CEASIOM: SIMULATING STABILITY & CONTROL WITH CFD/CSM IN AIRCRAFT CONCEPTUAL DESIGN

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Abstract

An overview is given of CEASIOM, the Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods. The benchmark for validation is the F12 windtunnel model of a generic long-range airliner. First results for the design of the Transonic Cruiser (TCR) high-speed passenger transport concept are presented.

1 Introduction

Present trends in aircraft design towards augmented-stability and expanded flight envelopes call for an accurate description of the flight-dynamic behaviour of the aircraft in order to properly design the flight control system (FCS). Hence the need to increase knowledge about stability and control (S&C) as early as possible in the aircraft development process in order to be "First-time-right" with the FCS design architecture. The review paper by Vos et al. [1] describes these ideas in terms of the 'Virtual Product' and explains much of the background motivation for our work here. The starting point and inspiration for the software development leading to the present CEASIOM (Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods) was provided by Isikveren [2], who developed the MATLAB™[3] QCARD package for aircraft conceptual design with quasi-analytical shape definitions, aero-data correlations, and performance predictions.

In order to address this need, development of the CEASIOM simulation system is currently underway. The CEASIOM code is developed within the frame of the SimSAC (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. Work began 1 November 2006 and continues for 3 years, (see www.simsacdesign.eu). The SimSAC project aims at significantly enhancing CEASIOM functionality by introducing software that initially will focus on rapid low fidelity analysis, and as appropriate, resort to higher fidelity numerical simulations. Moreover CEASIOM will involve stability and control driven sizing and optimization earlier in the design cycle than is stan-

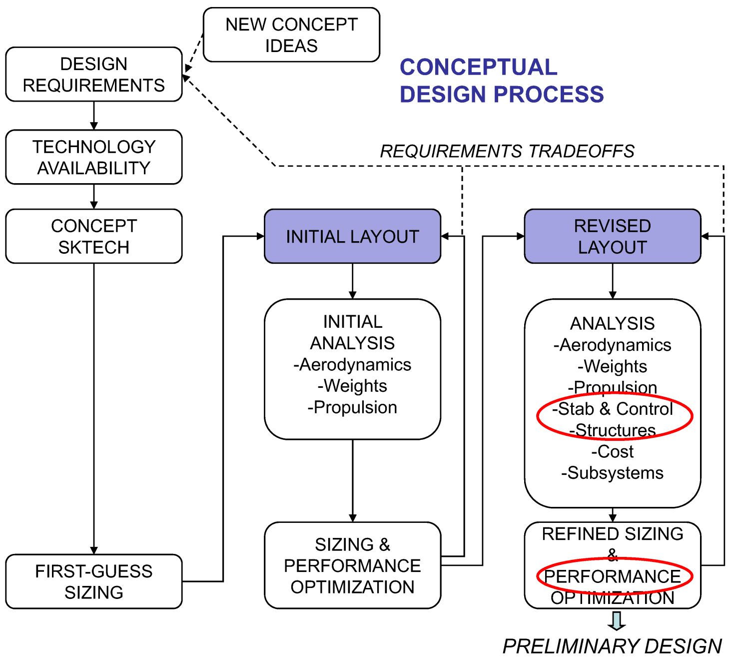

Fig. 1 Raymer's illustration [4] of the conceptual design process segmented into two cycles: the initial layout and the revised layout. CEASIOM focuses in particular on the S&C, structural-aeroelastic, and performance characteristics of the aircraft.(ⓒDaniel Raymer with permission)

dard practice today. CEASIOM runs under either Windows or Linux, and its basic version requires a MATLAB license only. In executable form the code can be run without a license.

Referring to Fig. 1 taken from Raymer's textbook [4], CEASIOM is meant to support engineers in the conceptual design process of the aircraft, with emphasis on the improved prediction of stability and control properties achieved by higher-fidelity methods than found in contemporary aircraft design tools. Moreover CEASIOM will integrate into one application the main design disciplines, aerodynamics, structures, and flight dynamics, impacting on the aircraft's performance. It is thus a tri-disciplinary analysis brought to bear on the design of the aero-servo-elastic aircraft. CEASIOM does not however carry out the entire conceptual design process. It requires as input an initial layout as the baseline configuration that it then refines and outputs as the revised layout. In doing this, CEASIOM, through its simulation modules, generates significant knowledge about the design in the performance, loads, and stability and control databases, see Fig 2. The information contained in these databases is sufficient input to a six Degree of Freedom engineering flight simulator, such as the EFS system developed by Wakayama and Kroo [5].

This paper provides an overview of the current status and planned development on the CEASIOM simulation system .

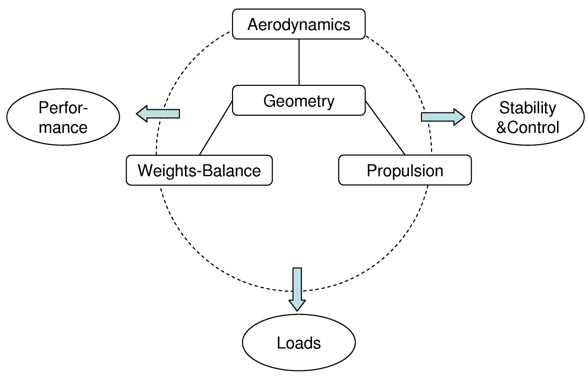

Fig. 2 CEASIOM by simulation constructs the stability and control, loads, and performance databases of the revised layout design.

