A400M WAKE FLOW STUDIES BASED ON RANS CFD METHODS ON HYBRID MESHES

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ABSTRACT

Knowledge of flow conditions in the vicinity of the aft section of military transport aircraft is crucial to ensure the safe and precise deployment of personnel and material. CFD methods used by Airbus and DLR allow valuable predictions of these conditions, taking into account the influence of flow deflectors, sponsons, open cargo hold doors/ramps, as well as propulsion slip-streams.

With the requirement of precisely delivering personnel and/or equipment into an area of limited size, while guaranteeing safe conditions for the airframe (as well as paratroops/dropped equipment), military transport aircraft pose unique challenges to aerodynamics. Among them: Guaranteeing the safety of parachutists, whose near aircraft trajectory is significantly influenced by the aircraft wake shedding substantial vorticity (the "safe separation" problem); and providing safe operational conditions within the aircraft, while open doors strongly influence the internal air flow.

Within this study, the hybrid Reynolds-averaged Navier-Stokes (RANS) multigrid flow-solver TAU, developed by the German research centre DLR, is used to assess the possibility of providing CFD support to such complex flow conditions as those occurring in the A400M military transport programme context. Accordingly, the following two items are the main subjects under investigation:

1. TAU is used to compute steady-state data suitable to assess the flow conditions in the aircraft wake area for characteristic aerial delivery flight conditions. Hybrid meshes specifically tailored to the needs of wake studies with corresponding refinements are generated from CAD models. Calculations are run with power- off settings on an A400M high-lift configuration.

2. Due to the aforementioned requirement that military transport aircraft operate with open doors/ramps, CFD tools have to prove their capability to calculate combined internal/external flows. Therefore, TAU is also used to calculate an A400M high-lift geometry with a simplified cargo hold and paratroop doors, as well as open cargo ramp and cargo door, again with power off settings.

Results from these investigations appear very promising. Validation against wind tunnel test data is ongoing.

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1.0 INTRODUCTION

Aerial delivery of personnel and equipment is an important mission scenario of the Airbus military transport aircraft A400M. For the safe and precise deployment of personnel and material a deep understanding of the flow physics for the corresponding flight conditions and geometries is necessary. Since the aircraft is still under development, the tools to improve this understanding are so far restricted to experiments and numerical simulations.

This work presents CFD calculations of the half model aircraft without empennage, a high-lift configuration with fully extended flaps and nacelles, see Fig. 1. The high-lift configuration has been used due to the typical conditions for air delivery operations – low-altitude and low-speed flight. The hybrid RANS solver TAU, developed by the German research center DLR, is used to calculate the flowfield of this geometry with a simplified cargo hold and paratroop doors, as well as with open cargo ramp and cargo door.

The flow in the aft section of the A400M is dominated by a complex system of vortices caused by the inclined underpart of the rear fuselage and the sponsons. With the cargo ramp down, regions with massively separated flow occur additionally, which further raise the complexity of this flow phenomena. This situation represents a big challenge for every RANS solver. Therefore, this first study was focused on an approximation of the main combined internal/external flow and an evaluation of the capabilities of the RANS solver applied to those cases.

A number of investigations dealing with TAU calculations of the A400M as well as valuable CFD studies of airdrop scenarios of other military transport aircraft and with other tools exist, e. g. [1]-[5]. Continuous effort is put into obtaining even more reliable and validated CFD results with respect to the A400M airdrop configuration. The work presented in the following is a first attempt in order to close this gap.

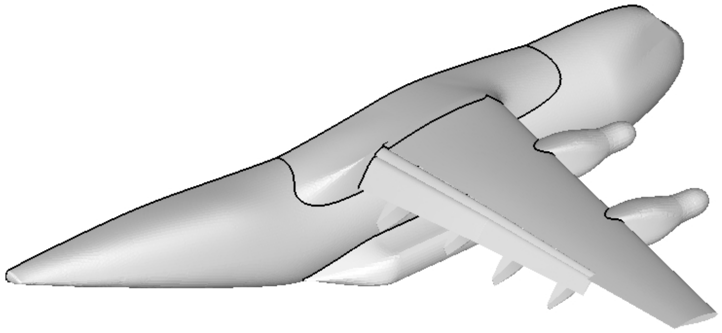

Figure 1: A400M high-lift configuration without empennage system

2.0 NUMERICAL TOOLS

2.1 Unstructured RANS Solver TAU

The DLR TAU software is a finite volume vertex-based solver with an edge-based data structure.

