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AERODYNAMIC DESIGN AND OPTIMIZATION TOOLS ACCELERATED BY PARAMETRIC GEOMETRY PREPROCESSING

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Abstract. *A preprocessing tool for generating input data for aerodynamic design, computational Fluid Dynamics (CFD) analysis and experimental model production is illustrated in a number of design case studies. A set of basic functions as well as gasdynamic flow elements are providing a rich variety of mathematically explicit relations to generate 2D curves, 3D surfaces which may move with time or optimization cycles.*

INTRODUCTION

Fluid mechanics and aerodynamics are used to design shapes, components and configurations for ground, sea and air transport with a possibly low drag. This has resulted in the development of design methods which should be useful for optimization following constraints and observing tradeoffs with optimizing other than hydro- or aerodynamic components: A multidisciplinary approach is called for if a truly optimum engineering design is to be carried out for a new product.

Such strategy is especially useful in the field of aircraft design where even small improvements in the lift/drag ratio can result in remarkable reductions of the direct operating costs. Applications to shape generation will be shown here therefore in the field of aerodynamic applications for air vehicles in all speed regimes, from glider wings to configurations operating in hypersonic Mach numbers.

Optimization strategy development is most needed in the high speed regime, where new concepts for transport aircraft design will be crucial for the actual production of a new generation supersonic transport (SST). A compilation of methods and strategies for SST design has been presented recently [1], here we apply the author's contributions to a selection of configurations.

It turnes out, for design aerodynamics, that the command of geometry generation is of paramount importance for all systematic use and application of both fast aerodynamic shape design and large scale numerical flow simulation (CFD). Here we show some approach to use mathematical basic functions and gasdynamic phenomena models to arrive at software tools to generate aircraft and other vehicle shapes which are not only realistic for practical applications, but also allow for arbitrary local and global variations which may be controlled by a small set of parameters. This is outlined in the book in contribution [2].

GEOMETRY

Practical surface definition is done usually with CAD systems. For aerodynamic early phase conceptual design, however, a step prior to the application of CAD is needed. The implementation of model solutions to strategies of shape design calls for a toolbox of dedicated functions which allow to focus on flow phenomena which are crucial for practical results like lift and drag. In software we have developed and adapted to the needs of aerodynamic design, the knowledge base of fluid mechanics reflects from the mathematical tools used.

A short illustration of the principle to generate shapes is shown in Fig. 1.

Functions, Curves and Surfaces

We favor a cartesian coordinates system in 3D to apply mathematical functions in 1D space: Basic functions with 4 free parameters within the unit square are scaled and composed together to yield arbitrary curves with a strong control of details. Support points and parameters are themselves functions of a third dimension, which allows the creation of smoothly varying curves as 3D surface cross sections. Finally, the parameters can be function of a fourth dimension which may be time for unsteady surface movement or the dimension of optimization steps in an evolutionary surface variation.

A rich variety of shapes for all purposes can be created using this approach. Resulting surface data grids are to be formatted as CAD input after such dedicated shaping, in order to align the practical design process with commercial tools widely used.

