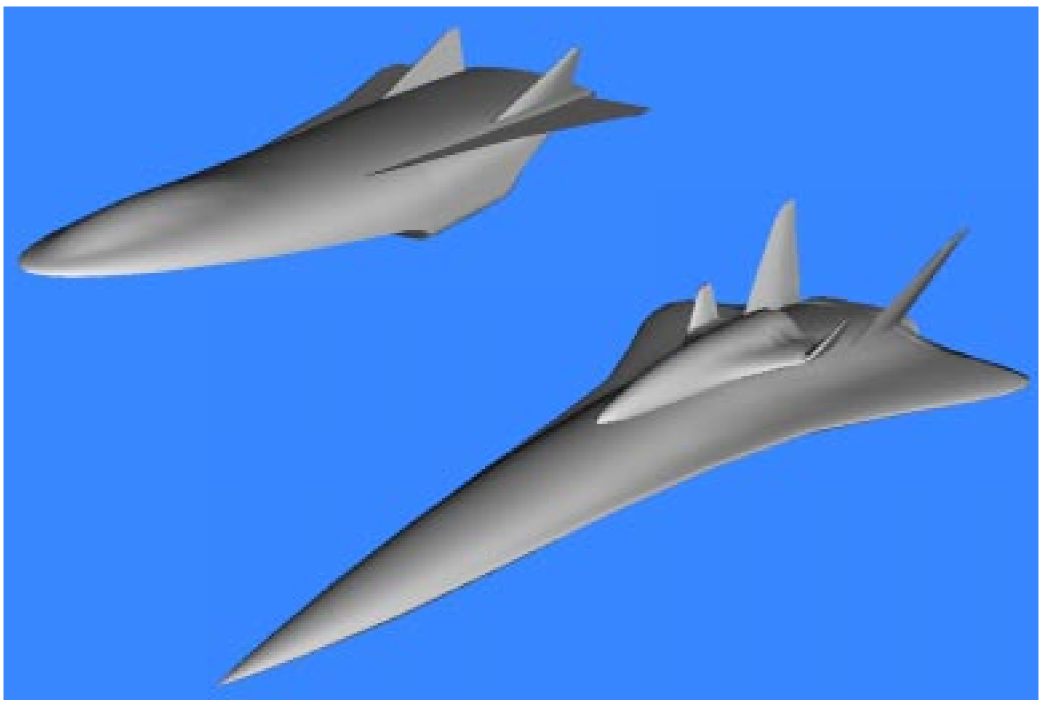
AIAA 91-3301CP

Helmut Sobieczky, Julienne C. Stroeve

DLR Göttingen / University of Colorado, Boulder

Generic Supersonic and Hypersonic Configurations



Paper presented at

9th AIAA Applied Aerodynamics Conference

Baltimore, MD

23. - 26. September 1991

AIAA-91-3301CP

GENERIC SUPERSONIC AND HYPERSONIC CONFIGURATIONS

Helmut Sobieczky*, Julienne C. Stroeve**

Abstract:
A geometry generator for preliminary aerodynamic design, parametric optimization and the preprocessing of CFD boundary conditions is presented. With emphasis on supersonic aircraft components, ranging from waverider caret wings to generic lifting bodies derived from recent aerospace research projects, the simple mathematical basis and its consequent use throughout various applications is illustrated.

Introduction

This paper is intended to present computational preprocessor software for aerodynamic education, research and development. Some years ago[1] the goal was the parameterized geometrical definition of typical transport aircraft components, like wings, fuselages and propulsive devices, for CFD code assessment as well as for the development of new strategies to arrive at more efficient transonic wings, with parameters guided by supercritical wing technology. Some very practical tools have resulted from this approach, to be combined with standard CAD/CAM software and this way allowing the aerodynamicist to define design variations for optimization studies rapidly and effectively. Subsonic and transonic aerodynamic performance is dominated by the wing quality, but aerodynamic interference at wing root, tip and engine nacelles is found important also so that this type of software is aimed at designing components independently but providing special mathematical techniques for their combination, like fillets, fairings, pylons, winglets etc.

Here we study typical supersonic test cases, derived from projects like the National Aerospace Plane or the German Sänger transport system. These configurations require major modifications to the abovementioned concept, as also design and optimization of such aircraft will require different strategies. We have to model configurations with a complete integration of wing, body and the propulsion system. Analog to the flow phenomena in transonic flow which taught us to provide flexible upper wing surfaces, in supersonic flow we should have control over the bow shock wave system which strongly determines aerodynamic performance at cruise conditions. Also, acoustic properties are a key issue resulting from the shock system.

