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Aerodynamic Modelling for Flight Dynamics Analysis of Conceptual Aircraft Designs

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Physics based simulation in conceptual design is widely seen as a way of increasing the information about designs, thus helping with the avoidance of unanticipated problems as the design is refined. This paper reports on an effort to assess the use of CFD level aerodynamics for the development of tables for flight dynamics analysis at the conceptual stage. A number of aerodynamic data sources are used with sampling and data fusion to allow the efficient generation of the tables. A refined design passenger jet wind tunnel model is used as a test case, and three simplified conceptual versions of this geometry are generated. The influence of geometry approximations and modelling influences are evaluated to assess the usefulness of CFD for this application. Finally, the aerodynamic differences are assessed in terms of basic longitudinal flight dynamics analysis.

I. Introduction

Present trends in aircraft design, towards augmented-stability and an expanded flight envelope, call for an accurate description of the flight dynamic behaviour of the aircraft to enable the design of the flight control system (FCS). In line with the general trends in design, this accurate description is needed early in the process. Unpacking the requirements for such a description, the aerodynamics and mass/inertia properties of the design must be quantified. Both of these rely on the geometry description, which becomes more detailed as the design evolves.

In the current paper we focus on the generation of aerodynamic data. Traditional methods in conceptual design rely on historical trends.[1,2] For non-conventional designs, by definition, there may be limited historical information. This provides motivation to move towards physics based simulation which in principle has no limitations related to geometry. At the highest level, Navier-Stokes based simulations have the potential to predict the full range of quantities and regimes of interest to the designer. At flight conditions we assume that it is the Reynolds' Averaged form (RANS) that is the only possible option.

Two issues arise which must be considered. The first is practical: can meshes be generated automatically and calculations run fast enough (to be consistent with use by a designer operating on a short timescale, rather than a CFD specialist on a longer scale). The second is related to geometry. Some aerodynamic phenomena are very sensitive to geometry. As an example, the drag can be significantly increased by wing-fuselage junction separations, and attention to blending to avoid these is a detailed design task which would not be done at the conceptual stage. The level of geometry at the conceptual stage would be likely to promote junction separations that would be predicted by a RANS simulation. In this sense high fidelity simulations on low fidelity geometries may provide misleading information about the underlying properties of the design.

Considering the first issue, the current state of the art in mesh generation does not allow automatic generation of meshes for RANS simulations around full aircraft configurations,[3,4] although progress is being

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made in this direction[5] . It is however possible to generate meshes for Euler simulations automatically. In addition, Euler simulations are significantly quicker[6] than those based on RANS. As a step in the direction of using RANS, it therefore seems practical to develop methods based on the Euler equations. A number of problems can be addressed, including the handling of geometry[7] and the generation of large data tables.[8]

This paper looks at the issue of matching the fidelity of the geometry to the fidelity of the CFD (Euler) modelling and considers possible consequences when it is ill-matched for a typical conventional passenger jet. The following approach is taken. We start with the DLR F12 wind tunnel model[9] as a geometry. This is a refined design of a development model for a large passenger jet, featuring an advanced aerofoil section, a fuselage-wing junction blending, twist and dihedral of the wings, and a realistic fuselage. This geometry has been simplified consistent with conceptual aircraft design. A number of investigations relating to the influence of geometry and aerodynamic model level are then carried out to see what can be learned from the simplified geometries, and how representative the lessons are of the final refined design.

The underlying software framework for this study is the CEASIOM code, developed within the SimSAC project (Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design) Specific Targeted Research Project (STREP) approved for funding by the European Commission 6th Framework Programme on Research, Technological Development and Demonstration. An overview is presented in reference.[10] Figure 1 shows aspects of its functionality, process and dataflow. Core modules in CEASIOM

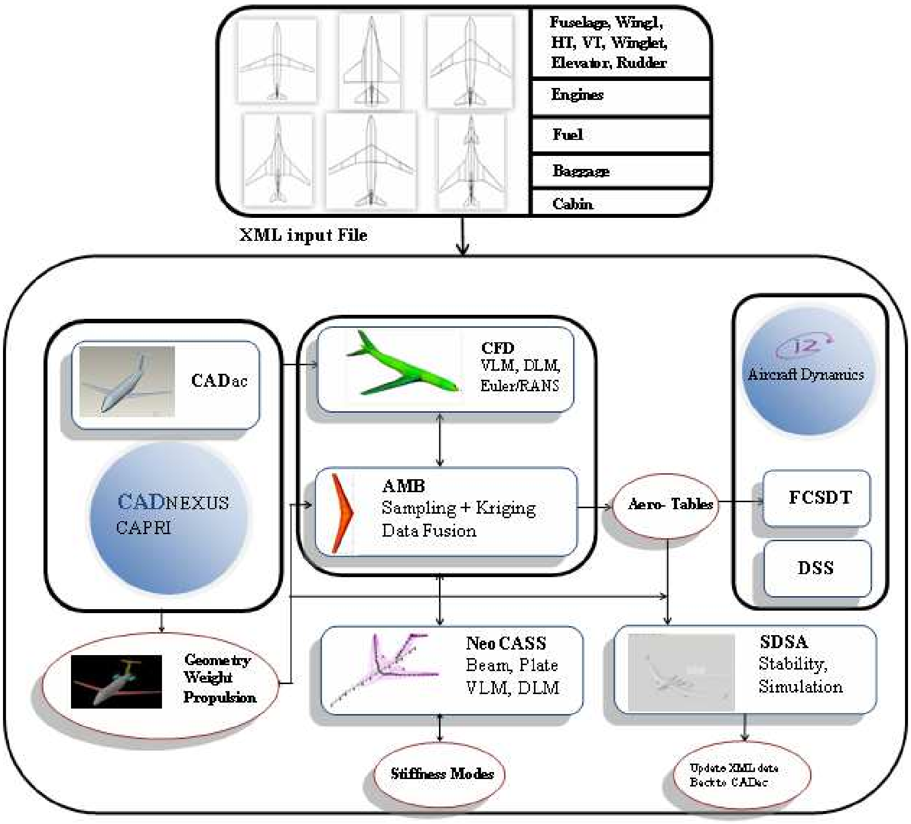


Figure 1. Core modules CADac, AMB-CFD, S&C in the CEASIOM software.

are:

1. The Geometry module CADac: A CAD-centric solid geometry construction system coupled to the user's own CAD and mesh generation systems.
2. The Aerodynamic module AMB: A range of aerodynamic prediction options (DATCOM, vortex-lattice, Euler) closely linked into the geometry module.
3. The Stability and Control module S&C: A static and dynamic stability and control analyser and flying-quality assessor linked in closely with the Aerodynamic module.

The focus of the present paper is on modules 1 and 2, although module 3 is used to illustrate how the aerodynamic differences observed impact on flight dynamics.

The paper continues with a description of the geometry handling and the prediction tools. The test case, geometry definition and mesh generation are then detailed. The building of aerodynamic tables is then described. Comparisons with measurements, the influence of geometry and aerodynamic modelling are shown. Finally, conclusions are drawn.

II. Geometry

The key to a tight integration of the aerodynamic tools is the treatment of the aircraft geometry. Here, a description of the geometry is used which is suitable for conceptual design based on a small number of numerical values (named in this paper as XML-aircraft).

The XML-aircraft is a simplified description of the aircraft geometry in terms of the main design variables for sizing and optimization purposes. In the XML-aircraft, the fuselage part is defined by three sub-sections of forward, centre and aft. The centre section has a constant horizontal and vertical diameter. The forward and aft sections are defined by a length ratio and two angles of **down-sweep** (this is the angle defined in the aircraft plane of symmetry between the horizon and a line connecting the nose to the mid-vertical diameter point) and **shield-sweep** (this is the angle defined in the aircraft plane of symmetry between the horizon and a tangent line to the above line segment of aft or forward section).