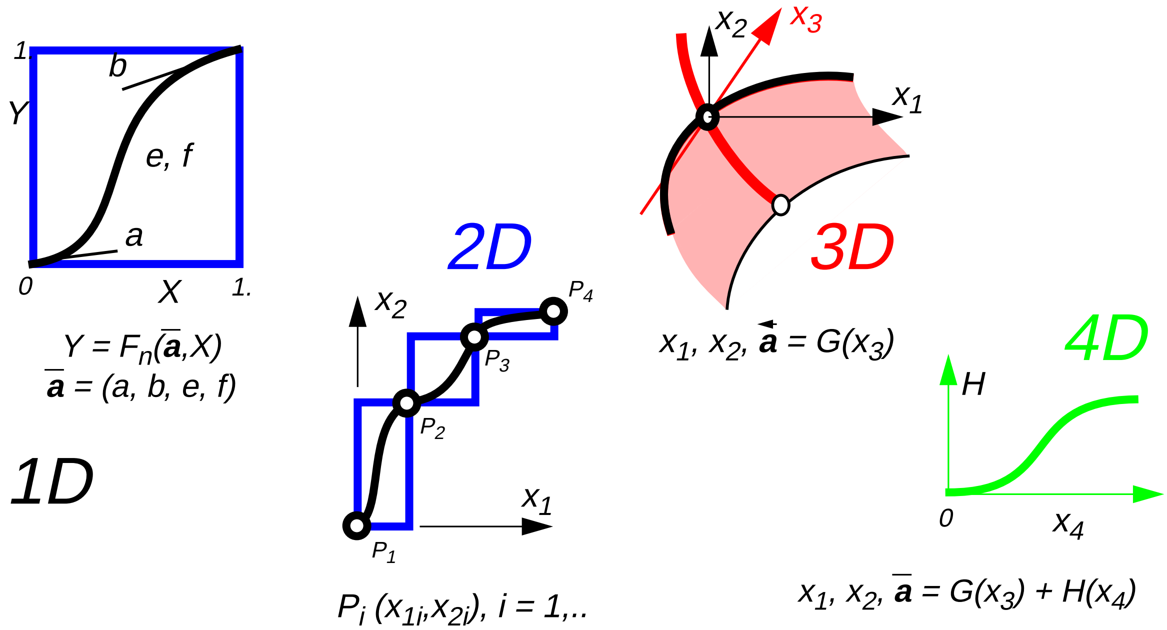

Figure 1. From 1D functions to 4D movingsurfaces

Fluid mechanic models

What makes this approach special for aerodynamic design, is the addition of fluid mechanic and gasdynamic model solutions which in some cases are given as explicit functions, usually simplified differential equations suggest the use of inverse techniques. This has been applied to transonic flows to arrive at shock-free airfoils, here it is illustrated for supersonic flow, Fig. 2:

For design of supersonic configurations the use of inverse model equations suggests to start not with a given contour shape, but with the shock shape resulting from the body contour in supersonic flow . Numerical evaluation of the flow field behind the shock in undisturbed upstream supersonic flow yields the contour streamline which is compatible with the prescribed shock wave. This is an inverse method of characteristics, it allows the definition of shock waves with varying strength and this way a strong shape control of the generating body.

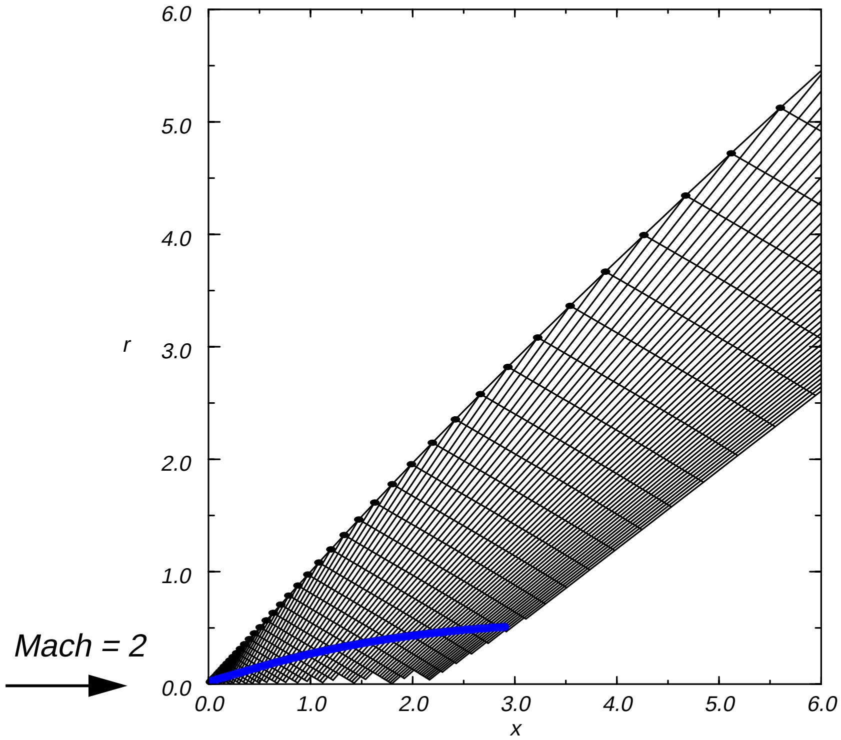

Figure 2. Axisymmetric flow: Inverse contour computation from given curved shock shape