2 CEASIOM

Figure 3 presents an overview of the CEASIOM software, showing aspects of its functionality, process and dataflow. Significant features are developed and integrated in CEASIOM as modules:

1. The Geometry module CADac
   A CAD-centric solid geometry construction system coupled to the user's own CAD and mesh generation systems by interfacing CEASIOM with MIT's Computational Analysis Programming Interface (CAPRI)

2. The Aerodynamic module AMB-CFD
   A replacement of current handbook aerodynamic methods with new adaptable-fidelity modules referred to as tier I (a. and b.) and tier II (c.):

   a. Steady and unsteady TORNADO vortex-lattice code (VLM) for low-speed aerodynamics and aero-elasticity

   b. Inviscid `Edge` CFD code for high-speed aerodynamics and aero-elasticity

   c. RANS (Reynolds Averaged Navier-Stokes) flow simulator for high-fidelity analysis of extreme flight conditions

3. The Stability and Control module S&C
   A static and dynamic stability and control analyser and flying-quality assessor. Test flights with six Degrees of Freedom flight simulation, and performance prediction are among the major functionalities of this module. The user can choose between two variants:

   i. SDSA (Simulation and Dynamic Stability Analysis), the SimSAC-developed and license-free software which includes a LQR-based flight control system package , or

   ii. J2 Universal Tool-Kit, the commercially-available industrial-grade engineering analysis tool for assessment and visualization of aircraft in flight. (see www.j2aircraft.com)

4. The Aeroelastic module NeoCASS
   Quasi-analytical structural analysis methods that support aero-elastic problem formulation and solution

5. The Flight Control System design module FCSDT
   A designer toolkit for flight control-law formulation, simulation and technical decision support, permitting flight control system design philosophy and architecture to be coupled in early in the conceptual design phase

6. The Decision Support System module DSS
   An explicit DSS functionality, including issues such as fault tolerance and failure tree analysis.

CEASIOM interfaces for seamless integration also with the J2 Universal software developed by the CEASIOM partner J2 Aircraft Dynamics, Ltd. (www.j2aircraft.com) are being set up. The flight control system design packages are under development by the CEASIOM partners Bristol University (http://www.bris.ac.uk/) and TsAGI (http://www.tsagi.ru/eng/). They employ H_∞-control law formulation and parameter optimization, and will provide a simple interface satisfactory for most users, as well as detailed interaction required by expert users. These developments are being reported elsewhere (e.g. see [6]. For this reason, the focus of the present paper is on modules 1 to 4. The following paragraphs give an overview of these modules.

2.1 Geometric module CADac

Most dedicated aircraft conceptual design packages with Computer-Aided Engineering (CAE) capability such as RDS [4], Piano [7], AAA [8], and ACSYNT [9] typically construct a simple

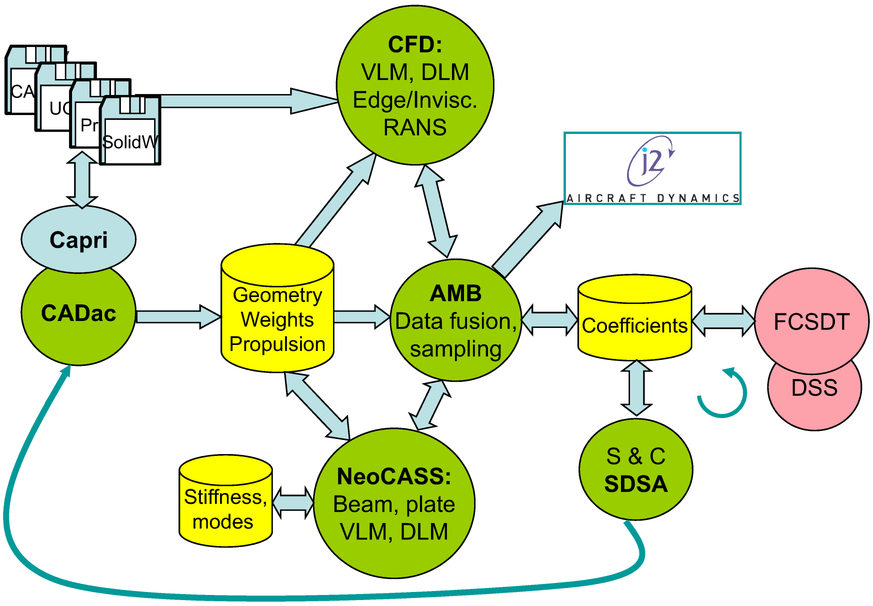

Fig. 3 CEASIOM software consists of modules CADac, NeoCASS, AMB-CFD, S&C, FCSDT and DSS, and interfaces to the *J2 Universal* package.

3D aircraft model by geometrical lofting techniques. The obtained geometrical definition is sufficient for a designer to quickly estimate future performance of a design. But it does not allow construction of a computational mesh for higher fidelity analysis without extensive re-formatting and CAD repair. Thus, these tools neither support increasing sophistication in geometric definition with growing design maturity nor compatibility with industrial-grade CAD software, and engineers need to (re-)create the configuration after the initial design phase as a CAD model.

The CADac (CAD-aircraft) tool [10] creates a proper CAD model from parameters which are intuitive and informative, such as aspect ratio, quarter chord sweep, area, etc., used by the designer to describe the aircraft morphology. A major innovation of CEASIOM is the functionality to *automatically* produce from these parameters a meshable CAD model for further analysis with tier I and II methods.

Different CAD systems differ in details, yet are sufficiently similar to enable the definition of a common user interface powerful enough to support the generation of appropriate CAD models for CFD. What is needed from the CAD system is a "meshable model" that grid generators will accept without need for CAD repair. The Application Programming Interface (API) CAPRI [11] (www.cadnexus.com) offers this functionality and generates this three dimensional solid model in CADac.