Together with a dual-grid technique various mesh element types can be used [6,7]. Time integration to steady state is accomplished either using the backward Euler LUSGS or the Runge-Kutta scheme. An improvement in convergence acceleration is achieved with multigrid and message-passing-interface (MPI)-based parallelisation [8]. For this application the averaged Navier-Stokes equations are discretised using a central differencing scheme and a Jameson-type scalar dissipation, the turbulence is modelled with the one-equation Spalart-Allmaras with Edwards modifications, the explicite Runge-Kutta scheme was applied as well as three level multigrid acceleration [9,10].

2.2 Mesh Generation

The initial hybrid meshes, consisting of prismatic, tetrahedral, and pyramidal elements, have been generated with the software system provided by CentaurSoft [11]. High-lift geometries in general are very complex to mesh and to calculate and lead to a high number of mesh points. By omitting the empennage system – it is assumed, that due to the T shape the influence on the qualitative results at the cargo exit could be neglected - the number of points could be reduced significantly. In the configuration with open cargo ramp the cargo hold was simplified as much as possible for the same reason. However, the grids created consist of 8.4 million points for the baseline configuration and 8.96 million points for the configuration with open doors and ramp. Figure 2 gives an impression of the surface mesh resolution of the fuselage. Further details referring to the applied CAD and Grid Generation Tools can be found in [12].