A common definition of lifting surfaces is used in the XML-aircraft. For the wing, horizontal tail and vertical tail, the gross theoretical area, span, taper ratio, sweep, apex longitudinal and vertical positions, dihedral and incidence angles are required. This includes tapered wings with a maximum of 2 kink positions. An XML-aircraft lifting surface can have any aerofoil section and number of LE and TE moving devices.

The aerodynamic module converts the XML-aircraft description into the native geometry format for the prediction tools. Of particular interest is the approach used for the unstructured Euler solver. A parametric CAD package CADac is used to produce a CAD model which is passed to an unstructured mesh generator.

Most dedicated aircraft conceptual design packages with Computer-Aided Engineering (CAE) capability such as RDS,[1] Piano,[11] AAA,[2] and ACSYNT[12] typically construct a simple 3D aircraft model by geometrical lofting techniques. The obtained geometry definition must be sufficient for a designer to quickly estimate the performance of a design. For higher fidelity analysis the CAD model must be water tight to allow the generation of a computational mesh. This can require the use of CAD repair software, significantly complicating the analysis. The CADac (CAD-aircraft) tool[7] creates a water tight CAD model from the XML definition of the design by exploiting the CAPRI software.[13]

III. Aerodynamics

A prerequisite for realistic prediction of the stability and control behaviour of an aircraft is the availability of complete and accurate aerodynamic data. Traditionally, wind-tunnel measurements are used to fill look-up tables of forces and moments over the flight envelope. These wind-tunnel models only become available late in the design cycle. To date, most engineering tools for aircraft design rely on handbook methods or linear fluid mechanics assumptions. These methods provide low cost reliable data as long as the aircraft remains well within the limits of the flight envelope. However, current trends in aircraft design towards augmented-stability and expanded flight envelopes require an accurate description of the non-linear flight-dynamic behaviour of the aircraft. The obvious option is to use Computational Fluid Dynamics (CFD).

The CAESIOM aerodynamic module, called the Aerodynamic Model Builder (AMB), has functionality to allow the generation of tables of aerodynamic forces and moments required for flight dynamics analysis. The approach is to use sampling and data fusion to generate the tables, with a variety of sources of aerodynamic data. These aspects are now described.

A. DATCOM

The Data Compendium (DATCOM) is a document of more than 1500 pages covering detailed methodologies for determining stability and control characteristics of a variety of aircraft configurations. In 1979, DATCOM was programmed in Fortran and renamed the USAF stability and control digital DATCOM.

Digital DATCOM is a semi-empirical method which can rapidly produce the aerodynamic derivatives based on geometry details and flight conditions. DATCOM was primarily developed to estimate aerodynamic derivatives of conventional configurations.[14, 15] For a conventional aircraft, DATCOM gives all the individual component (body, wing, horizontal and vertical tail), and aircraft forces and moments.

Digital DATCOM has been implemented in AMB. A DATCOM input file is produced by interpreting and formatting the XML aircraft data. In addition the flight conditions of interest are added to the DATCOM file.

B. Potential Solver

Tornado is a 3D Vortex Lattice program that can predict a wide range of aircraft stability and control aerodynamic derivatives[a]. The program is a Matlab developed code that solves the potential flow equations for a specified flight envelope and given aircraft geometry. The version of Tornado used simulates low-speed and inviscid flow.

The Tornado user guide[16] states:

> Tornado is based on standard vortex lattice theory, stemming from potential flow theory. The wake coming off the trailing edge of every lifting surface is flexible and changes shape according to the flight condition. For example: a rolling aircraft will have a corkskrew shaped wake, which will influence the aerodynamic coefficients. The classical horse shoe arrangement of other vortex-lattice programs has been replaced with a vortex-sling arrangement. It basically works in the same way as the horse-shoe procedure with the exception of that the legs of the shoe are flexible and consist of seven (instead of three) vortices of equal strength. To calculate the first order derivatives, Tornado performs a central difference calculation using the pre-selected state and disturbing it by a small amount, usually 5 degrees. With the distorting wake, non-linear effects will be visible in some designs, especially in those where main wing/stabiliser interactions are important.

The paneling for Tornado is automatically produced within AMB from the XML geometry description.

C. Edge

The unstructured flow solver Edge is used in AMB in Euler mode. As described in the Edge theory guide[17]

> Edge is a parallelized CFD flow solver system for solving 2D/3D viscous/inviscid, compressible flow problems on unstructured grids with arbitrary elements. Edge can be used for both steady state and time accurate calculations including manoeuvres and aeroelastic simulations.
>
> The flow solver employs an edge-based formulation which uses a node-centered finite-volume technique to solve the governing equations. The control volumes are non-overlapping and are formed by a dual grid, which is computed from the control surfaces for each edge of the primary input mesh. In any Edge mesh, all the mesh elements are connected through matching faces. In the flow solver, the governing equations are integrated explicitly towards steady state with Runge-Kutta time integration. Convergence is accelerated using agglomeration multigrid and implicit residual smoothing. Time accurate computations can be performed using a semi-implicit, dual time stepping scheme which exploits convergence acceleration techniques via a steady state from inner iteration procedure.

A Matlab interface was written in order to allow Edge calculations to be prepared and run. This call runs the preprocessing routines, launches the calculation and processes the solution for the forces and moments.

D. PMB

AMB also provides the possibility to exploit external CFD codes. This requires the provision of a mesh generated from the CAD model produced by CADac. The example code used in the current work is the Parallel Multiblock Code (PMB).[18]

The Euler and RANS equations are discretised on curvilinear multi-block body conforming grids using a cell-centred finite volume method which converts the partial differential equations into a set of ordinary

[a] www.ave.kth.se/divisions/aero/software/tornado/tornado.html

differential equations. The convective terms are discretised using Osher's upwind method. Monotone Upwind Scheme for Conservation Laws (MUSCL) variable extrapolation is used to provide second-order accuracy with the Van Albada limiter to prevent spurious oscillations around shock waves. The spatial residual is modified by adding a second order discretisation of the real time derivative to obtain a modified steady state problem for the flow solution at the next real time step, which is solved through pseudo time. This pseudo time problem is solved using an unfactored implicit method, based on an approximate linearisation of the residual. The linear system is solved in unfactored form using a Krylov subspace method with Block Incomplete Upper Lower (BILU) preconditioning. The preconditioner is decoupled between blocks to allow a high efficiency on parallel computers with little detriment to the convergence of the linear solver. For the Jacobian matrix of the CFD residual function, approximations are made which reduce the size and improve the conditioning of the linear system without compromising the stability of the time marching.

Given a block structured mesh, AMB can prepare input files and launch calculations using PMB.

E. Sampling and Data Fusion Methods

The application of the aerodynamic prediction methods in the current work is for the generation of tables of forces and moments. This potentially entails a large number of calculations, which will be a particular problem if CFD is the source of the data. This issue was addressed by sampling, reconstruction and data fusion in reference.[8]

Two scenarios were postulated in this reference, based on (1) a requirement for tables for a completely new design and (2) for updating tables for existing designs which are being altered.

In the first scenario it is assumed that the requirement is for a high fidelity model and that this can be generated offline (i.e. the calculation can perhaps be done overnight without a user waiting for the model during an interactive session). In this scenario the emphasis is on sampling finding nonlinearities in the forces and moments. Two approaches to this sampling (based on the Mean Squared Error criterion of Kriging and the Expected Improvement Function) were considered in reference.[8]

The second scenario is when a designer is involved in an interactive session. It is assumed that the aircraft geometry is incremented from an initial design, perhaps selected from a library, and that a high fidelity model is available for the initial design from the first scenario. Data fusion (based on co-Kriging) is then used to update this initial model, based on a small number of calculations at an acceptable cost (which at present rules out RANS). In this scenario it is assumed that the flow topology resulting from the initial geometry does not change during the geometry increments. If this is not the case (eg the wing sweep angle increases so that vortical flow starts to dominate at high angles), then either a new initial geometry needs to be selected, or the interactive session needs to be suspended so that a new high fidelity model can be generated under scenario one.