* Senior Research Scientist, DLR Göttingen, Germany

** Graduate Student, University of Colorado, Boulder

Development of techniques to control shock strength should lead to a knowledge base resulting in directly influencing the parameters of shape design. Our preprocessor software so far is applied to and further developed by some case studies derived from recent aerospace projects as briefly illustrated in the following.

Geometry Tools

The geometry tool developed here is aimed at aerodynamic configurations. It is intended to contain some of the most important parameters to be varied in numerical early stage design and optimization studies and finally yield a suitably dense set of data needed as an input for industrial CAD/CAM systems.
Focusing on surfaces of aerodynamically efficient aerospace vehicle components, we realize that the goal of surface generation requires much control over contour quality like slopes and curvature, while structural constraints require also corners, flat parts and other compromises against otherwise idealized shapes. When familiarity was gained with a set of simple analytic functions and the possibility was used to occasionally extend the existing collection of 1D functions, ground was laid to compose these functions suitably to yield 3D surfaces of a nearly unlimited variety within conventional, new and exotic configurations. Some earlier publications and reports[2, 3, 4] explain the approach of starting with 1D curves to obtain 3D surfaces and CFD grids, here therefore only the principle is repeated briefly and some new options introduced especially for supersonic aerodynamics are presented.

Function Catalog

A set of functions Y(X) is suitably defined within the interval $0 < X < 1$, with end values at $P_1(0, 0)$ and $P_2(1, 1)$, see Fig. 1. We can imagine a multiplicity of algebraic and other explicit functions Y(X) fulfilling the boundary requirement and, depending on their mathematical structure, allowing for the control of certain properties especially at the interval ends. Figure 2 shows a list of the first 8 basic functions used: these and a collection of more sophisticated relations may be selected individually by the function identifier g, and up to four individual parameters with the first and second (a, b) defining the slope at interval ends. As easily verified from the list in Fig. 2, we have polynomials, Bezier functions, exponentials, trigonometrics and curves with arbitrary exponents available, besides the linear connection fit.

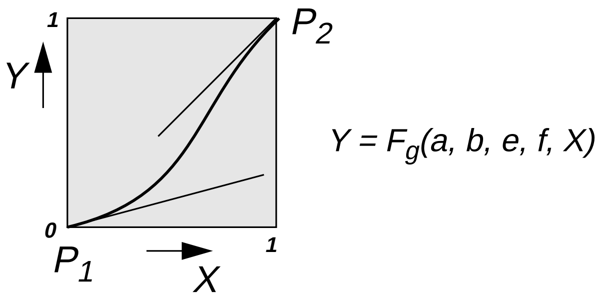


Fig. 1: Basic function within unit square

g = 0.:	$Y = [1 - (1 - X^e)^f] \bullet [1 - b + (b - a) \bullet X] + a \bullet X$
g = 1.:	$Y = [(1 - (1 - X)^f)^e] \bullet [1 - b + (b - a) \bullet X] + a \bullet X$
g = 2:	$Y = c \bullet X^{(2 \bullet c - 1)} + (1 - c) \bullet X^{2 \bullet c}, \quad c = (b - a)/(1 - a)$
g = 3:	$Y = U \bullet (A + (1 - A) \bullet U); U = B - \mathrm{sqrt}(B^2 - C \bullet X)$, $A, B, C = \mathrm{Fct}(a, b)$
g = 4:	$Y = X$
g = 5:	$Y = a/e \bullet (\exp(e \bullet X) - 1) + A(a, e) \bullet X^{\alpha(a, e)}$
g = 6:	$Y = \Sigma(c_n \bullet X^n)$, n = 1, 5; $c_n = c_n(a,b,e,f)$
g = 7:	$Y = X^{1/2} \bullet \Sigma(c_n \bullet X^n)$, n = 1, 3; $c_n = c_n(a,b,e,f)$
g = 8:	$Y = A(a) \bullet \sin(\pi \bullet X/2) + (1 - A(a)) \bullet (1 - \cos(\pi \bullet X/2))$
. . .	. . . .

Fig. 2: Catalog of first 8 basic functions in unit square

More recent extensions include combinations of these functions, like curves g = 1 or g = 2 with extended straight ends, Fig. 3: parameters e and f are used now to define location and relative size of the embedded functions. This gives smooth connections as well as the limiting cases of curves with steps and corners. Implementation of these mathematically explicit relations to the computer code allows for using functions plus their first, second and third derivatives.