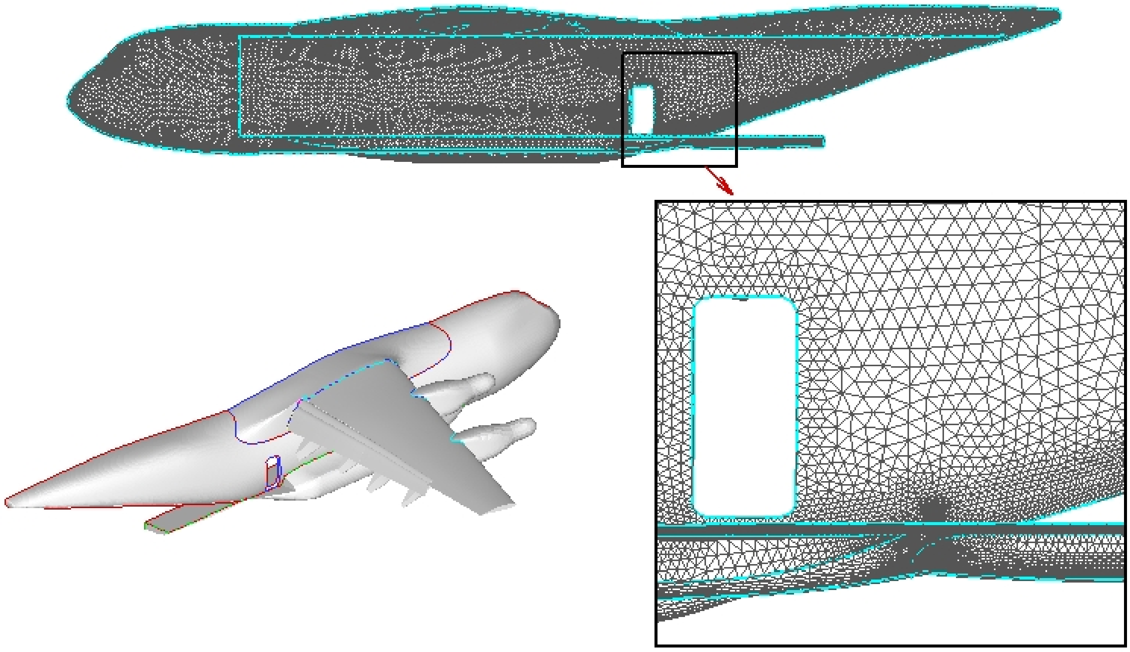

Figure 2: Open cargo doors and ramp configuration

3.0 RESULTS

Within the A400M operational envelope, flight conditions unique to a military transport aircraft, namely air delivery operations, which involve flying with different combinations of opened paratroop doors, cargo ramp and cargo door, occur. Especially the mixed delivery of troops and cargo is of great aerodynamic interest. Both, the paratroop doors and the cargo door are opened in this case, while the load is released from a special system in the closed cargo ramp, known as *wedge* due to its characteristic shape. This concept is based on the idea, that interior flow has to be limited to guarantee a safe environment for all operations inside the cargo hold by keeping the ramp closed. In the Transall airlifter, curtains help to protect payload and crew-members from the airflow. A good understanding of flow behavior in the cargo hold might hint the necessity of such provisions, and, if those things are required, where to locate them.

The calculations were performed for typical flight conditions for aerial delivery at an altitude of 500m, horizontal flight with AOA $\alpha=0°$ and a velocity corresponding to am Mach number of Ma=0.2. The Reynolds number was about 25 million.

In Fig. 3 numerous streamtraces were generated with seed points in five different regions to get a detailed view on several flow phenomena. The colors of the streamtraces refer to the region where the seed points were set. The first group of streamlines (grey) were initialized on a cut plane x=15.72m in the cargo hold. The seed points were distributed uniformly over the whole cut plane. Streamlines in both directions cross this cutting plane. They entered the cargo hold through the lower part of the paratrooper door, changing their direction to the front end of the cargo hold then finding their way back out of to the rear end of the cargo hold.

The second group of streamlines (light blue) were initialized on a cut plane x = 29.6m at the rear end of the open ramp. The bulk of these streamlines enters the cargo hold through the upper part of the paratrooper door and feeds the highly disturbed irregular flow region at the cargo hold exit. Here they are mixed mainly with the next group of streamlines (red) initialized at the outer fuselage near the junction point of the open ramp and the lower corner of the cargo hold exit (fig. 4). These streamlines characterize the flow coming from the lower side of the sponsons, streaming directly above the ramp to pass into the backflow area in this region.

The next group of streamlines (green) were initialized at the bottom of the cargo ramp. Depending on their distance to the border of the ramp, they were separating at the side or at the end of the ramp. They pass the highly irregular flow region above the cargo ramp tangentially without any mixing with other streamlines. The streamlines separated on the side follow the inclined shape of the rear fuselage while the others separate earlier horizontally. The streamlines of the last group (purple) which flow from the wing fuselage fairing to the open cargo hold at the lower part of the rear fuselage show a similar behavior. Without mixing with the other streamline groups some of them follow the shape of the rear fuselage while others separate earlier.

Compared with the streamlines of the closed cargo configuration in Fig. 5 it can be seen that the flow behavior of the purple and green streamline groups is almost not affected by the open cargo ramp. The grey streamlines don't appear at all in the closed configuration, since their seed points lay completely in the cargo hold, which is not simulated in this configuration.

Another view on the interior flow in the cargo hold is presented in Fig. 6, where the velocity components at a distance of 1m from the symmetry plane are mapped. The overall results appear to be plausible, but further investigations into this subject are recommended. In addition to these considerations, one should keep in mind, that the interior of the cargo hold has been simplified significantly. The character of the flow may change, when more and more details are added to the mesh.

