cooling and combustion air of the engines were carried out based on the pressure coefficient distribution on the surface of the fuselage. It has to be noted that with the presence of cooling air flow the hovering characteristics are changed, but still a large extent of the fuselage can be characterized by large scale vortex formation. Using the previously mentioned advanced flow analysis tools the structure of the flow field can be better understood than by analyzing pressure distributions and streamlines only. In this way the behavior of the aerospace vehicle can be understood on a deeper level. ■

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Production rates and workload increase at Cessna

Workers at Cessna's plant in southeast Kansas plan to double the delivery rate of Mustang aircraft from 45 last year to 100 aircraft in 2008, to meet increasing demand.

This will rise next year to 150 as the plane hits its full production rate, the company says. Workers in Kansas already turn out around four single-engine planes a day and one Mustang a week. This year, they will average two Mustangs a week.

To create more floor space for Mustang production, Cessna has shifted some single-engine work to another plant in Georgia.

Two thirds of the factory in Independence is dedicated to producing Mustangs. Cessna has made a number of changes to the site recently, including a new paint preparation facility, flight centre and the conversion of a flight hangar into a delivery centre and showroom, which is estimated to have cost around $20 million.

Meanwhile, engines for its long-range Citation Columbus business aircraft are expected to be made in Canada. Cessna recently chose Pratt & Whitney Canada to provide 'greener' engines for the aircraft.

The four-year development phase should create hundreds of jobs in Canada and will be split

The Citation Columbus

between Pratt & Whitney's facilities in Mississauga and Longueil. Manufacturing will occur in Halifax and Longueil.

Harness design software could help reduce aircraft weight and bandwidth

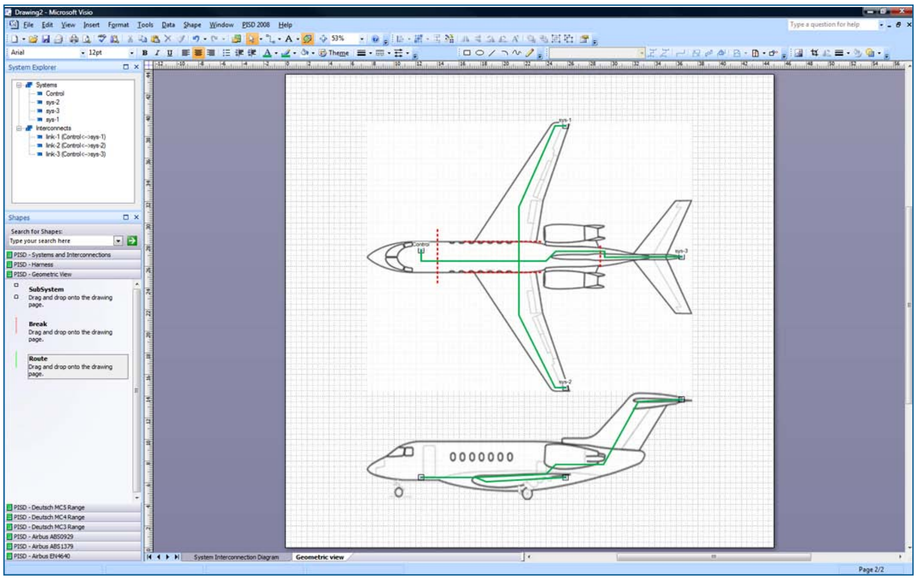
A new design tool has just been launched that will allow system engineers to design, install, test and build fibre optic cable harnesses for next generation aircraft.

Trace Technologies developed the Photonic Interconnect Systems Design tool (PISD), which it hopes will significantly reduce the time and cost involved in designing pre-prototype harnesses.

According to co-founder Geoff Fisher, the software should save 60 per cent of the cost and time needed to deliver a pre-prototype harness. "It will allow engineers to design harnesses with greater speed and confidence," he says.

The aerospace industry is under pressure to develop more fuel efficient aircraft that will fly longer distances and provide more in-flight services such as wireless internet, video and telephony.

Fibre optic cabling reduces the weight of aircraft, increases bandwidth and improves security compared with traditional copper cabling. This means reduced fuel burn, increased range, improved cabin services and greener flights.



Current methods leave a lot of room for error, Fisher claims. System engineers have to use numerous applications and documents which have to be cross-referenced.

PISD uses a Windows-based drag and drop operating system that allows users to choose components and make modifications throughout the process without having to start from scratch if the design proves unsuccessful. Two major players in the commercial and defence aerospace industry have already signed a letter of intent to purchase the product.

A free trial download is available on the Trace Technologies website: www.tracetechnologies.co.uk.

Tunisia beckons once more for French manufacturer

French aerospace manufacturing firm Latecoere has chosen to build a third factory in Tunisia.

The plant will produce nose assemblies for Airbus aircraft and is expected to create around 1,000 jobs for skilled Tunisian workers, engineers and technicians.

It is already constructing two factories in Tunisia that will produce cable components to the aircraft industry.

Tunisia provides attractive tax incentives to foreign investors. According to government sources, France is the country's biggest foreign investor, with over 1,000 businesses situated there.

Chairman Francois Junca has reassured workers in France that their jobs are not at risk. "On the contrary, we will hire at least 500 additional workers to meet the needs of our customers," he says.

Investors key in plans for Symphony restart

Production of the two-seat Symphony Aircraft SA-160 piston single could restart in the second half of 2008 if enough investors give the go ahead. Incomplete aircraft and all the machinery and parts still remain at the Three Rivers plant after the company went into liquidation last year.

Engineering company Aviatech is analysing production simplification and expansion of in-house parts manufacturing to study whether or not a restart would be worthwhile.

Lou Simons is leading the creation of the North American Factory for Technologically Advanced Aircraft, which will replace bankrupt Symphony Aircraft Industries.

The new company's intended location is still undecided, Simons confirmed. He hopes 2010 production could reach 80 to 110 aircraft a year.

UK secures £3 billion contract

A contract to build aeroplanes for the US Air Force could bring £3 billion worth of work to the UK. Airbus' parent company EADS and US-based firm Northrup Grumman secured the deal to produce around 179 airborne refuelling planes over the next few years.

Workers in north Wales and Bristol will play a vital role in the manufacture of these aircraft.

The size of the contract, worth around £18 billion in total, should secure work for the UK industry, benefiting not only Airbus but many other UK suppliers.

General Arthur J Lichte said the winning design allowed for more passengers, cargo, flexibility and dependability.

Boeing's loss of the contract has sparked angry protests in the US however. Boeing is awaiting an explanation from the military before deciding whether or not to appeal.

AMTRI hopes to rise from the ashes

Work is continuing to rejuvenate former UK-based engineering consultancy AMTRI, which had gone into administration.

AMTRI provided special purpose machinery, automation systems and specialist technical consultancy for the manufacturing industry. This new venture, renamed AMTRI Cobble, is backed by machinery manufacturer Cobble, based in Blackburn, Lancashire.

It will operate from new premises in Macclesfield, explained general manager Ian Laven, and use the Blackburn factory's manufacturing facilities.

For the first six months of trading AMTRI Cobble will be upgrading Cobble's carpet tufting machines and carpet looms. In the meantime however, they will be trying to re-affirm AMTRI and win business from aircraft manufacturers.

"We will have competitors. But AMTRI had a unique skills base and we are hoping to bring that back together again," Laven explained.