The next step is the composition of curves by a piecewise scaled use of these functions. Figure 4 illustrates this for an arbitrary set of support points P_i, with slopes prescribed in the supports and curvature or other desired property of each interval determining the choice of function identifiers g. The difference to using spline fits for the given supports is obvious: for the price of having to prescribe the function identifier and up to four parameters for each interval we have a strong control over the curve. The idea is to use this control for a more dedicated prescription of special aerodynamically relevant details of airframe geometry, hoping to minimize the number of optimization parameters as well as focusing on problem areas in CFD flow analysis code development.

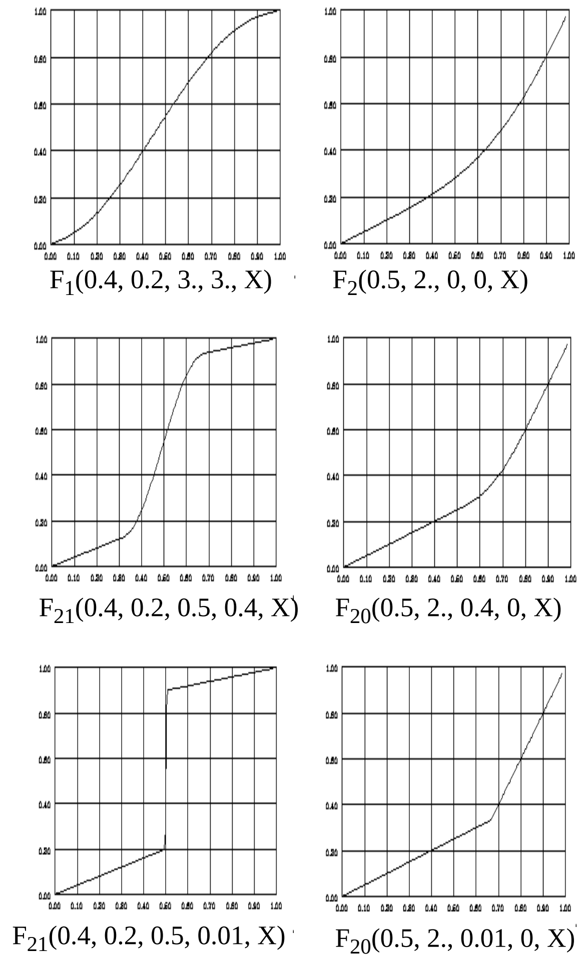


Fig. 3: Functions g = 21 and 20 developed from g = 1 and g = 2

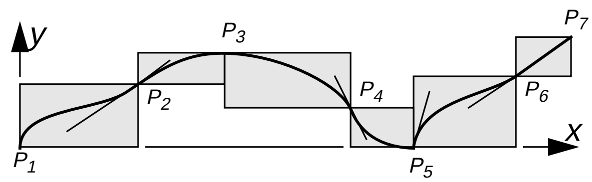


Fig. 4: Composition of complex curves by piecewise scaled use of the basic functions

Characteristic curves ("keys") in 3D space for describing airplane properties to be carefully varied in design and optimization studies are crown lines, planforms and the leading edges of lifting bodies, inlet lips, wings and fins. They need to be defined before the surface connecting these curves is computed.

Wings: Blending Airfoils along span

Wings of large or medium aspect ratio are suitably defined along a spanwise axis y, with leading and trailing edge as well as twist axis coordinates x, z , airfoil distribution blending and wing twist all functions of the spanwise coordinate y. A set of given airfoils is used for wing section definition, as illustrated earlier in detail[1].

Using various given airfoil datasets instead of creating wing sections from mathematical functions as advocated here, takes into account the aerodynamicist's practical work: wing design starts from airfoil developmentand besides the classical NACA 4Digit series very few useful airfoils may be described by parametric mathematic functions. They rather are given as a set of dense coordinate data and are therefore a necessary part of the geometry input. The same way to generate wings from a given set of *cross sections* normal to the streamwise axis instead of *airfoils* normal to the spanwise direction is of course possible, too. We have used the wing tool in a "cross section interpretation" for simple supersonic waverider delta wings[4] requiring only one or two support cross sections, obtaining section variation solely by the keys for leading edge coordinates and thickness distribution.

Bodies: Using functions varying along the axis

For fuselages the axial direction x is the independent variable to define cross section geometries. The need to define geometry details at transport airplane wing - body junctions has led to a use of the above functions to create the spanwise body coordinate **y(x, z)** depending on axial station x and vertical coordinate z between upper and lower crown line.