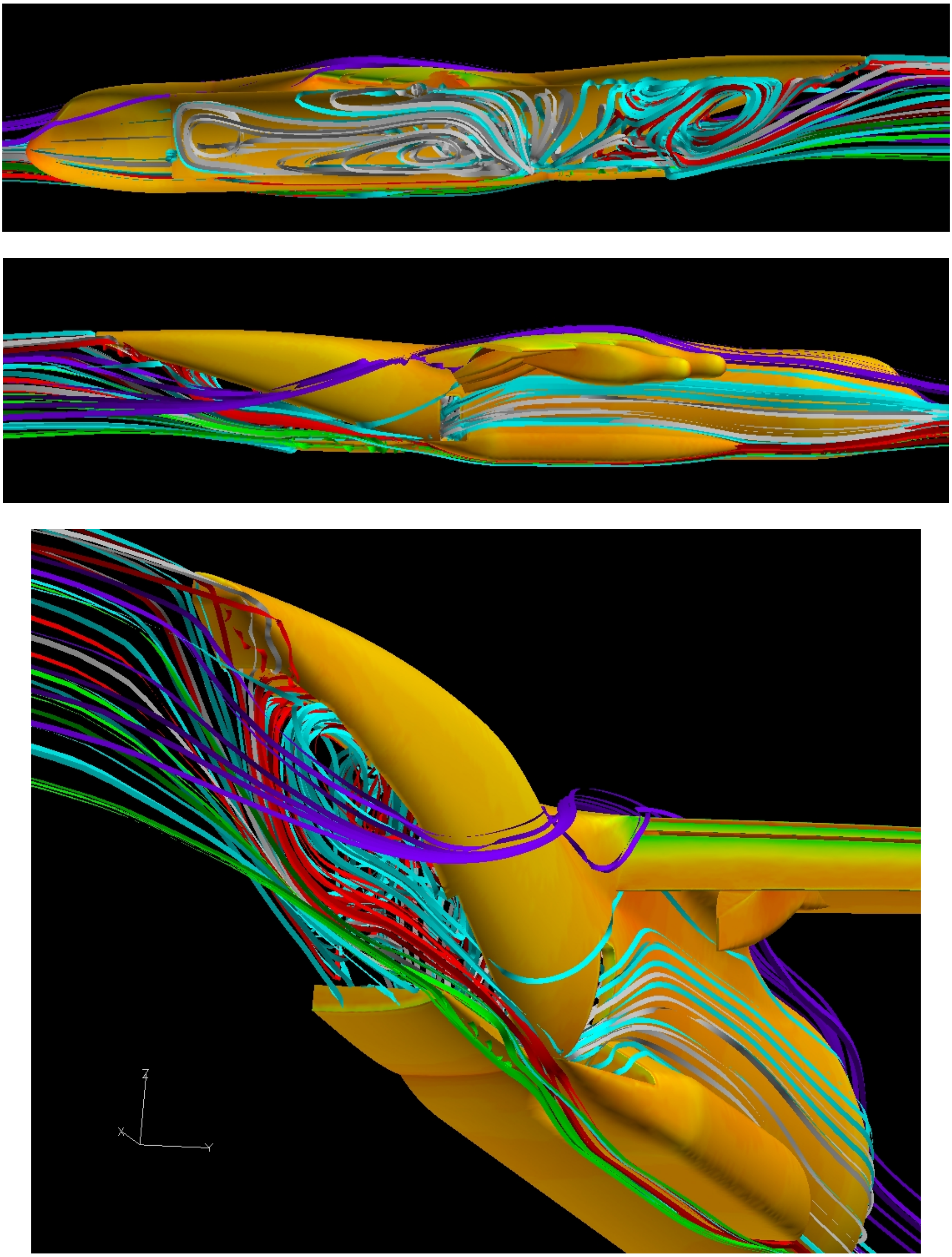

Figure 3: Streamline visualisation of the open cargo ramp results. interior flow (top), exterior flow (middle), and cargo exit flow (bottom)