Using these techniques it was shown that tables could be generated in the order of 100 calculations under the first scenario and 10 calculations under the second scenario.

IV. Geometry and Meshes

A. Passenger Jet Configuration

The configuration used for testing is based on the F12 wind tunnel model from the German Aerospace Center (DLR). The model consists of wing, body, horizontal and vertical tail. The aircraft layout is shown in Figure 2. The model is a 1:29 scale development model of a passenger jet. The CAD model includes a detailed blend at the wing root and an advanced supercritical aerofoil section. The model was wind-tunnel tested by DLR to provide static and dynamic data for benchmarking the aerodynamic modules of CEASIOM.[9] This geometry is referred to as the wind tunnel (WT) geometry in this paper.

Based on the detailed CAD model of the WT geometry, three XML descriptions were produced, referred to as XML1, XML2 and XML3. From these XML descriptions the CAD definition was reconstructed. These CAD models have generic aerofoil sections and lack refinements like the fuselage/ wing junction blending, and are meant to represent the detailed design as it would have been during the conceptual phase.

The XML1 and XML2 aerofoil sections are identical. The aerofoil is cambered and has maximum thickness at 0.0889c at 0.3684c. This aerofoil is much thinner than WT model. The XML3 wing uses the NACA 0012 aerofoil with a -3.74 degree incidence angle at the wing root. In contrast to this, XML1 and XML2 have 3.79 degree of incidence angle, slightly larger than the WT model.

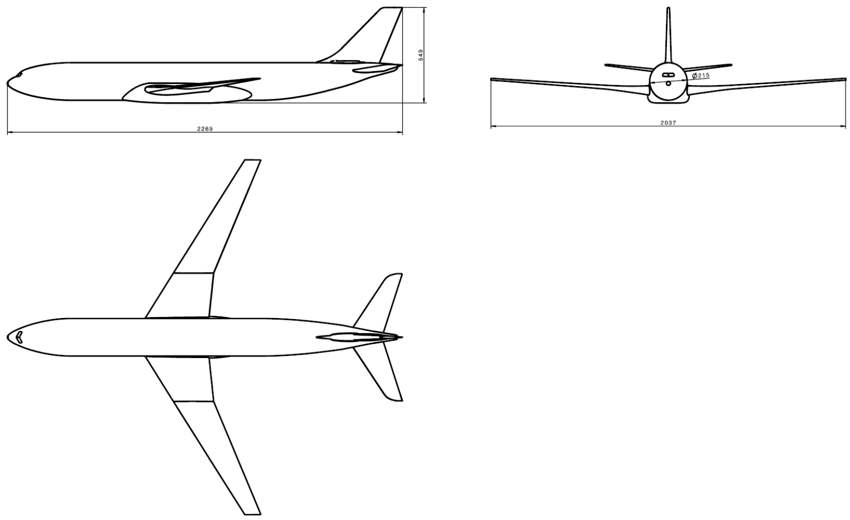


Figure 2. Three View of DLR-F12

XML1 and XML2 dihedral and sweep angles are close to the WT model, but the XML1 wing is placed lower than those on the WT and XML2 geometries. The XML1 vertical placement is at 14% of fuselage diameter from the bottom of the fuselage. This distance for the XML2 geometry is 24%. The XML3 wing is lower positioned relative to the WT model, the value is close to the one used for XML2. The XML3 model has zero degrees dihedral angle.

The Horizontal tail of the XML1 and XML3 geometries is positioned above the WT and XML2 geometries. The vertical placement ratio is 0.4, while the XML2 value is 0.2653.

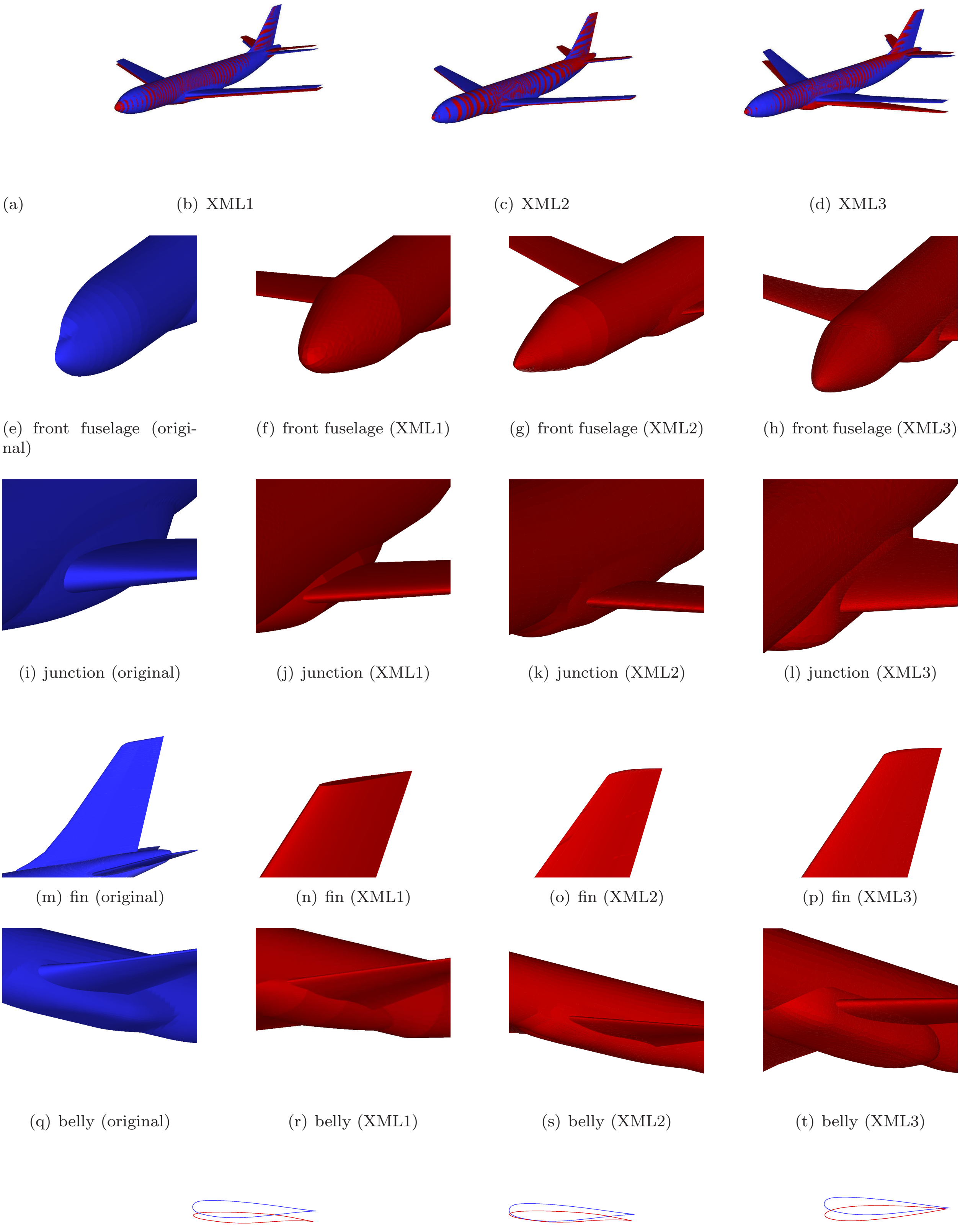
There is a sharp transition from nose to the mid fuselage sections for the XML geometries. The non-smooth junctions present in the XML1 and XML3 geometries, were smoothed manually for XML2 geometry. However, the fairing still lacks the detailed WT design. The XML wing, tail and fin tips are flat instead of rounded as in the original design. Also, there is no dorsal fin section model in the XML files.