Here we stress a modified way of defining body surface data: upper and lower coordinates **z(x, y)** are computed using functions with parameters varying along the x - axis, the body surface composed by an addition of several dedicated "bumps", Fig. 5. For junctions with other components, explicitly available vertical coordinates allow now for the same "blended projection technique" to mount inlet and vertical or tilted fins onto the surface, as has been done in horizontal direction for transport aircraft. The resulting arcs determine cross section geometry at any axial station, the individual curves are defined by support points from crown line and planform geometry and other parameters along the whole x-axis.

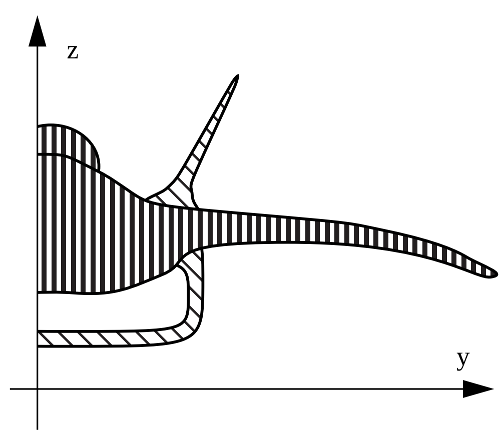


Fig. 5: Vertical composition of body surface

Interactive Methods

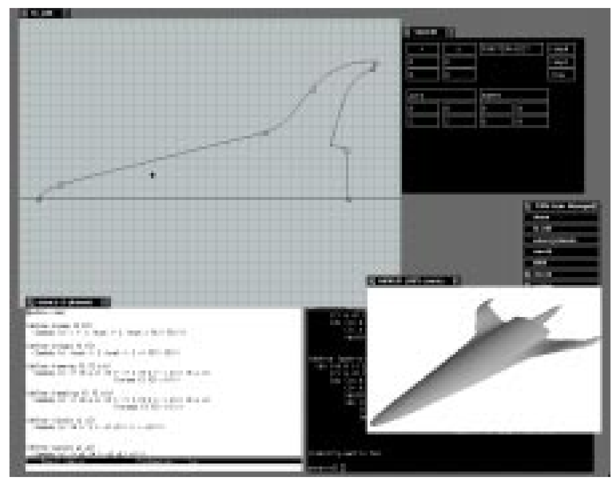


Fig. 6: Screendump of workstation X Window environment for new interactive version[6] of the geometry generator. Example: planform variation of generic supersonic airplane.

Modern workstation computers invite to develop interactive versions of this approach: Pagendarm et al[3] have developed an early interactive version; at aerospace industry a tool has been developed by Rill and Becker[5] and is in practical use for applications in transport airplane design: There the goal of bridging the gap between suitable tools for CFD and theoretical aerodynamics, and the CAD/ CAM tools for project design and production seems to have been reached.

At DLR the use of new faster workstations sparks interest in adding another dimension to creating 3D configurations: Optimization as well as shape adaption to variable operating conditions asks for whole series of geometries varying between corner configurations[6]. The idea is to vary the whole set of key curves with additional transition ramps, using again functions as illustrated above. The technique is used already for new graphic visualization software to move generated objects[7].

Combining gasdynamic with geometry parameters

Supersonic gas dynamics for inviscid, ideal flows provides us with relations between Mach number, shock wave obliquity and post-shock flow deflection. There is a need to design configurations at given cruise Mach numbers with certain position and quality of the bow shock wave relative to the leading edge geometry. This requires a coupling of geometry tools with shock and expansion wave relations determining post-shock flow quality compatible with surface geometry. It would be desirable to define shock wave geometry and find the surface geometry which creates such a shock wave at a specified design Mach number. Such an inverse approach in 3D space, in general, forms a mathematically ill-posed problem. However, there are exact solutions to the supersonic inviscid flow model (Euler) equations, which allow for a selection of 3D stream surfaces forming simple lifting bodies.

Waveriders

The need to arrive at high ratios of lift over drag for an aerodynamic cruise configuration has sparked renewed interest in such simple configurations with controlled shock waves. They are known as “waveriders”. These basic shapes are found by exploiting known inviscid flow fields exhibiting plane oblique or axisymmetric conical shock waves. Quite recently[8] the concept of using conical flows for the design of waveriders has been extended to prescribe now shock waves as more general rule surfaces (“Osculating Cones Concept”), thus expanding the possibilities of shape generation remarkably.