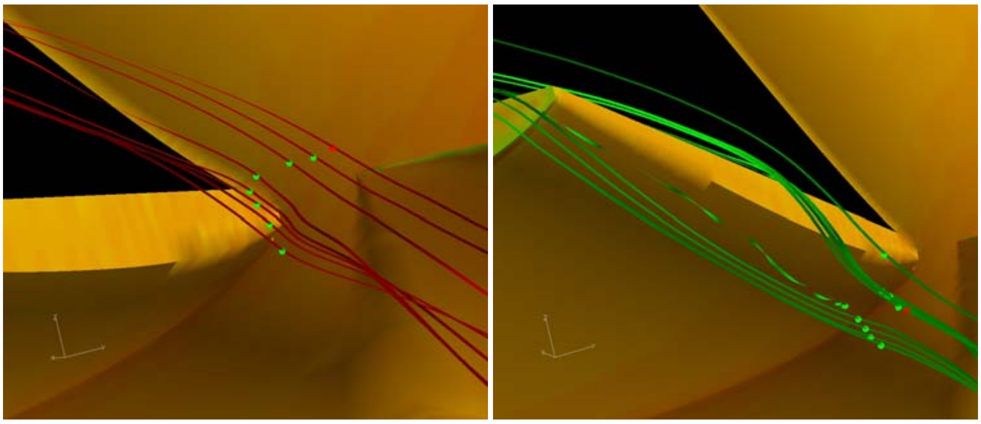

Figure 4: Seed points of the red streamlines (left) and the green streamlines (right)

Figure 7 gives an overview of the rear fuselage flow with Mach number contours and velocity vectors on the symmetry plane and vorticity contours on three x-constant-planes between cargo door and cargo ramp. On the first cut plane the high vorticity area at the open door can be seen. A comparison with the next cut planes gives an indication of the high dissipation rate outside the prism layers. The sponson wake as well as the primary vortex caused by the flow running from the wing and wing fairing area to the underpart of the rear fuselage are weakly resolved and quickly vanishing caused by dissipation. Further improvement of the accuracy of the calculation is necessary.