In summary, the XML1 and XML2 geometries are closer respresentations of the WT geometry, and the XML2 has improved blended joints.

B. Mesh Generation

A multiblock structured grid was generated by CERFACS[9] for the WT geometry. The commercial grid generation tool ICEMCFD was used. Grids for Euler and RANS solutions were generated. The original grids had hanging block faces, and were pre-processed to enforce one to one face connectivity as required for the PMB flow solver. In addition, the original grids were for half configurations, and were reflected to allow cases with side slip to be computed. The summary of the grid sizes is shown in table 1. Views of the surface grid for the fine Euler grid are shown in figure 4. In addition the RANS grid features a blunt trailing edge. The CERFACS Euler blocking was projected onto the XML1 and XML2 aircraft CAD files, and some of the spacings were adjusted.

The Edge meshes were generated by Politechnico di Milano and University of Liverpool for the XML1 and XML3 geometries respectively. The meshes consist of tetrahedra, and were generated around the XML aircraft CAD file produced by CADac. The grid for XML1 includes 210 thousand nodes, 997597 elements and 1292453 edges. Agglomerated meshes for 4 multigrid levels were produced. The grid for XML3 consists of 105,722 nodes and 103,177 edges. Views of the surface grid for the XML-1 fine Euler grid are shown in figure 5.



(a) (b) XML1 (c) XML2 (d) XML3

(e) front fuselage (original) (f) front fuselage (XML1) (g) front fuselage (XML2) (h) front fuselage (XML3)

(i) junction (original) (j) junction (XML1) (k) junction (XML2) (l) junction (XML3)

(m) fin (original) (n) fin (XML1) (o) fin (XML2) (p) fin (XML3)

(q) belly (original) (r) belly (XML1) (s) belly (XML2) (t) belly (XML3)

(u) (v) XML1 root aerofoil (w) XML2 root aerofoil (x) XML3 root aerofoil

Figure 3. Details of Comparison of original (blue) and XML (red) aircraft geometries.

Table 1. WT Geometry Block Structured Grid sizes

Case	Number of Grid Points
Euler Half Configuration Coarse	299,320
Euler Half Configuration Fine	2,024,772
RANS Half Configuration Coarse	1,573,470
RANS Half Configuration Fine	12,587,757
RANS Full Configuration Coarse	25,175,514

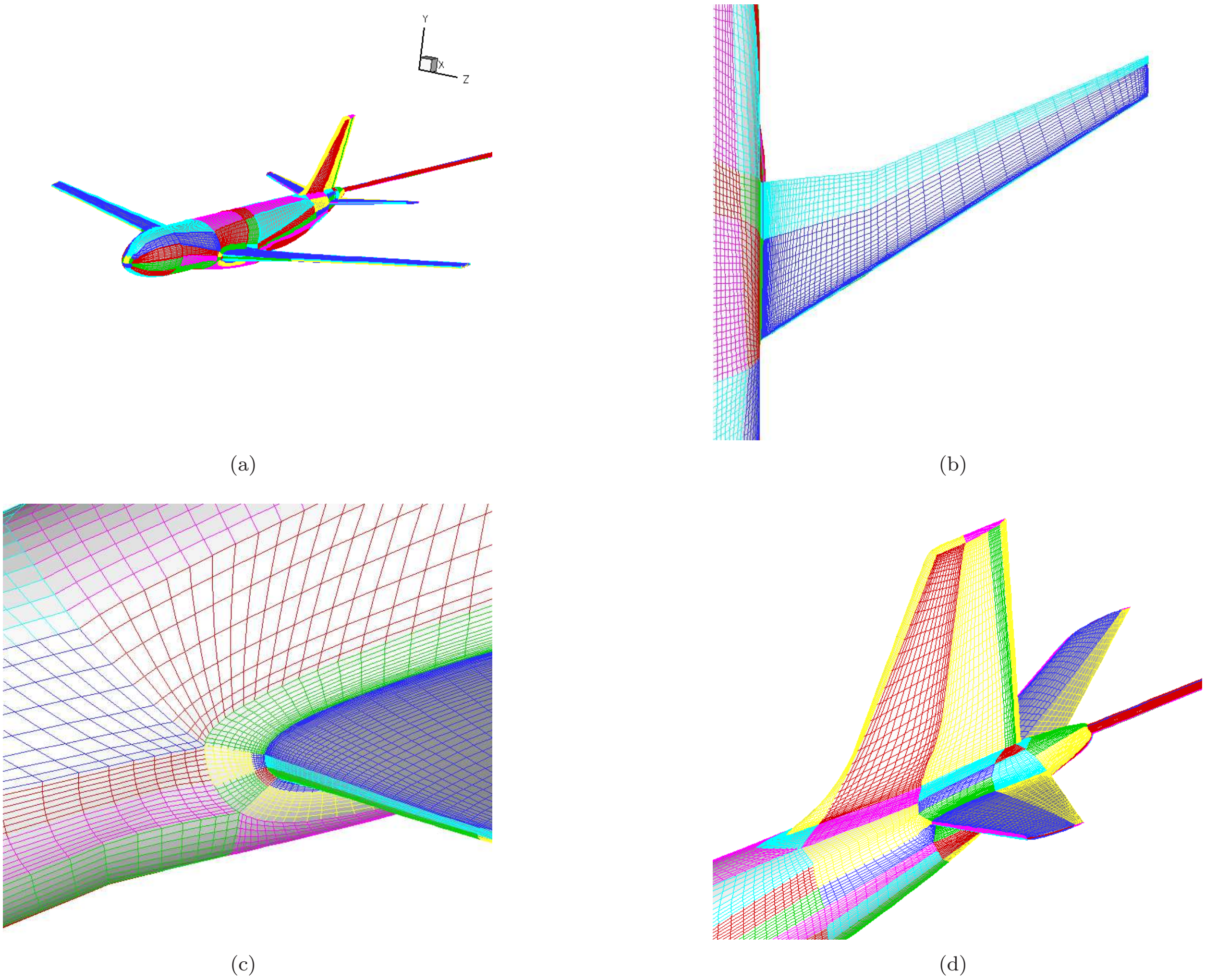
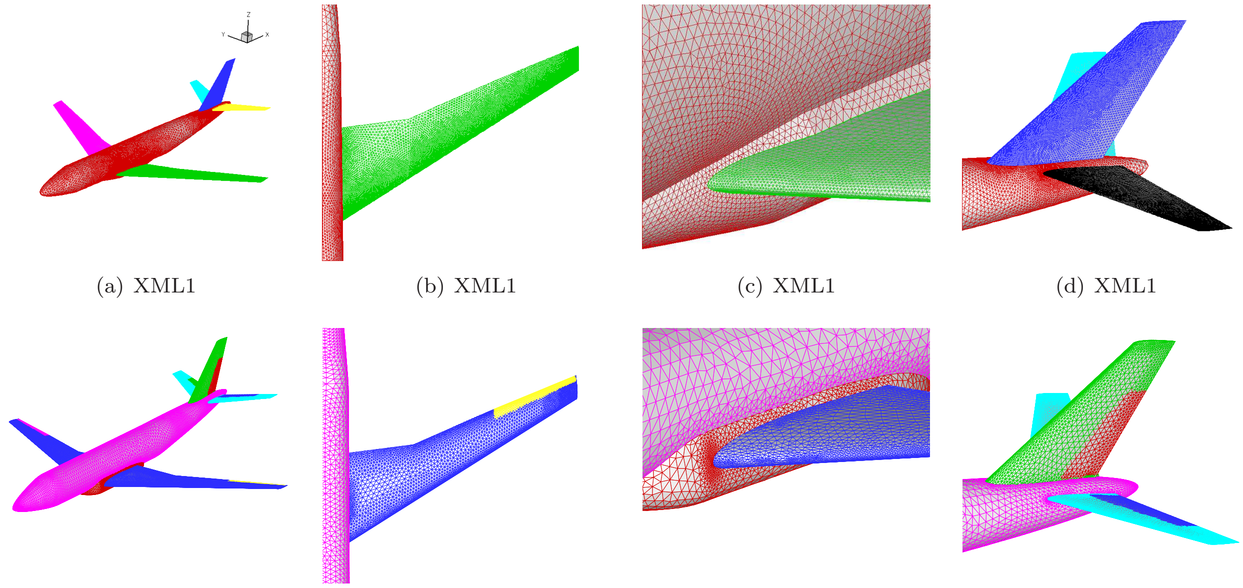


Figure 4. Views of the fine Euler multiblock surface grid for the WT Geometry.