Figure 7 a - c shows some examples of waveriders designed using this method. Only cruise Mach number, the shock angle, the leading edge and the shock profile in the exit plane (ideally aligned with a propulsion inlet lip curve) are prescribed as an input for rapid interactive design of such generalized waveriders with sharp leading edge[9]. Some very interesting waverider shapes have been generated by this method. A combination of this design approach with direct geometry control is the next step. Gasdynamic tools like the Taylor-Maccoll solution and its extension for waverider design are now added to the geometry functions for arbitrary shapes, allowing for a more or less extensive use of waverider elements in configuration design: Practical requirements will dictate rounded leading edges and a higher volumetric efficiency than waveriders have, so the designer needs to blend theoretically derived more academic cases with geometrical requirements dictated by the constraints. Fig. 7d shows such a compromise: a waverider geometry is modified by slightly rounded leading edges and a more convex upper surface with an added bump to model a canopy.

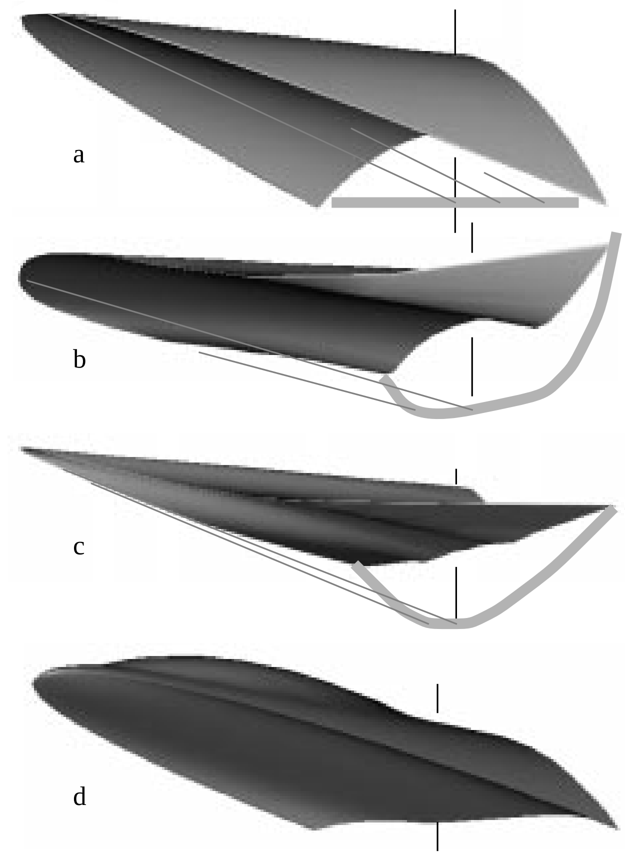


Fig. 7: Various Waveriders (a, b, c) and a generic forebody (d) with some waverider characteristics

Aircraft Configurations

Having developed geometry parameters which allow for arbitrary cross sections as well as such ones following from waverider theory, we have a quite flexible tool to create fuselages for lift production as will be required for high Mach number cruising vehicles. The following illustrations are shown to demonstrate the flexibility in using the geometry generator to create surface data of whole aircraft. Presently these generic shapes serve as test configurations for CFD code development.

Europe as well as America has ambitious programs for transport into orbit, the respective programs lend themselves to study aerothermodynamic phenomena on simplified configurations. It is the purpose of the presently developed geometry tool to show that simplification does not need to go too far: we should be able to model realistic details with good accuracy, without slowing down the preprocessing work of CFD input data. Here we show results of working with generic configurations derived from the transport systems ‘Sänger’ and ‘Aerospace Plane’.

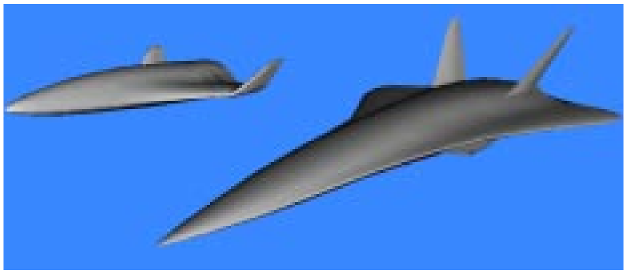


Fig. 8: Generic Configurations derived from the Sänger Two-Stage-to-Orbit Transport System