A hierarchical component based approach has been adopted. Each component (fuselage, wing, tail, etc.) is fully described by a finite set of parameters stored in a unique XML file. Such component libraries have been created in four major CAD systems: SolidWorks, Unigraphics, Pro Engineer and CATIA, allowing designers to use their favorite environment. The different components of the aircraft are loaded from this component library, then sized and assembled in order to create the meshable solid model of the complete aircraft (see Fig. 4). Both surface meshes for panel methods and CFD volume meshes for Euler or RANS calculations can be produced. Automatic grid-generators such as `TetGen` (www.tetgen.berlios.de) can generate, with minimal user intervention, the computational meshes for Euler flow computations.

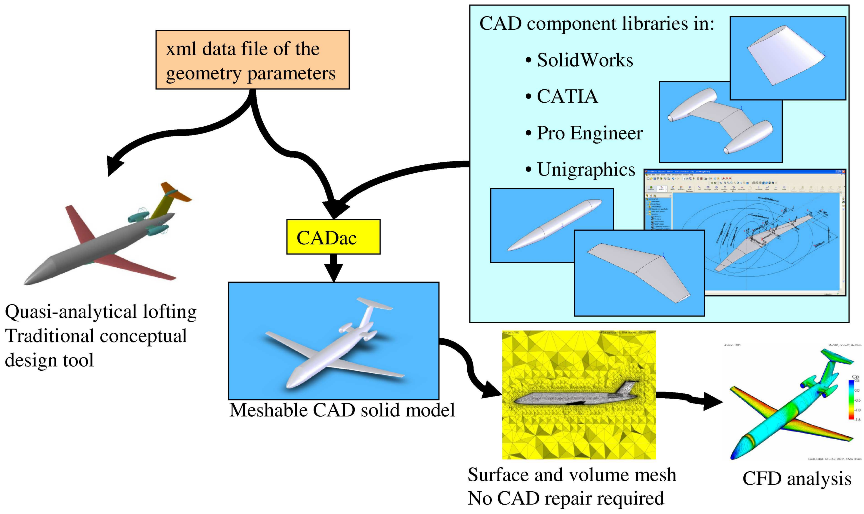

Fig. 4 CADac process: from parameters via a component library to a meshable model. The meshable model can subsequently be used directly as input by the Tier I or II solvers of the Aerodynamic module AMB-CFD.

2.2 Aerodynamic module AMB-CFD

A prerequisite for realistic prediction of the S&C behavior and sizing of the FCS is the availability of complete and accurate aerodata (i.e. the S&C database). Traditionally, wind-tunnel measurements are used to fill look-up tables of forces and moments over the flight envelope but wind-tunnel models become available only late in the design cycle. To date, most engineering tools for aircraft design rely on handbook methods or linear fluid mechanics assumptions. The latter methods provide low cost reliable aerodata 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) early in the design cycle. It has the predictive capability to generate data but the computational cost is problematic, particularly if done by brute force: a calculation for every entry in the table. Fortunately methods are available that can reduce the computational cost.

There are essentially three issues, see Fig 5.
First, a spectrum of computational tools are available, from RANS to potential flow models and semi-empirical methods. Each of the tools has a range of validity which can be exploited to keep the computational cost down. For the preliminary design of the aircraft and its FCS and as long as the flight attitude remains well within the limits of the flight envelope in the range of low-speed aerodynamics, tier I computational methods can provide the aerodata.
For a refined design of the FCS or for flight attitudes close to the border of the flight envelope, the linear or inviscid methods used in the tier I tools fail to predict the proper aerodynamic behavior and tier II RANS methods will be used to derive the aerodata. In addition, data fusion can be used for data from different methods, with low fidelity / low cost data indicating trends and a small number of high fidelity / high cost simulations correcting the values.
Secondly, interpolation methods can significantly reduce the number of data points which actually need to be computed to fill the table. Some studies [12, 13, 14] of using kriging for the generation of aerodynamic data have been published.
Thirdly, the identification of parameter regions where the aerodynamics is nonlinear, and hence where tier II fidelity is needed, is a *sampling* problem. Therefore CEASIOM's Aerodynamic

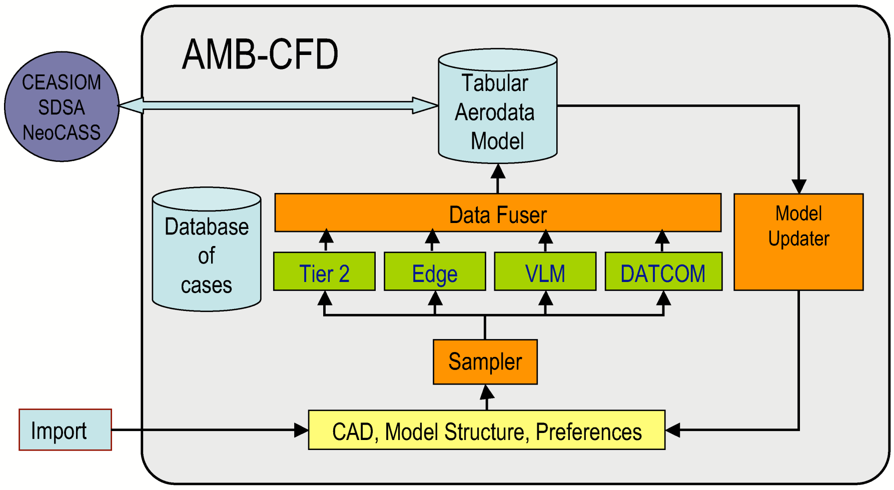

Fig. 5 AMB-CFD architecture

module develops along with these three elements.