(a) XML1 (b) XML1 (c) XML1 (d) XML1

(e) XML3 (f) XML3 (g) XML3 (h) XML3

Figure 5. Views of the XML1 Edge Euler surface grid.

V. Data Generation

Sampling and data fusion were used to generate aerodynamic tables for the XML1, XML2 and XML3 geometries. The process followed was meant to mimic that of scenarios 1 and 2 summarized above.

The original conceptual geometry was chosen to be XML3. The tables for this geometry were generated from scratch under scenario 1. A 648 entry, three-parameter table (angle of attack, Mach number and side-slip angle) was first generated using the Edge solver. The sampling was used to define 55 calculations, and Kriging was then used to construct all of the table entries. The generated table describes the basic behaviour of the XML3 aerodynamics. Ten test samples were generated at random flight conditions and the predictions from the table are compared with those calculated by the Edge solver at these samples (figure 6). Close agreement is obtained for all samples.

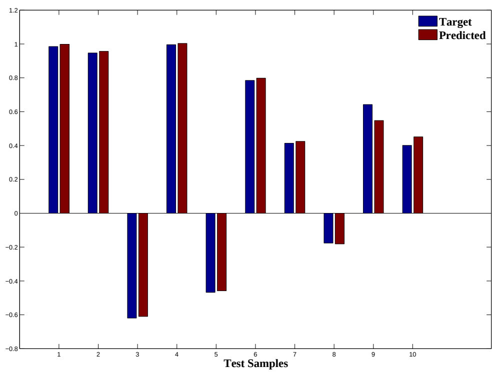
Next, the table for angle of attack, Mach number and elevator was generated. Twelve additional samples at non-zero elevator angles were defined around the border of the table and in the nonlinear regimes highlighted by the first table.

Under scenario 2 we assume that the XML1 and XML2 geometries are increments of the XML3 geometry. This assumes that the flow regimes are the same, although the magnitudes of forces and moments can be different. Again 12 samples were defined (some at the border to avoid extrapolation and some at non-linear regime from the XML3 table) and calculated for the XML1 geometry using the Edge solver, and the XML3 angle of attack, Mach number and side-slip table was updated using co-Kriging. The result for the aerodynamic coefficients for the XML1 geometry are evaluated in Fig. 7. Here, 40 test samples were defined at random and the predictions from the table are compared with CFD calculations at these samples. Good agreement is obtained for all samples.

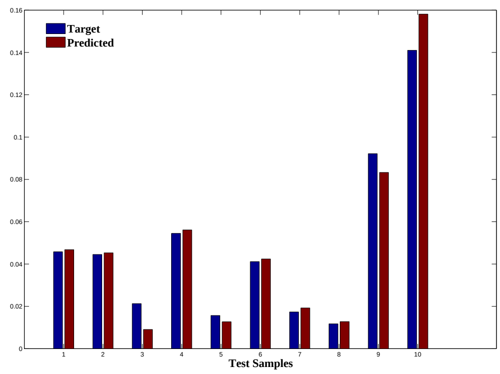
The XML1 and XML2 geometries do not include a defined elevator. To allow the tables with the elevator effect to be generated it is assumed that the increment in the force or moment arising from the elevator deflection is identical to that arising for the XML3 geometry.

VI. Evaluation of Predictions

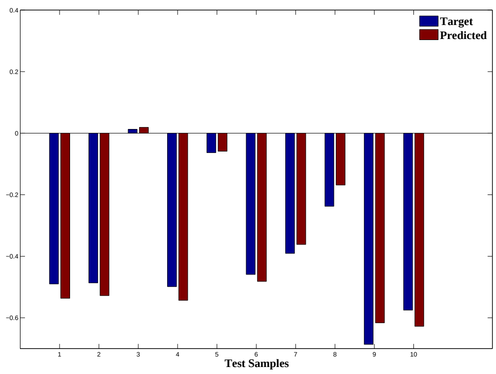
In this section the influence of the geometry and aerodynamic model selection on the aerodynamic force and moment predictions is now evaluated. First, the CFD predictions are compared with measurements for the WT geometry. This is done for RANS and Euler modelling to create a benchmark for the error incurred



(a) C_L

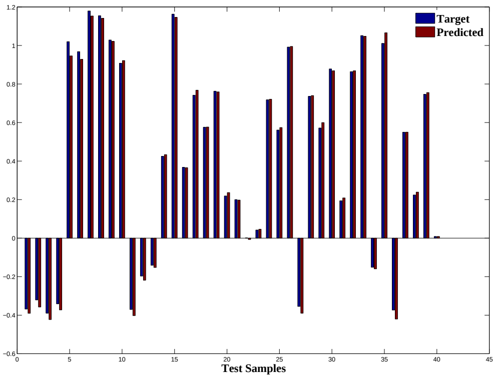


(b) C_D

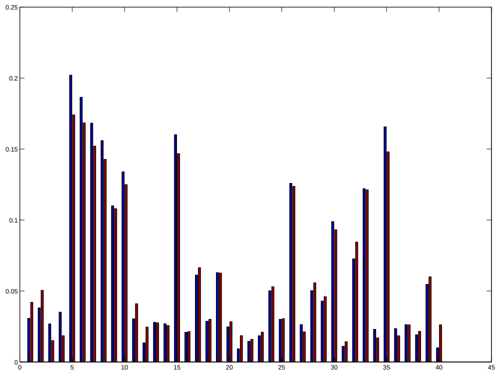


(c) C_m

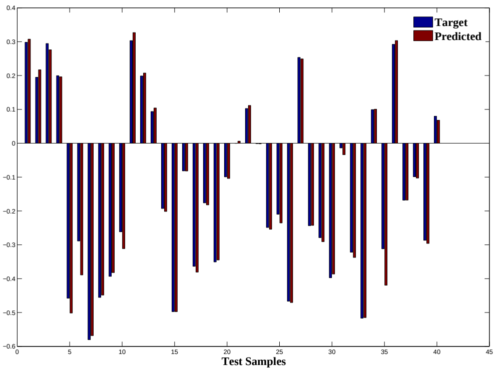
Figure 6. Target and Predicted Values of Sampling Scenario for the XML3 geometry



(a) C_L



(b) C_D



(c) C_m

Figure 7. Target and Predicted Values of data fusion model for the XML1 geometry

by using Euler modelling. Then the influence of geometry is considered by comparing the Euler predictions for the three XML geometries against the WT geometry predictions. Finally, the predictions of different aerodynamic models for the XML3 geometry are compared.