Sänger

In Germany, the Two-Stages-to-Orbit Transport System Sänger is a hypersonic technology program. The first stage is a super/hypersonic airplane with an integrated delta wing-body configuration. It was a challenge to model a reasonably similar generic test configuration for CFD codes development. At first the generator operational for subsonic /transonic transport aircraft was used. The result was not satisfactory, it was found necessary to make some extensions to the code as outlined above: here we no longer define the (main) wing separate from the body, we rather extend the body definition to include the wing. This new tool allows now for a completely smooth combination of wing and body, it is in fact one component as sketched in Fig. 5. Figure 8 illustrates the result for both vehicles: the first stage has, in addition to the new integrated wing-body, an inlet and fins which where all created using the previously developed wing tool. The second stage reentry vehicle consists only of a wing-body, with turned up tips to form winglets.

This configuration so far was generated to provide forebody boundary conditions for a CFD code(10) and data for

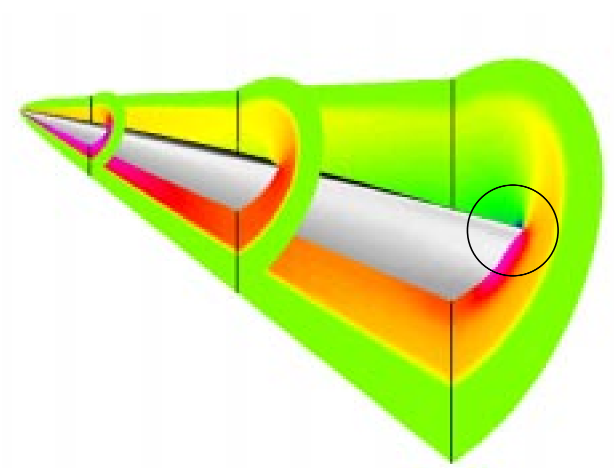


Fig. 9: Generic Forebody in supersonic flow Mach = 4.5: Color graphic visualization of shock wave and pressure distribution. Detailed studies at the leading edge (circle)

post-processing software development(11). Euler and Navier Stokes codes computation and subsequent graphic visualization (Fig. 9) of numerical results is currently carried out at DLR using this configuration and its modifications: Fig.10 shows analysis with a detail at the leading edge. The study was started to see response of flow simulation to changing just one single geometry parameter which controls leading edge camber distribution. Also, rapid surface coordinates calculation in arbitrary points suggests a use of such preprocessing for adaptive grid generation techniques(12). Results of these studies show the high flexibility through carefully developed input parameters of the generator.

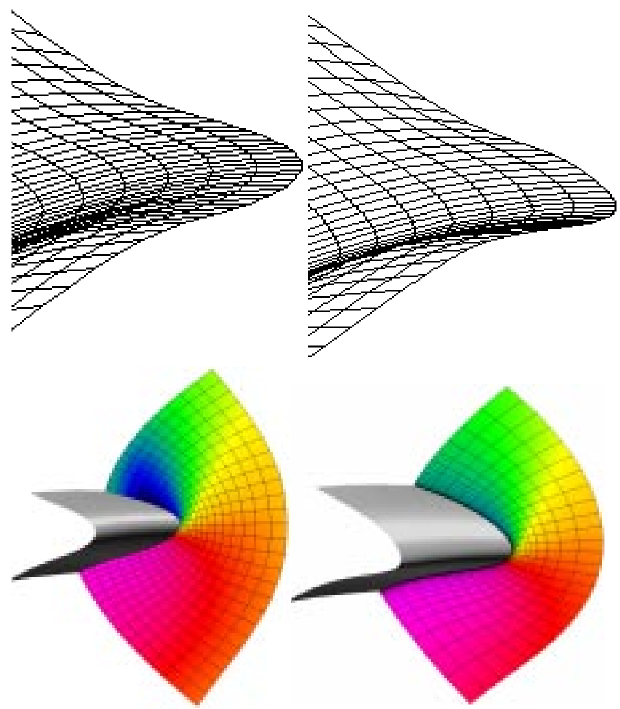


Fig. 10: Generic Forebody: Variation of the leading edge camber. Grid and pressure color graphics in cross section plane.