A range of computational tools are available in CEASIOM. TORNADO [15], a vortex-lattice method for conceptual aircraft design and education has been integrated into CEASIOM as the main tier I tool. TORNADO allows a user to define most types of contemporary aircraft designs with multiple wings, both cranked and twisted with multiple control surfaces located at the trailing edge. Each wing is permitted to have unique definitions of both camber and chord. The TORNADO solver computes forces, moments, and the associated aerodynamic coefficients. The aerodynamic derivatives can be calculated with respect to: angle of attack, angle of sideslip, roll-pitch-yaw rotations, and control surface deflections.

To account for viscous effects, CEASIOM provides a correction to the steady vortex lattice method by the strip theory that combines the linear potential results with the 2D viscous airfoil code XFOIL (http://web.mit.edu/drela/Public/web/xfoil/). A basic unsteady version of TORNADO is currently under development in CEASIOM. Slightly more elaborate than vortex lattice methods is the inviscid version of the `Edge` CFD code [16] (www.foi.se/edge) that has been selected to determine the aerodata for transonic flight.

A first exercise with the Horizon 1100 aircraft aimed at checking the quality of the CAD solid model created by CAPRI and the complete simulation procedure from simple analytical aircraft description to CAD description, automatic meshing and CFD solution [17]. The `Edge` solver gave a fully converged result in 800 MultiGrid four-level cycles on a modern laptop in 15 minutes (see Fig. 4), and all the steps described above took less than one and a half hour, with minimal user intervention.

No tier II CFD tools are currently embedded in CEASIOM because users are mainly interested in coupling their own RANS CFD tools. Therefore only standard interfaces and file formats are defined in CEASIOM to which different RANS solvers can be coupled.

2.3 Aeroelastic module NeoCASS

It is well known that the aerodynamic forces induce structural deformations which in turn will affect performance and S&C characteristics. The forces and the structural deformations can be *static*, e.g. the wingtip flex due to the wing's own weight and lift distribution, or *dynamic*, e.g. wing or tail buffeting or transonic flutter. To account for the effect of these loads on the structure of the aircraft, aeroelastic models have been coupled to the tier I aerodynamic tools.

The NeoCASS (Next generation Aero Struc-

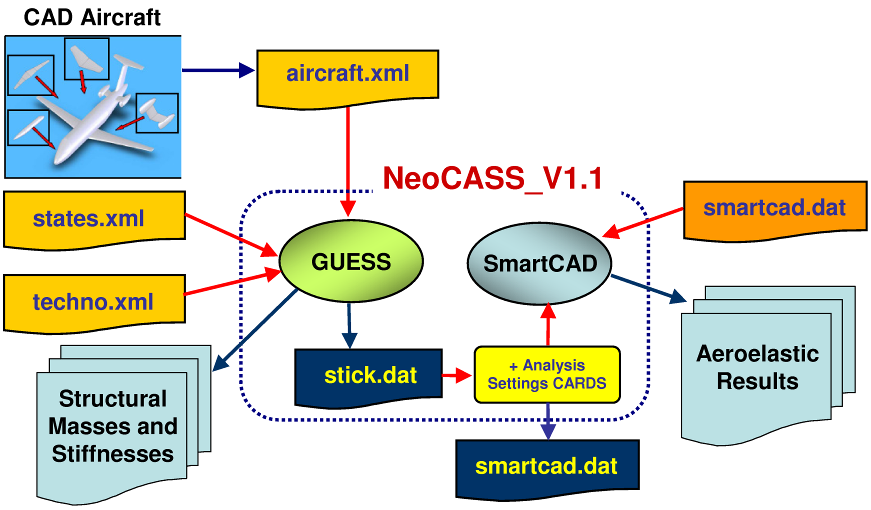

Fig. 6 Architecture, function and process of NeoCASS

tural Sizing) module combines state of the art computational, analytical and semi-empirical methods to tackle all the aspects of the aero-structural analysis of a design layout at the conceptual design stage (see [18] and [19]). It gives a global understanding of the problem at hand without neglecting any aspect of it: aerodynamic, structural and aeroelastic analysis from low to high speed regimes, buffet onset, divergence, flutter analysis and determination of trimmed condition and stability derivatives both for rigid and deformable aircraft.
The aerodynamic data in NeoCASS are provided by the tools presented in section 2.2 according to the desired fidelity level. The buffet envelope is estimated using a newly developed semi-empirical tool [20]. Buffet onset prediction is usually performed much later in the conceptual design phase, a somewhat constrained procedure because the geometry of the future airplane is by then quite fixed. Such a situation hampers generation of better designs since the buffet onset is highly dependent on the geometry. By bringing the analysis up-front in the design process, NeoCASS ensures that this important feature is not neglected.

Two classic lifting surface methods are implemented. The Vortex Lattice Method (VLM) is used for subsonic steady aerodynamic and aeroelastic calculations, and the Doublet Lattice Method (DLM) for subsonic flutter analysis and prediction of harmonic stability derivatives. For higher fidelity and higher Mach number CEASIOM uses the inviscid version of the CFD code `Edge`. Aeroelastic analyses and control surface deflections are carried out by the transpiration boundary-condition method which accounts for structural motion and deformation by specifying the velocity direction at the wall [20]. This method avoids complex and time-consuming re-meshing as well as sliding mesh techniques and the meshing of narrow gaps.
Similarly to the aerodynamic module, structural models of increasing accuracy and computational cost provide consistent structural representation of the aircraft from the early conceptual definition until the late detailed definition (see Fig. 6). Preliminary analysis is focused on determining and representing a reasonable structural/non-structural mass and stiffness distribution which satisfies strength, stiffness and stability requirements. A few structural elements capable of giving equivalent structural behaviour are available, such as a linear equivalent plate and a linear/non-linear equivalent beam to introduce geometry non-linear effects. These models lead to low-order algebraic problems, keeping the computational cost very low and allowing several configurations to be examined quickly.