A. WT CFD predictions

Wind tunnel data for the lift, drag and pitching moment coefficients is available at low speed. The conditions of the wind tunnel tests were $U = 70$ m/s, $Re = 1.215$ million, $P_\infty = 100246.1$ Pa, $T_\infty = 294.4$ K for a wind tunnel model with a wing span of 2.018m. The comparisons between the measurements and the RANS and Euler predictions using PMB applied to the WT geometry are shown in figure 8. The RANS results match the measurements well, with the exception of an overprediction of the drag at the higher angles. As expected, the lift coefficient is well predicted by the Euler equations also. The drag is shifted down when compared with the RANS predictions, reflecting the lack of the skin friction contribution. The pitching moment is more negative from the Euler results.

No transonic measurements are available. Code to code comparisons are shown in figure 9. The RANS and Euler predictions of lift are again close. The drag predictions become closer as the angle of attack increases, reflecting the increasing dominance of wave drag as the shock wave increases in strength. In the transonic speed range, the airplane aerodynamic centre shifts aft,[2] resulting in a larger pitching moment curve slope compared with the subsonic regime. However, as the angle of attack is increased, the shock becomes stronger and this might result in a forward shift of the aerodynamic centre as observed in Fig.

B. XML geometry comparisons

Euler predictions are compared for the WT and XML geometries. The main interest is whether the differences between the XML geometries can be computed or whether the rough features present in all three conceptual aircraft CAD models dominate the predictions.

At low speed, shown in figure 10, due to the negative wing-root incidence angle, less lift and drag are predicted for the XML3 geometry. This also results in a negative pitching moment coefficient at zero angle of attack.

At transonic conditions, the thicker XML3 airfoil section results in stronger shocks in the conceptual geometries, leading to higher drag. Also, the XML1 drag is above XML2 model, possibly due to additional drag rising from non-blended interferences.

In general it is not obvious that the rough geometry is driving the comparisons between the three geometries. The differences seem to be driven by the wing geometry, and in particular the aerofoil section.

C. Comparison of Model Predictions

The predictions for the XML1 geometry using Euler, DATCOM and Tornado are now compared.

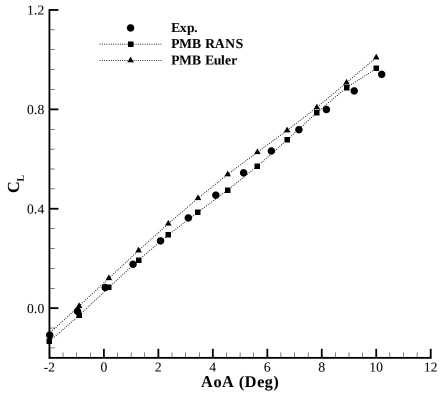
The AMB integrated Datcom model only allows predictions for a straight tapered wing, which is not the case for DLR F12 model. The Datcom wing model has average values of spanwise changes, for example, incidence, sweep and dihedral angles. The Datcom and Tornado models have a single aerofoil section along the wing span. Also, Tornado does not consider the fuselage effects, resulting in a different pitching moment slope.

Datcom does not predict any transonic regime data ($0.6 < M_\infty < 1.2$), thus for transonic comparisons, the $M_\infty = 0.6$ is plotted. The version of Tornado used has no compressibility or viscous effects. Datcom has an estimation of compressibility effects up to transonic regime.

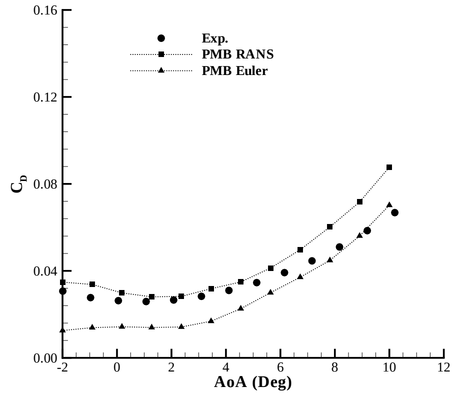
The comparison of the different model predictions is shown in figure 12 for the subsonic case and figure 13 for the transonic case.

The Euler predictions for the XML1 and XML2 lift and drag coefficients are close to those for Datcom as well at the low speed regime. There is an off-set for the pitching moment probably due to different moment arms because of the positions of the main wing and horizontal tail. Also, as the aerofoil and incidence angle varies from the other geometries it has an underestimation of lift and drag coefficients at low speed. This is also observed in the Euler predictions.

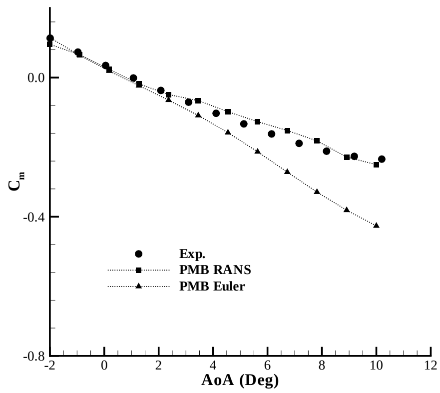
Datcom transonic values are not accurate. There are slight changes for aerodynamic coefficients from low speed but the big jump in Euler drag and changes of the lift and pitching moment slopes are not predicted



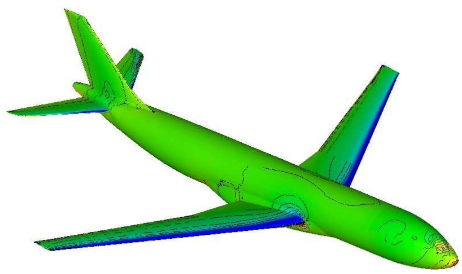
(a) CL



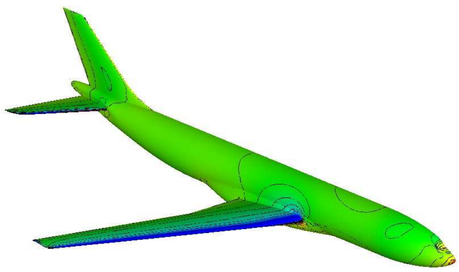
(b) CD



(c) Cm

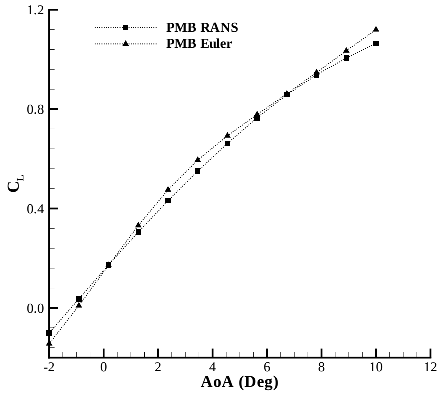


(d) Euler-AoA=8^o

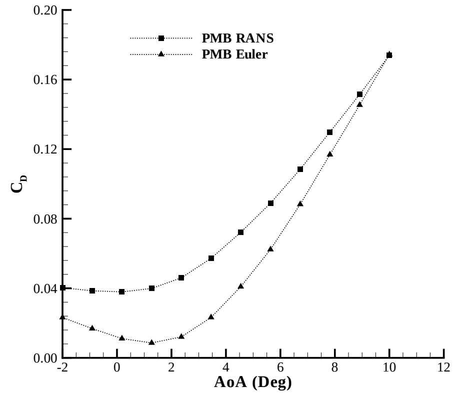


(e) RANS-AoA=8^o

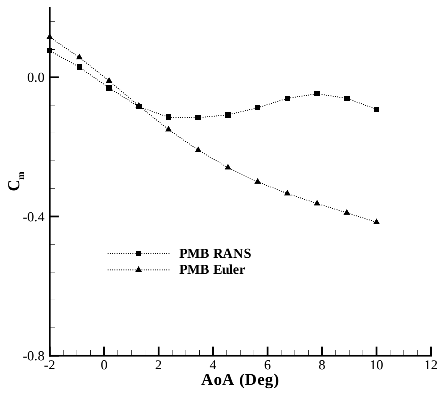
Figure 8. Comparison of PMB predictions for the WT Geometry at M=0.2.