Aerospace Plane

Very recently the configuration for the United States National Aerospace Plane (NASP) was selected(13). For the years to come this configuration might be subject to an extreme concentration of research and development in hypersonic technology. There will be a need to break the whole project into components and define airframe and structural models for a multiplicity of research goals. It is therefore a very natural challenge to test and further develop our geometry tool using the features of this quite new type of configuration:

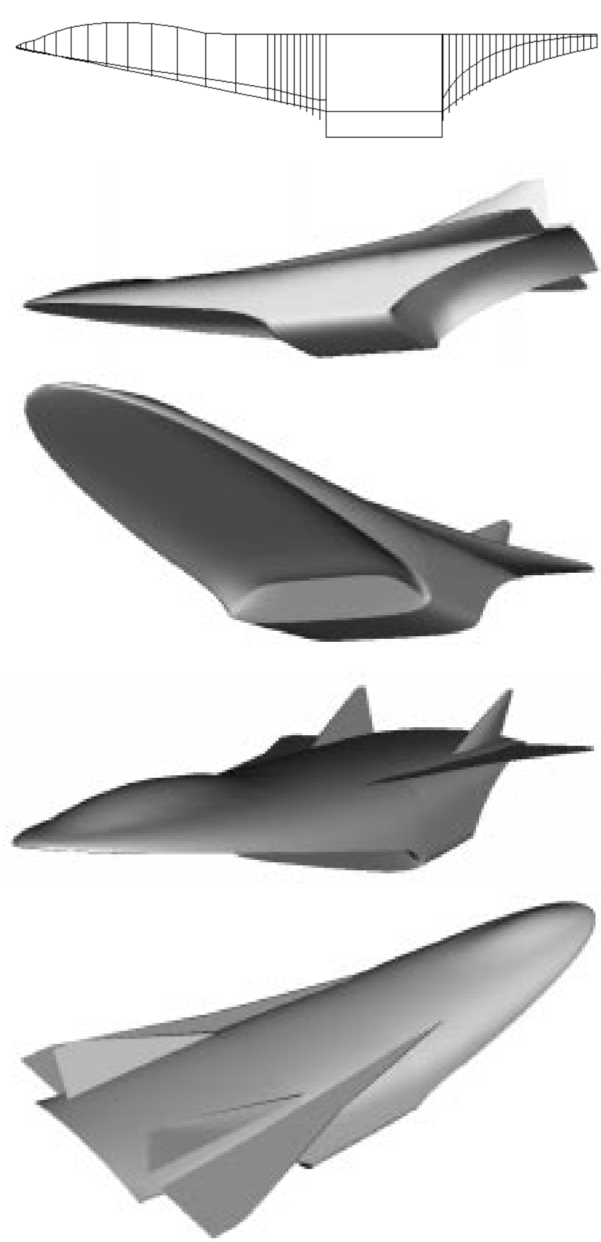


Fig. 11: Generic configuration derived from the National Aerospace Plane (NASP)

Unlike the present status Sänger first stage the NASP is is not really a winged aircraft, it is a wide lifting body. The wings are added rather for carrying control surfaces. The configuration does not show wing-body integration but propulsion is completely integrated. Presently we try to model a rea- sonable configuration based on only few illustrations available to us so far (Fig. 11). This should result in presenting a few test cases for CFD. Later the parameters may be adjusted to more real numbers. Opti-

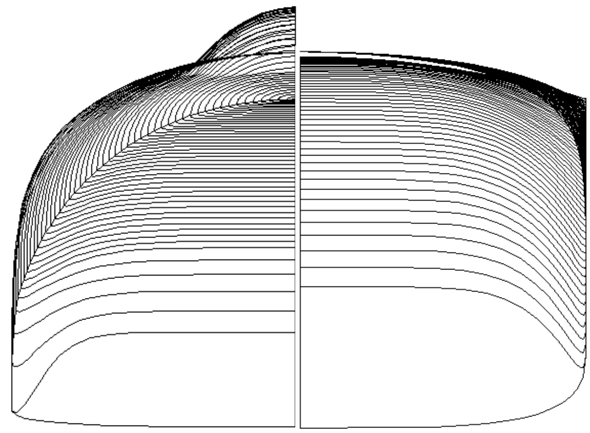


Fig. 12: Cross sections of the NASP model forebody (left) and expansion nozzle (right).