Flutter analyses are carried out by Reduced

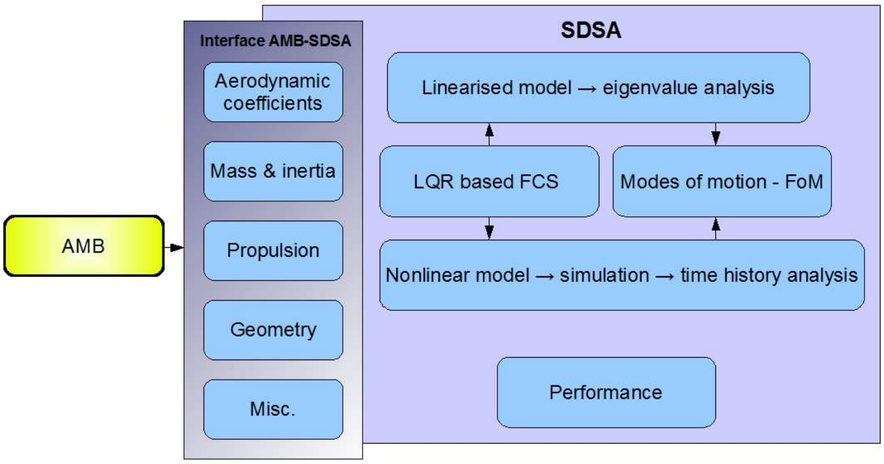

Fig. 7 SDSA structure and functionality

Order Models (ROM) constructed by the DLM and `Edge` solvers. Indeed, the aerodynamic ROM is determined through a numerical perturbation to the system starting from an equilibrium condition. The determination of the trimmed steady state of the aircraft flying a frozen manoeuvre is an important sub-problem in most analyses, to determine pressure-load distribution and structural deflections/twists, and to assess flutter instability [21]. With non-linear models an iterative process is required to determine this condition. NeoCASS uses a Jacobian-Free Newton-Krylov (JFNK) method which does not need the Jacobian of the system [22]. Coupling of structural and aerodynamic models is accomplished by a "meshless" radial basis function scheme which allows any combination of them [23]. With the structural model so specified, the aeroelastic stability coefficients, the so-called ‘eta’ values can be determined.

2.4 Stability and Control module SDSA

Once the aerodynamic coefficients have been obtained for the flexible aircraft using the ‘eta’ values (i.e. the S&C aerodata database is in hand) along with the mass and inertia properties, the S&C analysis can begin with either SDSA, described here, or J2 Universal Tool-Kit, presented in [6]. SDSA (Simulation and Dynamic Stability Analyser) covers the following functionalities:

1. Stability analysis:
   a. Eigenvalue analysis of linearized model
   b. time history identification (nonlinear model)
2. Six Degree of Freedom flight simulation:
   a. test flights, including trim response
   b. turbulence
3. FCS based on Linear Quadratic Regulator (LQR) theory
4. Performance prediction
5. Miscellaneous (data review, results review, cross plots, etc.)

Figure 7 illustrates the structure and functionality of this module.

SDSA uses the same Six DoF mathematical nonlinear model [24] of the aircraft motion for all functions. For the eigenvalue analysis, the model is linearized by computing the Jacobian matrix of the state derivatives around the equilibrium (trim) point numerically. The flight simulation module can be used to perform test flights and record flight parameters in real-time. The recorded data can be used for identification of the typical modes of motions and their parameters (period, damping coefficient, phase shift). The

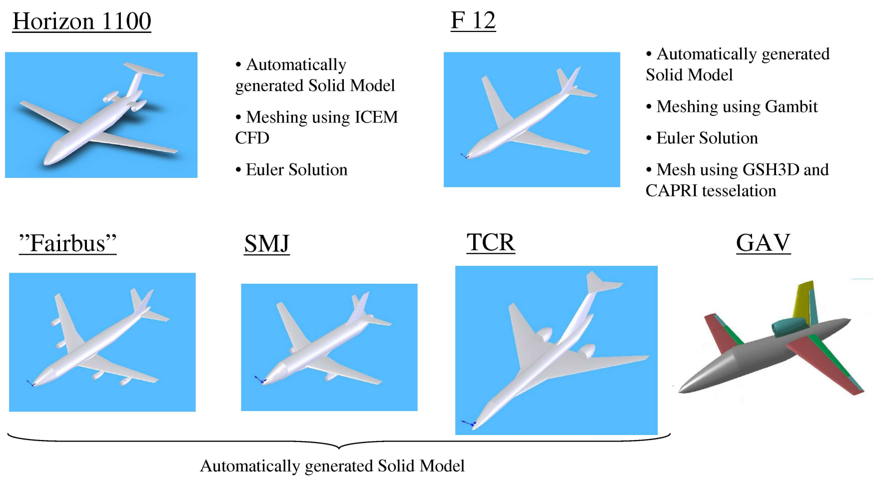

Fig. 8 Catalog of models created: Horizon example, and three SimSAC configurations - F12/Fairbus, SMJ and TCR.