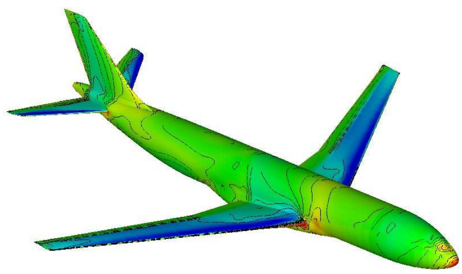
(a) CL



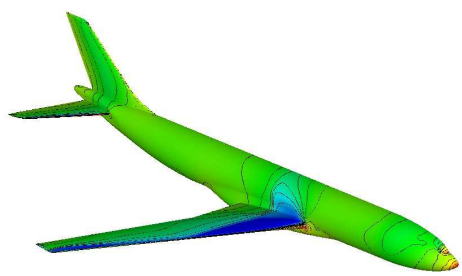
(b) CD



(c) Cm

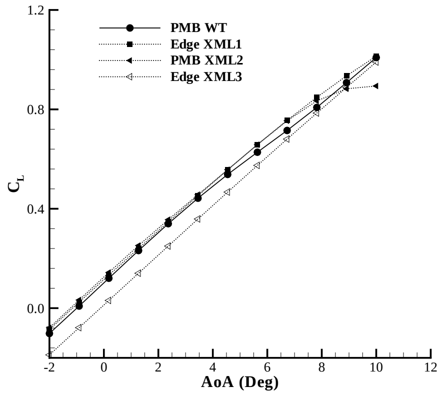


(d) Euler-AoA=8^o

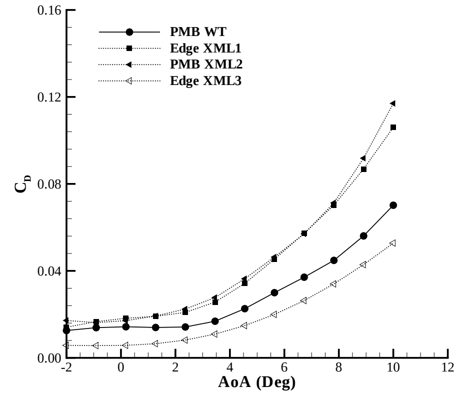


(e) RANS-AoA=8^o

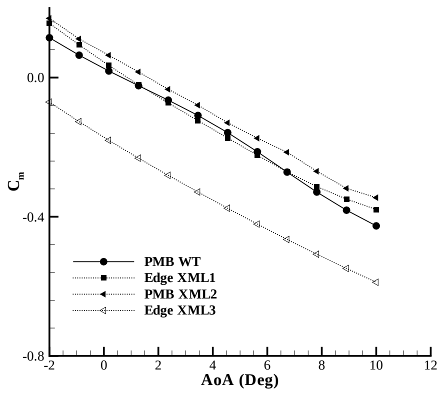
Figure 9. Comparison of PMB predictions for the WT Geometry at M=0.8.



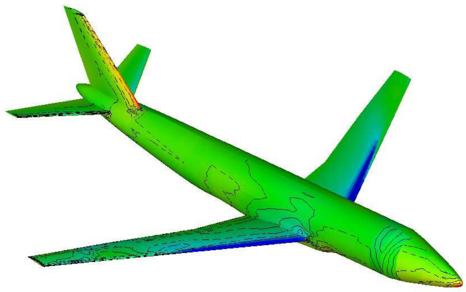
(a) CL



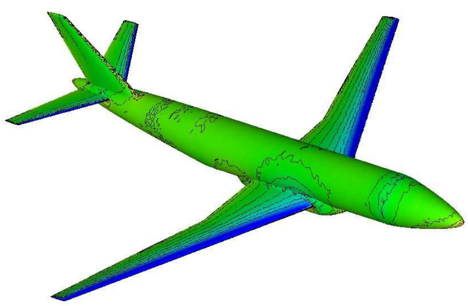
(b) CD



(c) Cm

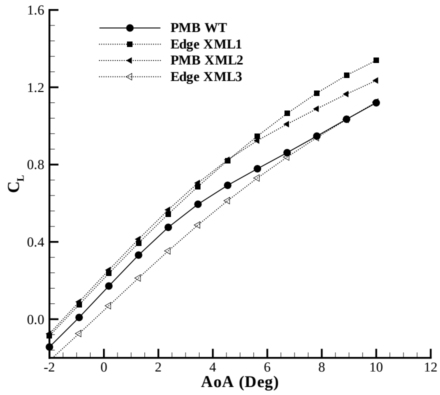


(d) XML2-AoA=8^o

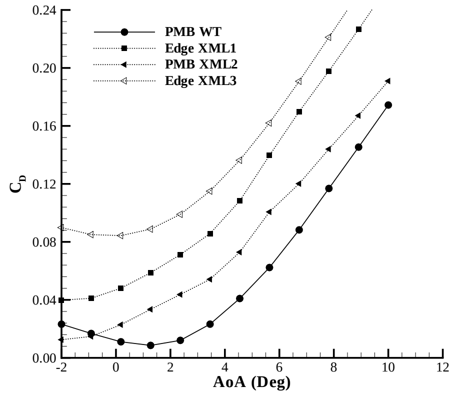


(e) XML3-AoA=8^o

Figure 10. Comparison of Euler predictions for the various Geometries at M=0.2.



(a) CL



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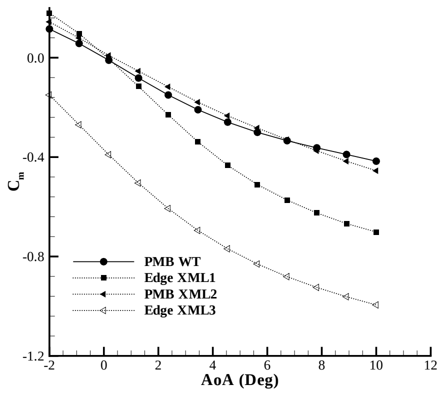

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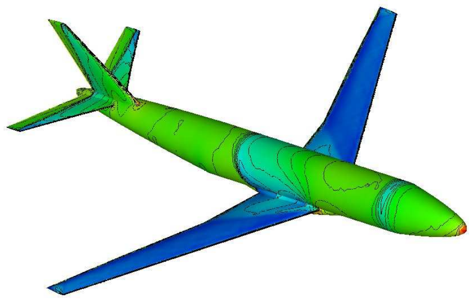
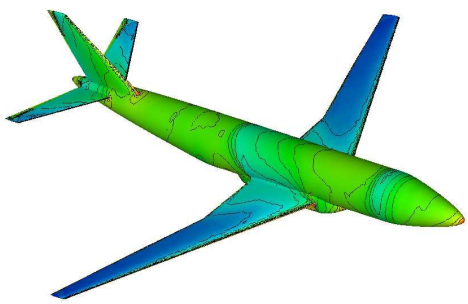


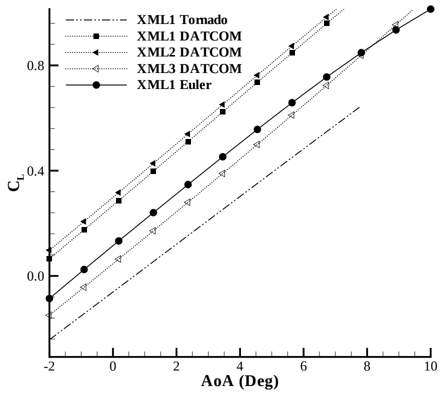
(d) XML1-AoA=8^o



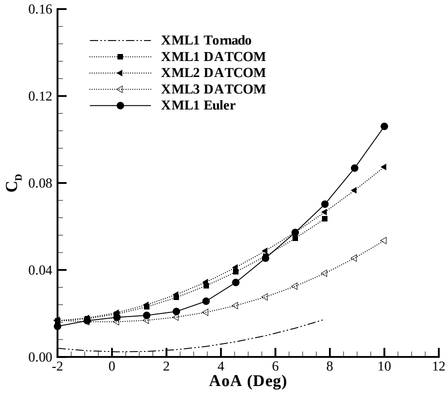
(e) XML3-AoA=8^o

Figure 11. Comparison of Euler predictions for the various Geometries at M=0.8.