Aerodynamic components

Practical aerodynamics is used to implement 2D airfoil shapes in 3D wing design. Such airfoils can be given externally or created with a set of input parameters which, for optimization effort purposes, should be as small as possible but large enough to allow for influencing flow quality where it is needed.

Fig. 3 is a sketch showing that there are two basic types of configuration components. Most parts of an aero-vehicle can be composed by one of these two basic components if the („key“-) parameters are chosen suitably. The examples shown here and in the compilation [3] are defined by relatively simple sets of input parameters, refinement observing more needed details can then be done easily by inserting additional data modeling crves as sketched in Fig. 1.

WING TYPE SHAPES:
aircraft wings
helicopter rotors
turbomachinery blades
empennage fins
pylons
struts
variable airfoils

BODY TYPE SHAPES:
aircraft fuselages
rotor hubs and shrouds
channels and tubing
axisymmetric bodies
nacelles
containers
variable cross sections

Figure 3. Basic aerodynamic configuration components

Software for interactive geometry definition

With many configurations defined for various purposes of our research and project work it became a task for software developers to create versions for interactive use and rewritten in modern programming languages like C++ and JAVA allowing use on any platform.

CASE STUDIES

A number of examples is depicted here graphically but a more detailed presentation of case studies designed in the framework of projects and international cooperations is available in a constantly updated web site [3].

In the following figures some of these examples are depicted, applications range from airfoil definition with local surface modifications, to wing - fuselage junctures and high lift systems of low speed and transonic aircraft (Fig. 4).

Generic configurations for subsonic, transonic and supersonic aircraft have been created using this kind of geometry definition: Fig. 5 shows graphic visualizations including novel configurations like flying wing aircraft which will require a multidisciplinary approach when optimum solutions should be obtained. Aerodynamic and structural design needs to be supported by possibly one geometry input data set.

High speed configurations are shown in Fig. 6.: New generation SST will need to be optimized also for lowest possible sonic boom, and like other design cases will require extensive CFD analysis. For supersonic and hypersonic applications we use given shocks for inverse 3D surface design resulting in waverider configurations. Design variations of these, but also integration of such forebodies to shape complete aerospace vehicles is suitably done by the illustrated geometry generation approach. This way our software serves as a preprocessor for CAD, CFD and model fabrication, as a first step for fully virtual product design....

See also some recent publications about the above studies listed in the web site [3].