stability analysis results are presented as "figures of merits" based on JAR/FAR, ICAO, and MIL regulations (see Fig. 13). The SDSA embedded flight control system is based on a LQR approach. The FCS module allows computing control matrices for the whole envelope, saving them for future use during simulation or stability analysis. Therefore it allows to compute stability characteristics for the "closed loop" case and to make flight simulation with FCS. The performance option is designed to compute basic performance parameters: flight envelope (V_{min} and V_{max} versus altitude of flight), selected manoeuvres (e.g. regular turn), range and endurance characteristics. For all mentioned functionalities the starting point is the computation of the trimmed state with sufficient initial conditions. The SDSA interacts with the user through a system of GUIs, for initial conditions, weather conditions, including gusts (wind shear) and turbulence, etc. The test flight settings include initial state, disturbances, and single / double step controls. SDSA is a stand-alone application integrated into CEASIOM. As a module of CEASIOM, it receives all the necessary data (aerodynamics, mass, inertia, available thrust), when available, without special prompting.

3 Results

3.1 Validation of CEASIOM

Figure 8 presents the models produced by CADac thus far. The Horizon 1100 [17] is as an example case of a 70 passenger regional propfan concept (a student project design), and the other three, the F12/Fairbus, the SMJ and the TCR are SimSAC design cases. So far the Horizon and the F12 have been meshed and analyzed in Euler computations.

The F12 is a generic model resembling the Airbus 340-300. It is now being wind-tunnel tested by DLR to provide static and dynamic data for benchmarking the aerodynamic modules of CEASIOM. Figures 9 and 10 show a few of the results obtained so far. The F12 geometry as defined by the CAD-file ("original") that manufactured the model was approximated by the CEASIOM parametric geometry xml-file ("XML"). Two CFD codes, PMB (in-house, Liverpool) and `Edge` were used, as well as DATCOM and TORNADO. The `Edge` and PMB results for inviscid ("Euler") flow are expected to agree. The Euler and RANS surface pressure maps (Fig. 9) for Mach 0.8, zero sideslip and angle of attack show only minor differences. The discussion here focuses on the accuracy of the Euler analysis of the XML geometry, which turns out *not* to be significantly better than the low-cost linear models. The XML geometry deviates from

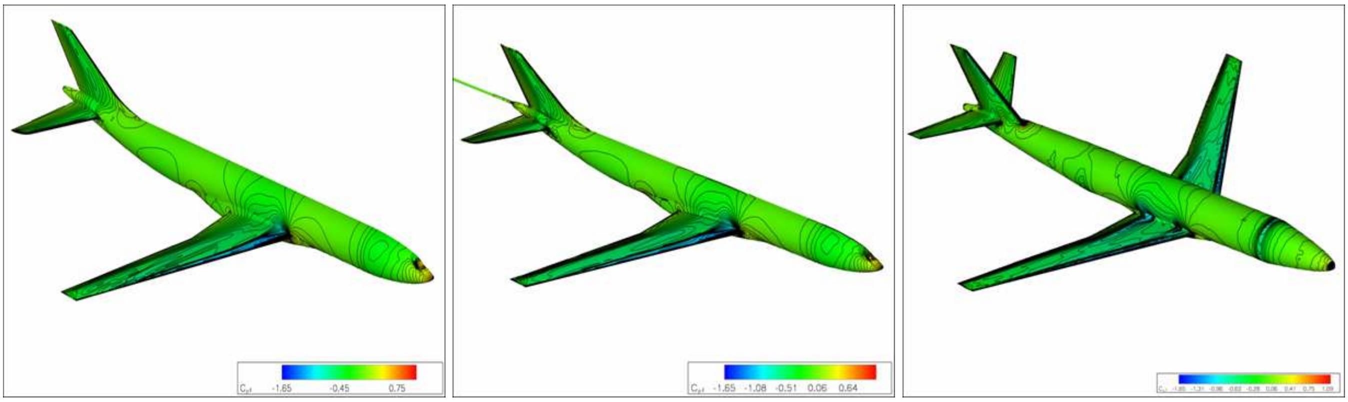

Fig. 9 F12 original i.e. the exact wind-tunnel configuration (left and center) and XML-approximation to it (right), pressure coefficient predictions for Mach 0.8 by RANS (left) and Euler (center and right) computations.

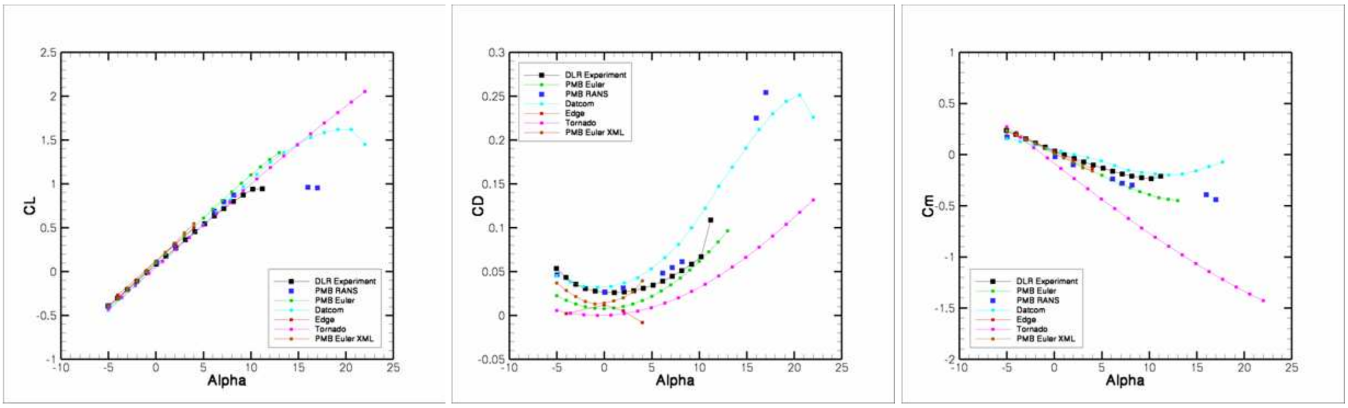

Fig. 10 F12 original and XML-version, force predictions for Mach 0.2, by Euler, RANS, DATCOM, and TORNADO; Measurements from DLR.