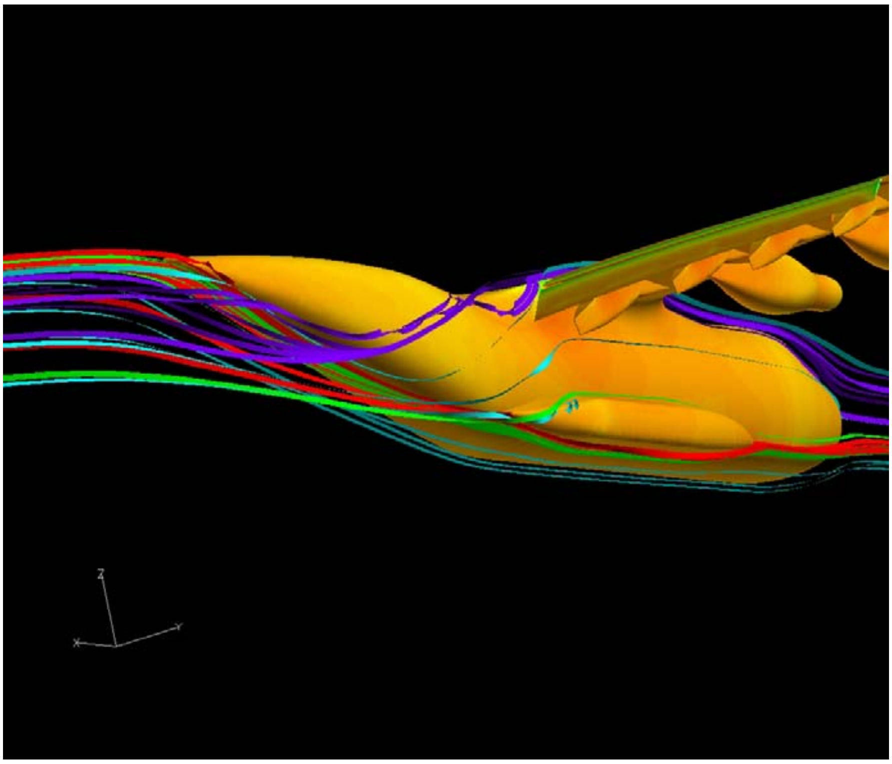

Figure 5: Streamline visualisation of the baseline configuration results

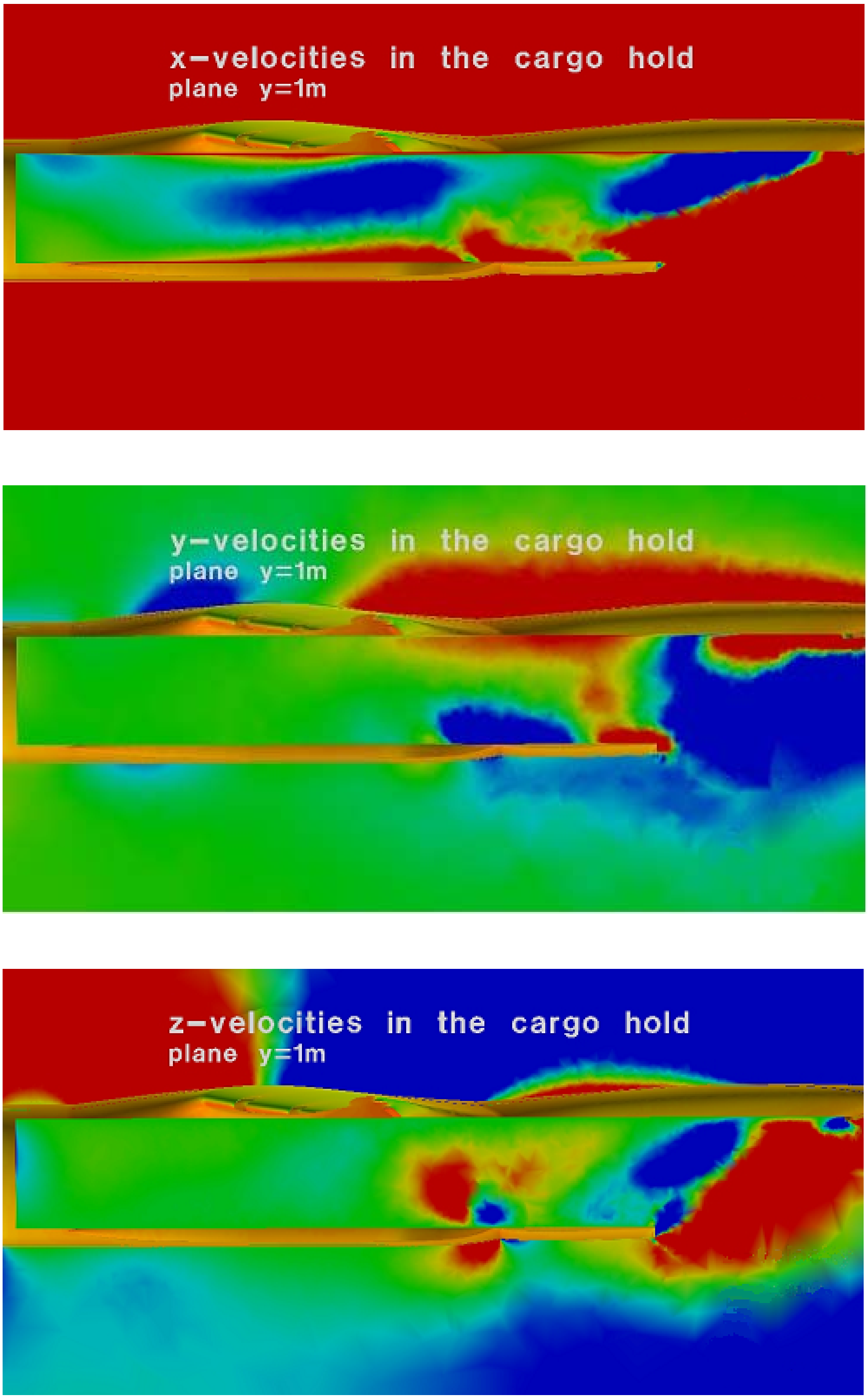

Figure 6: Velocity components in the cargo hold. Coloring between -3m/s and 3 m/s.