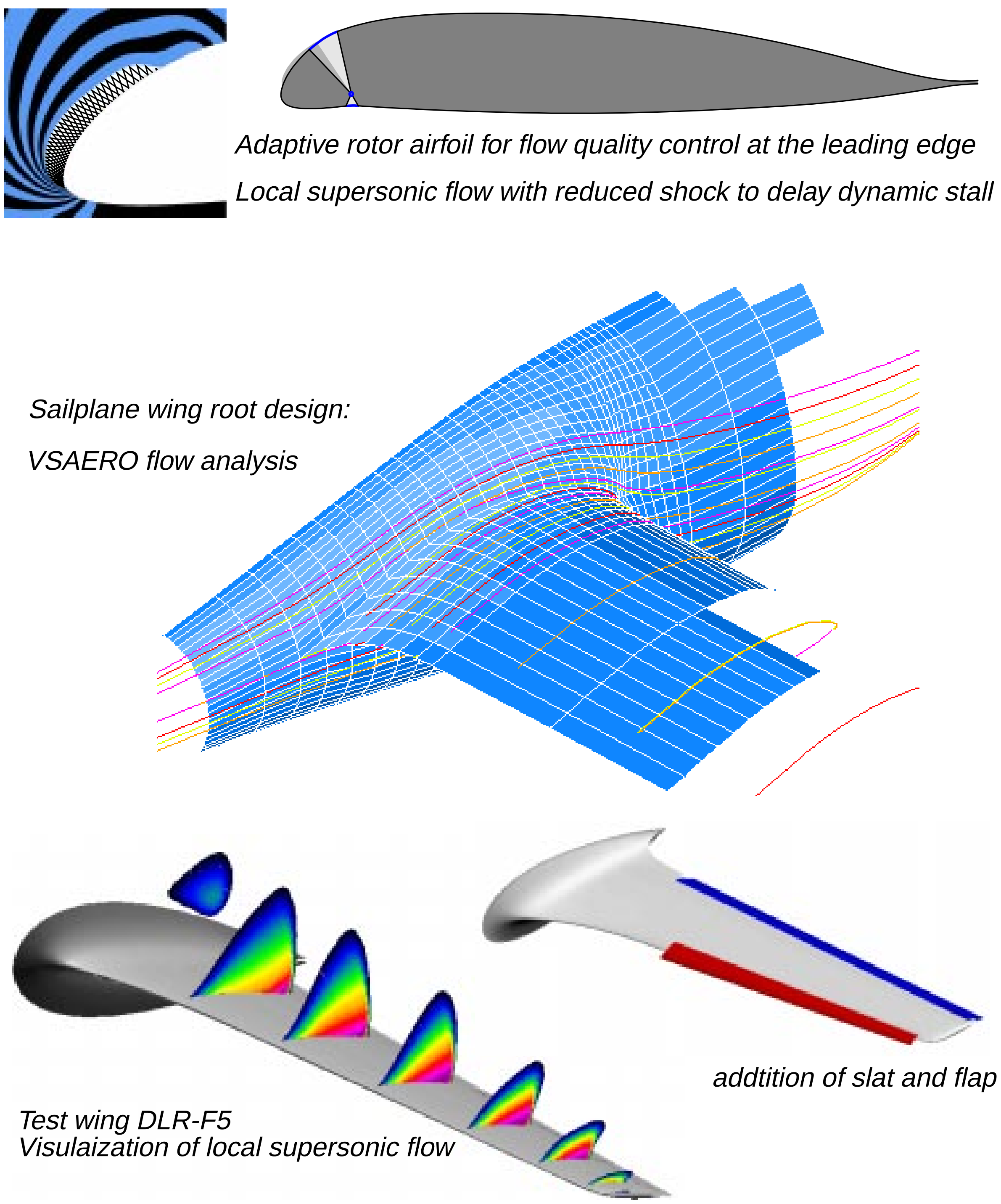

Figure 4. Subsonic and transonic airfoil and wing design case studies

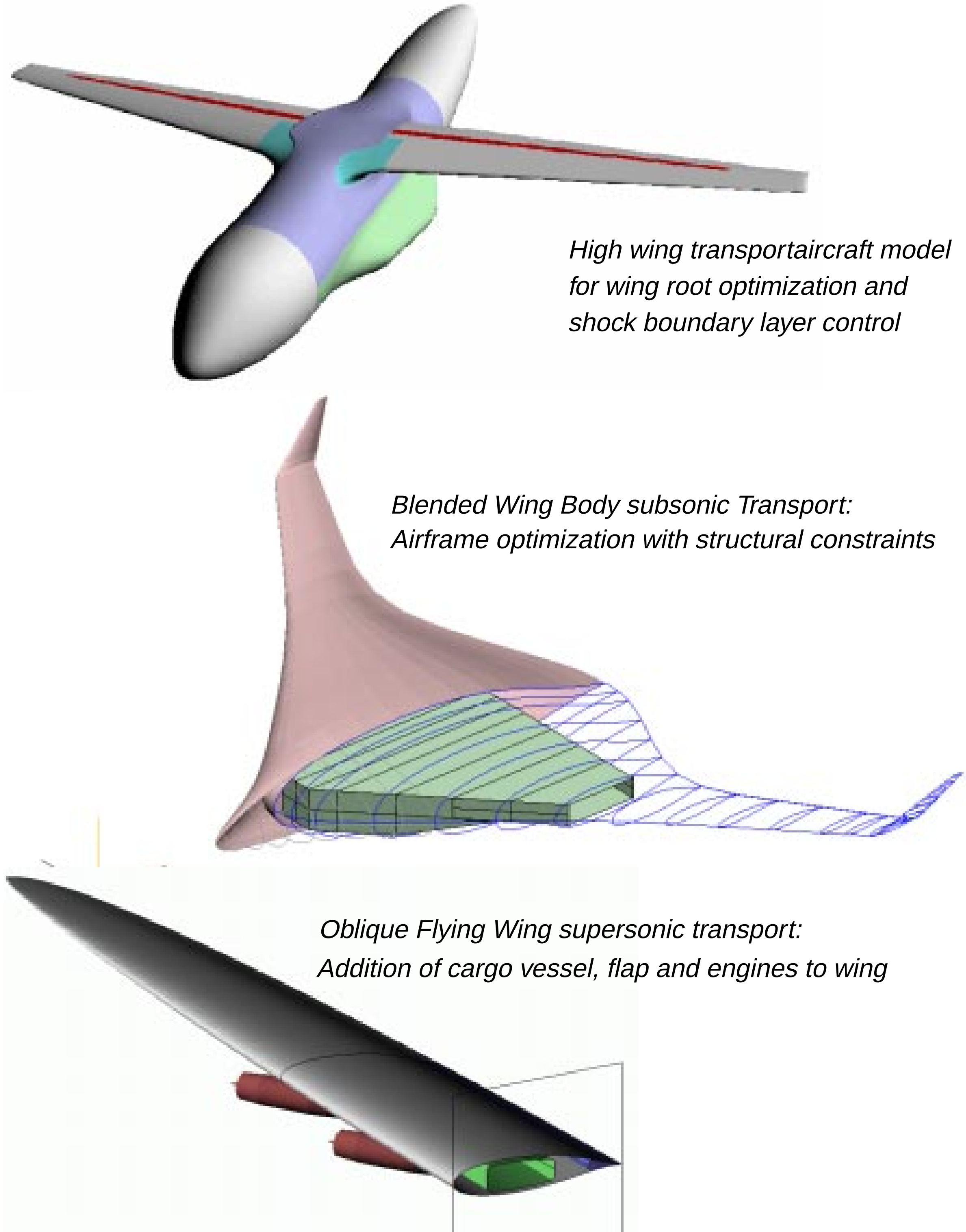

Figure 5. Modular configurations for multidisciplinary design optimization

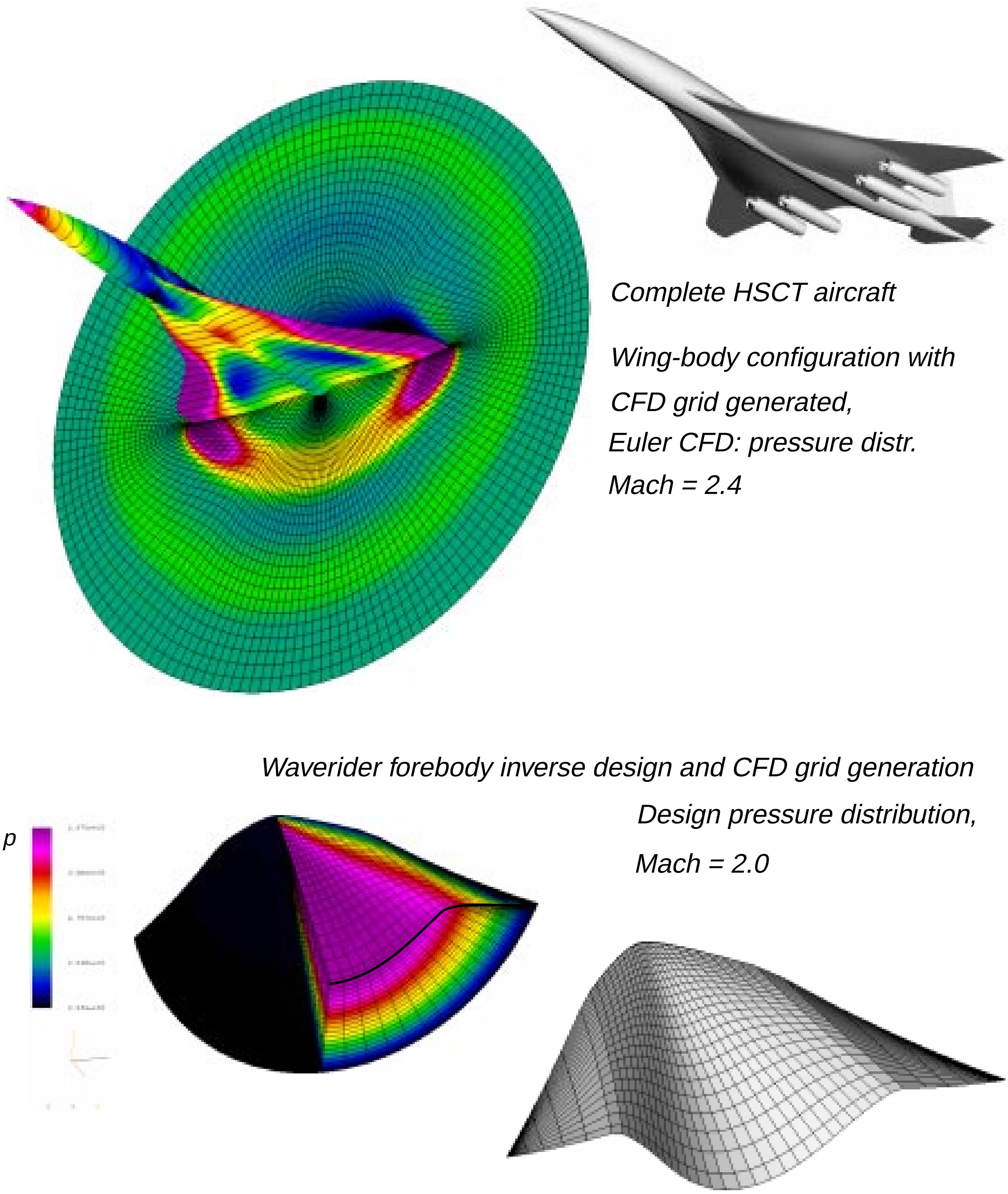

Figure 6. High speed configurations: Computational design of airframe and CFD grids.

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PDF | A preprocessing tool for generating input data for aerodynamic design, computational Fluid Dynamics (CFD) analysis and experimental model | Find, read and cite all the research you need on ResearchGate.Â For aerodynamic design optimisation as well as for multidisciplinary design optimisation studies, it is very desirable to limit the number of the geometric design variables. In Ref. 1, a 'fundamental' parametric aerofoil geometry representation method was presented. Aerospace Series. â€" Wiley, 2014. â€" 265 p. â€" ISBN-10 0470662573, ISBN-13 978-0-470-66257-1. Aircraft Aerodynamic Design: Geometry and Optimization is a practical guide for researchers and practitioners in the aerospace industry, and a reference for graduate and undergraduate students in aircraft design and multidisciplinary design optimization. Optimal aircraft design is impossible without a parametric representation of the geometry of the airframe. We need a mathematical model equipped with a set of controls, or design variables, which generates different candidate airframe shapes in response o encourage systematic evaluation of aerodynamic optimization frameworks, a suite of benchmark optimization problems is being developed by the AIAA Aerodynamic Design Optimization Discussion Group. The purpose of these benchmarks is to exercise the capabilities of aerodynamic optimization frameworks on challenging design problems. In this work we solve the benchmark problems using an adaptive shape optimization approach comprised of two basic elementsÂ Geometric functionals (e.g. thickness and volume) are computed by a standalone tool that provides analytic derivatives to the functionals. The design framework communicates with these geometry tools via XDDM, which is an. 2 of 18. American Institute of Aeronautics and Astronautics.