the original in wing and vertical tail fairings and nose-fuselage junction smoothness. The resulting high-pressure regions contribute primarily to spurious wave drag, which impacts the performance but not so much the stability and handling properties. The low-pressure "necklace" created by the slope discontinuity between nose and body, however, has significant moment arm w.r.t. the center of gravity and may seriously affect the pitching moment variation with angle of attack. The original wing camber, thickness, and twist all vary substantially from root to tip, and the XML wing's linear lofting between three span stations may be too inaccurate, especially near the root, leading to the high (spurious) pressure gradients on the trailing portion of the XML wing.

The conclusion is that geometry fidelity must match the flow model fidelity in order for the increased modeling and computational effort to pay off. The wind-tunnel model engineer comes armed with file and putty, so we learn that the CFD engineer must be similarly armed, too. The XML geometry definition is being revised to support smoother junctions and better fairings. This is consistent with the process of improving the baseline layout - the first XML geometry - towards an improved layout, with smoother pressure gradients. It is expected to be closer to the "original". The analysis of the aerodynamic effects of the remaining discrepancy, as seen in differences in the subsequent S&C analysis, promises to be very interesting.

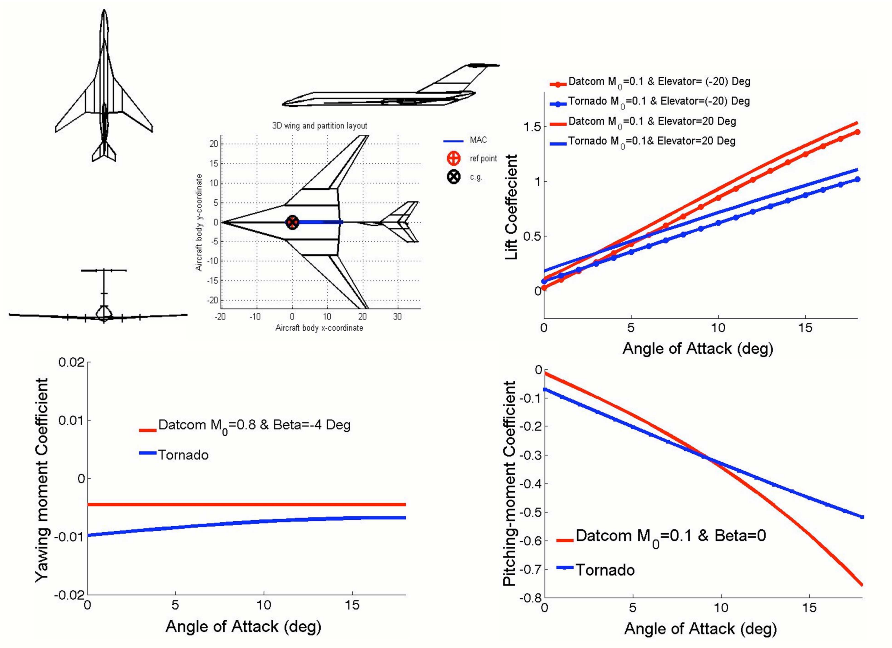

Fig. 11 TCR analysis by AMB with DATCOM (red) and TORNADO (blue). Upper left, 3-view, TORNADO idealization, moment reference point, CoG, and MAC; Lower: Yawing moment, and Pitching-moment coefficients; Upper right, Lift coefficient for elevator deflected + and - 20 deg.

3.2 Design case: Transonic cruiser TCR

CEASIOM is being applied to a selection of design exercises of two types: 1) new unconventional configurations, and, 2) improved design of existing configurations.
In category 1, the design mission of the transonic cruiser (TCR) specifies a commercial transport carrying 200 passengers with a range of 5500 nm at a cruise speed of $M = 0.97$. To begin this study, the TCR has been analyzed for low-speed aerodynamics by TORNADO and DATCOM, as shown in Fig. 11. Studied here is the meshable model of the baseline configuration created by SAAB and shown in Fig. 8. This baseline was suspected to have problems with trim and elevator effectiveness. In category 2, the F12 is an existing wind-tunnel model, and the design task is to protract it into a transport aircraft with roughly the specification of the Airbus 340-300. Since the F12 is a wind-tunnel model without engines or control surfaces, the task involves scaling the configuration, mounting engines and sizing the control surfaces. The resulting baseline configuration, dubbed the Fairbus, is shown in Fig. 8.

The following describes the work done to date using CEASIOM for the analysis of the TCR baseline configuration, considered as a rigid airframe. First the aero coefficients are computed with AMB-CFD, then the structural model for the mass, center of gravity, and inertias which specify the aircraft are constructed with NeoCASS and finally, S&C SDSA analyzes the flight dynamics.