Local grid refinement is one way to overcome this drawback and to improve the quality of the solution. This can either be done in the grid generation process by setting geometric sources in grid areas of higher interest or by adaptation of the grid with respect to the current solution of the original grid. The adaptation module of TAU allows multiple successive adaptation steps with sensors based on differences or gradients of several flow variables.

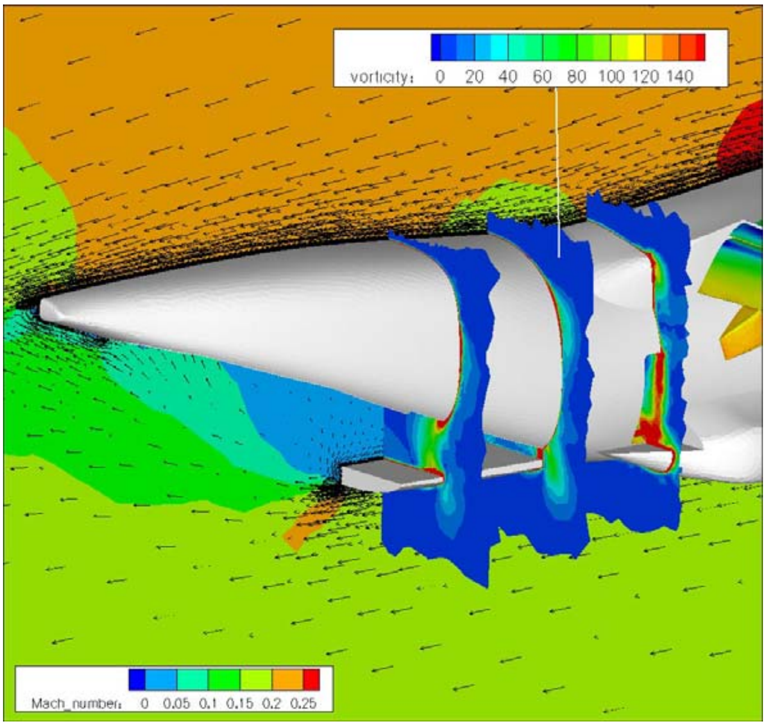

Figure 7: Vorticity development at the rear aircraft

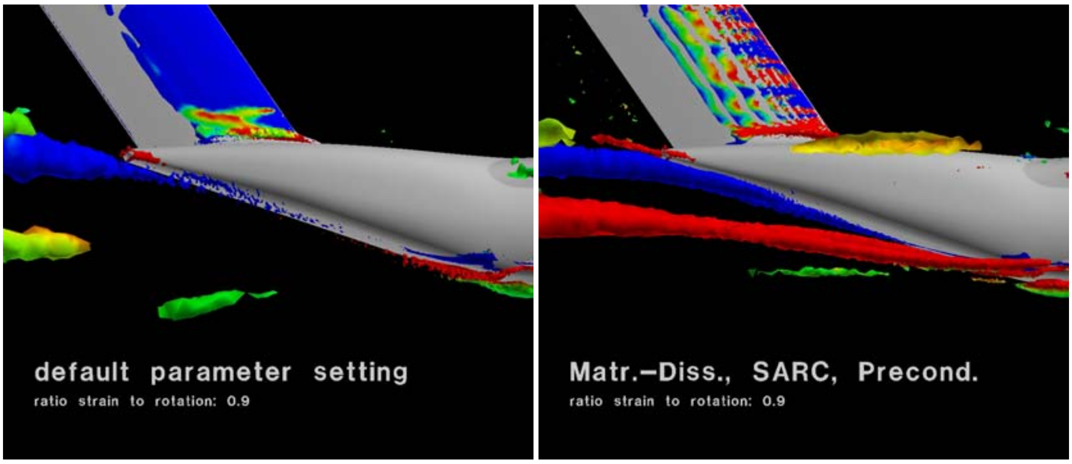

Figure 8: Effects of optimised solver parameter setting

Additionally, TAU provides some optional parameter settings deviant from the default parameter setting used for the calculations above. Matrix dissipation, an alternative formulation for the numerical dissipation terms, which is not as robust as the classical dissipation terms of the central scheme by Jameson, leads in general to less dissipative solutions and is therefore closer to the flow physics. For a better resolution and conservation of vortices a vortical flow correction can be switched on, which limits the production term of the turbulence model in flow regions with a high ratio of rotation to strain, e. g. vortex cores. And finally, a preconditioning for low Mach number flows is implemented, which leads to an improved stability and convergence behaviour in those cases.

The effects of those changed parameter settings on the A400M rear fuselage flow have been analyzed recently for a baseline configuration with empennage system. A comparison between default and improved parameter setting results for exactly the same grid is shown in Fig. 8. Vortices have been made visible as isosurfaces with a strain to rotation ratio of 0.9. It can be seen clearly, that the primary vortex (blue) as well as the sponson vortex (red) is much better resolved and conserved upto regions far behind the aircraft. The coloring of the vortices refers to the sign of ω_x, which means that they rotate in opposite directions.

4.0 CONCLUSION

The main objective of this work was to examine the combined internal/external flow of the military transport aircraft A400M at typical aerial delivery conditions with open doors (cargo door and paratroop doors) and cargo ramp within a feasibility study using the CFD RANS solver TAU. The air entering the cargo hold through the paratroop door is split into two main flow regions, one moving downstream, maintaining its velocity, and one region, which is strongly decelerated, moving forward into the cargo hold. At low speed conditions this air moves up to the forward end of the cargo hold, and flows back along the wall and floor surfaces, thereby being accelerated again and joining with the air immediately going downstream. Behind the door, above the cargo ramp, the flow receives an upwarding momentum, resulting from a recirculation zone, which is located above the cargo ramp, before finally leaving the aircraft again.