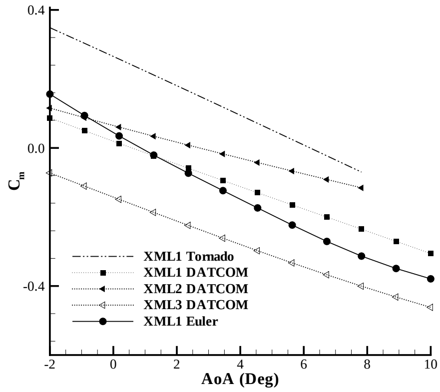
by Datcom. Also, at transonic conditions the XML3 drag is less than the others, whilst for Euler the XML3 geometry has the highest drag in the transonic regime.



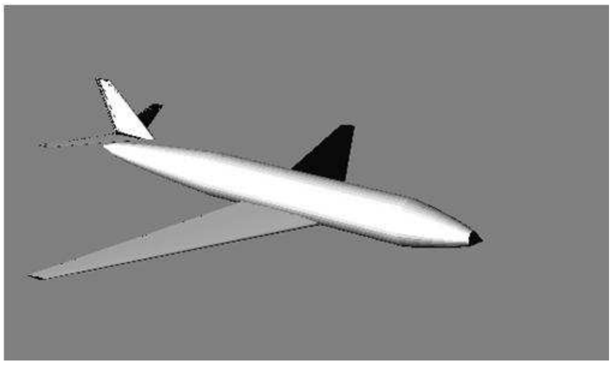
(a) CL



(b) CD



(c) Cm



(d) DATCOM model

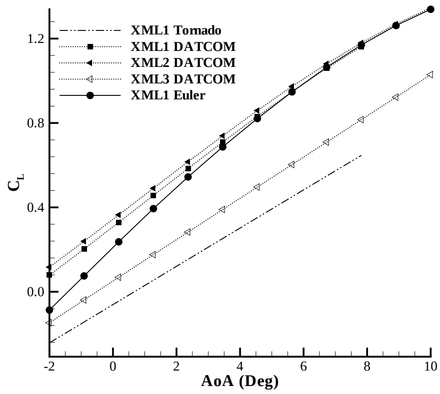
Figure 12. Comparison of model predictions for aero sources at M=0.2.

VII. Flight Dynamics Analysis

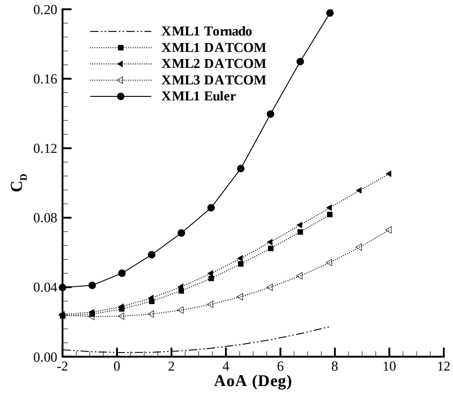
The SDSA (Simulation and Dynamic Stability Analysis) code employs a nonlinear model of aircraft equations of motion given in references.[20,21] For eigenvalue analysis, the non-linear model is linearized numerically using the Jacobian Matrix of the state derivatives around equilibrium point. SDSA also facilitates a six DoF flight simulation , figures of merits based on JAR/FAR, ICAO and MIL regulations, flight control model and trim analysis.

The generated aerodynamic look up tables including angle of attack, Mach number and elevator deflection values are fed to SDSA code. Figure 14 shows the comparison of values of angle of attack and elevator deflection for trimming the DLR F12 model for a range of flight speeds at 10,000m altitude.

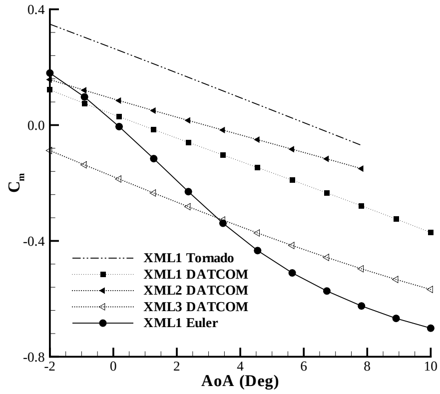
The predictions based on the Euler generated aerodynamic are all in close agreement. The predictions based on Datcom and Tornado show more spread.



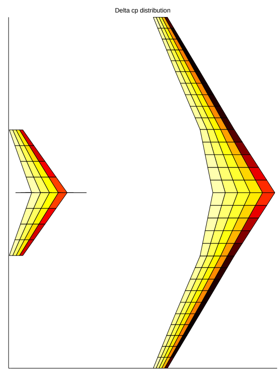
(a) CL



(b) CD

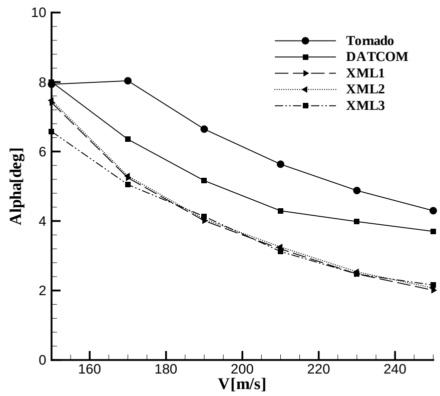


(c) Cm

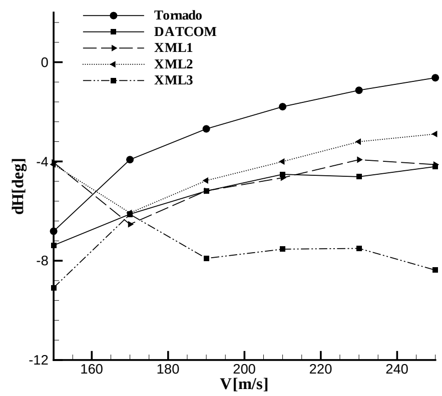


(d) Tornado Panelling

Figure 13. Comparison of model predictions for aero sources at M=0.8.



(a) AoA



(b) Elevator

Figure 14. Wings-Level Trim Analysis at 10,000 m altitude

VIII. Conclusions

Tables for flight simulation have been generated for several conceptual geometries using different sources of aerodynamics. The Euler equations was used as the highest level of modelling since the geometry handling and mesh generation can be automated from the high level XML description of the geometry through to the construction of the tables of forces and moments. Sampling and co-Kriging were demonstrated for the table generation.

The important geometry differences in the three conceptual geometries turned out to be associated with the wing geometry, and in particular the aerofoil section and twist distribution. The Euler geometries have some roughness associated with kinks in the fuselage description and at junctions. However, the differences in predictions could be associated with the differences in the conceptual description of the aircraft rather than these features. This provides evidence, together with the efficiency of the table generation and the automation of the analysis, that it is worth pursuing the use of the Euler equations for this application. The trimming analysis showed the advantage of using the CFD, namely that the spread of results due to required simplifications is reduced.

Future work will involve two avenues. First, the test case used in this work is a very conventional design. The usefulness of the CFD for unconventional designs needs to be evaluated. Secondly, the use of RANS provides extra predictive potential but also more serious possible difficulties arising from geometry roughness. This needs to be examined.

IX. Acknowledgements

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