3.2.1 Aerodynamics

The lift coefficient for elevator up and down, (upper right in Fig. 11), shows that DATCOM predicts slightly smaller elevator effectiveness, with a $\delta C_L/\delta e$ of about 0.13 vs. 0.16 per rad. The interpretation is as follows: As seen in Fig. 11, the TORNADO panel, TORNADO assumes the elevator to extend from root to tip, as specified by the control-surface definitions in the geometry XML file, while DATCOM considers the actual elevator span value which is smaller. This lack of precision in defining the control surface needs to be remedied by enriching the input data. Notice that DATCOM predicts larger $\delta C_L/\delta\alpha$.

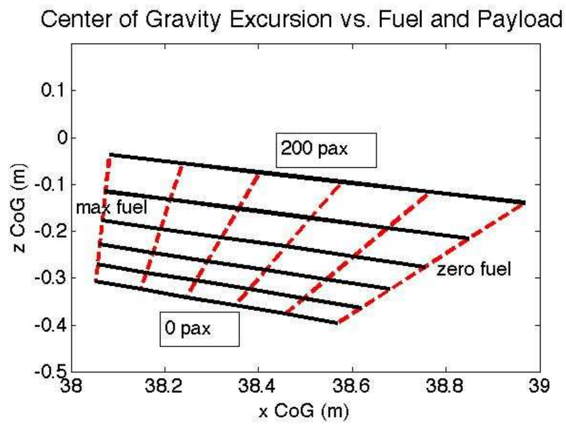

Fig. 12 Center of gravity excursion predicted by the structural model of NeoCASS as function of payload and fuel.

Reasons for this are that: 1) DATCOM considers the part of the wing inside the fuselage, and 2) DATCOM methods for a wing+Body+Tail configuration are limited to a straight tapered wing (see DATCOM Manual). For cranked wings, average values for sweep angle and dihedral angles are used. Usually, this estimation method overestimates the lift compared with TORNADO using the actual wing geometry. The corresponding effect is seen in the pitching moment vs. AoA, lower right: the DATCOM slope is steeper for much the same reason.

3.2.2 Weights and balances

The fuel burn en route changes weights and balances, as does different payloads - here synonymous with different number of passengers. The GUESS module of NeoCASS produces estimates of structural weights and stiffnesses, when given a few parameters which determine the technology. Also, placement and size of fuel tanks is indicated by a few parameters. The carpet plot in Fig. 12 shows the position of the centre of gravity in the standard geometry coordinates (origin at nose, x positive rearwards, and z up) for 0 to 200 passengers (incl. luggage), and fuel from empty to full.

3.2.3 S&C Analysis

Figure 13 presents selected results from SDSA for the stability analysis of the TCR baseline configuration. The first graph shows phugoid results referred to ICAO recommendations. The characteristics of the phugoid are acceptable and are placed on the border between "satisfactory" and "acceptable for emergency conditions" according to ICAO. The second graph presents short period characteristics referred to ICAO recommendations too. They are mostly below the line, where the pilot rating is equal to 3.5: lateral stability characteristics are not so good as the longitudinal ones. The Dutch roll mode is stable, however not enough for high altitude flights, according to the MIL-F-8785C regulations. Roll and spiral modes are partly coupled but stable, with over 150s period and time-to-half-amplitude about 20s. The lateral characteristics should be improved, e.g by increasing the vertical tail area or it's arm, or by decreasing the main wing dihedral. The center of gravity position could be shifted forward, but this changes also the longitudinal characteristics, so it must be done very carefully.

4 Concluding Remarks and Future Work

The paper has presented the status of CEASIOM and its application in design at the halfway mark in the three-year SimSAC Project. Work continues in the next eighteen months when:

- CADac will prescribe the control surfaces in the meshable CAD model and automate further the mesh generation process
- A geometry builder with visual feedback will be set up
- NeoCASS will produce the 'eta' aeroelastic coefficients and determine flutter boundaries
- A seamless interface to the J2 Universal software will be in place

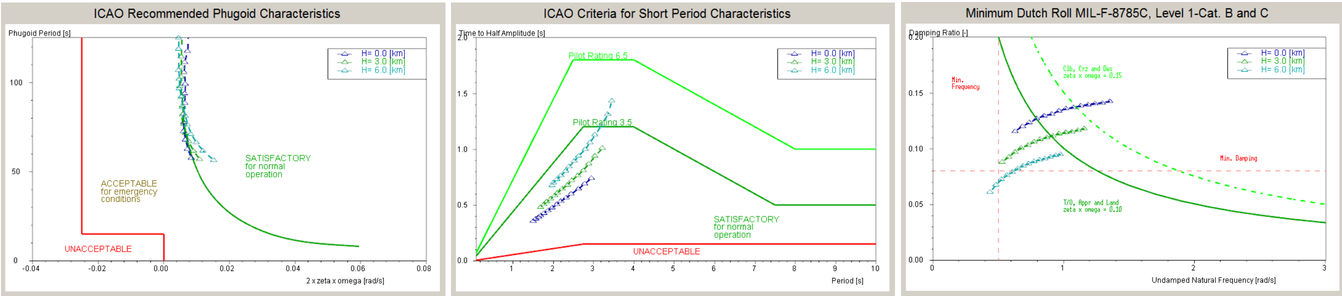

Fig. 13 SDSA predicted characteristics: a) phugoid mode, b) short-period and c) Dutch roll mode for the TCR configuration.

- The FCSDT elastic TCR configuration will be analyzed with Euler CFD solutions for high-speed flight

The design exercises will also continue with tier I$^+$ and tier II analysis and configuration refinement of the baseline designs of TCR, SMJ, Fairbus and GAV concepts.

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