The second objective was to test the capability of the RANS solver TAU with respect to configurations leading to flow conditions dominated by vortices and massive separations. Currently, no validation data regarding the interior flow exists that could prove the correctness of the results. But the overall results appear to be consistent and nothing that would rule out their qualitative correctness was observed.

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SYMPOSIA DISCUSSION – PAPER NO: 7

Author's Name: F. Doetter

Discussor's Name: Y. Bury

Question:
Concerning unsteady calculations, how would you initiate instability that leads to unsteady behavior of the flow, and that is naturally not taken into account by the solver, even using a time dependant algorithm?

Author's Response:
So far, this has not been decided. In general the steady state solution is used as initial solution for the unsteady calculations.

Discussor's Name: R.K. Nangia

Question:
It was mentioned the ঽ = 0 for the calculations. Is all the lift generated by high lift system –

Guess G ς.. 1.5 or so?

Author's Response:
Lift and drag considerations was not in the focus of this work, where in a first attempt the general flow phenomena are discussed.

Discussor's Name: I.I. Lipatov

Question:
Have you plans for a future experiment to be compared with the numerical data? There are two physical things influencing the flow field. The first one is the engine jet and the second one is the flow unsteadiness in the region nearby open ramp. Can you take into account these effects?

Author's Response:
Experiments are planning and ongoing with the A400M at airdrop conditions. Slipstream effects will be taken into account by actuator disc modeling in future work. The effect of unsteadiness will be examined by comparison of these steady results with averaged results of unsteady calculations.

Discussor's Name: P. Starke

Question:
Did you introduce the cargo door (Aft part moving up) in the open ramp configuration?

Author's Response:
The upward moving cargo door was omitted in the calculation. Since the cargo hold was rather simplified, the (additional) influence of the cargo door seems negligible!

Discussor's Name: B. Eussen

Question:
Will there be acoustic calculations made with JAU for the A400 cargo-hold?

Author's Response:
Future application – grid not fine enough for acoustics.