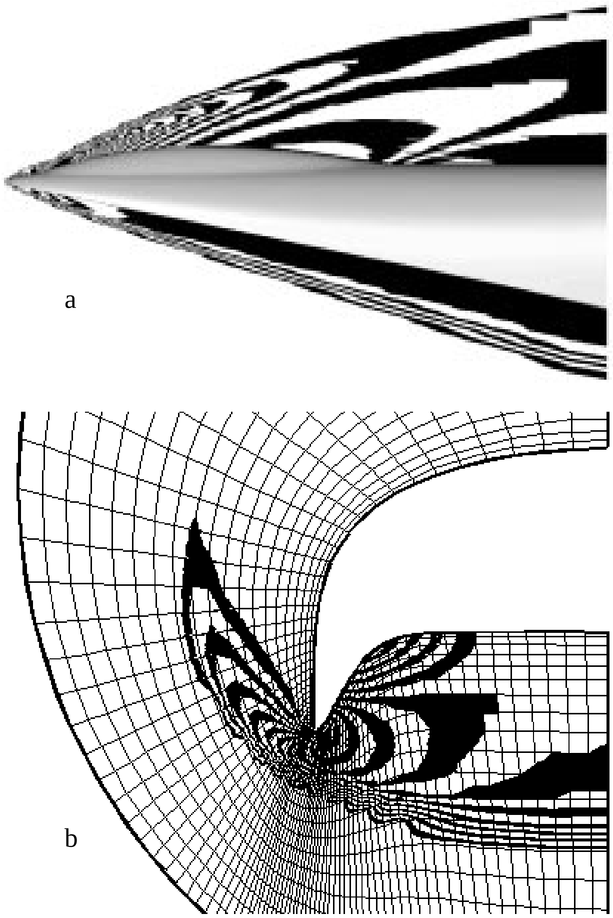
mization strategies for the external parts of the propulsion system, which uses the forebody for air compression and the aft body as an expansion nozzle, may be developed using a set of parameters to be varied. The forebody shape (Fig. 12) may allow for a contained shock like a waverider flow: the geometry created so far allows to include waverider elements as illustrated above. A large concave portion of the aft lower surface models the expansion nozzle, here we need a nozzle design procedure to couple surface definition parameters with design results.

The model created lends itself as a test case for various CFD analysis tools. First, algebraic grid generation is performed in cross section planes, with control parameters determining far field boundary surface, grid clustering strength and location again as functions of the axial direction. Grids are obtained this way very rapidly, they are found quite suitable for CFD analysis but alternatively may be used as first step for grid optimization and solution - adaptive grid generation[12].

First CFD results for the forebody using the Euler marching code[10] have been obtained (Fig. 13) for a few operating conditions. They are carried out to learn how much of ideal waverider flow characteristics (i. e. desired shock wave containment under the lower body surface) may be observed if the generated configuration compromises between a theoretical waverider and practical requirements.

Conclusion

The purpose of this paper is to illustrate preprocessor software for aerodynamics in the supersonic flow regime, to create aircraft components or whole configurations with integrated wing-body-propulsion, and with some basic gasdynamic flow elements incorporated in the variety of mathematical shape definition functions. Examples are shown for generic test cases which may be useful for present and near future education, research and design strategies development in the aerospace sciences.



a

b

Fig. 13: Visualization of pressure distribution (Mach = 5.35) in center plane (a); grid, shock spillage in exit cross section plane (b) of NASP model forebody, using an Euler code[10].

Acknowledgements:
This work is funded by DLR German Aerospace Establishment basic funds. Additional support by the University of Colorado, College of Engineering is gratefully acknowledged.

References

1. Sobieczky, H., 'Geometry Generation for Transonic Design', Recent Advances in Numerical Methods in Fluids, Vol. 4, Ed. W. G. Habashi, Swansea: Pineridge Press, pp. 163 - 182. (1985).

2. Sobieczky, H., 'Analytical Surfaces and Grids. In: AGARDograph No. 309, Three Dimensional Grid Generation, H. Yoshihara (Ed.), (1988)

3. Pagendarm, H. G., Laurien, E., Sobieczky, H., 'Interactive Geometry Definition and Grid Generation for Applied Aerodynamics', AIAA 88-2415CP (1988)

4. Stroeve, J. C., Sobieczky, H., 'Geometry / Grid Generator for Design Aerodynamics, a User's Manual with Illustrations', University of Colorado, College of Engineering, Project Report 90 - 01. (1990)

5. Rill, S., Becker, K., 'Simulation of Transonic Inviscid Flow over a Twin Jet Transport Aircraft', AIAA 91-0025, (1991).

6. Choudhry, S. I., Pagendarm, H. G., Sobieczky, H., 'Interactive Geometry Generation for Variable and Adaptive Aerodynamic Configurations', DLR Report to appear.

7. Choudhry, S. I., Pagendarm, H. G., 'A Low Cost Approach to Animated Flow Visualization Using High Quality Video', Proc. Second Eurographics Workshop on Visualization in Scientific Computing, 22. - 24. April 1991, Delft, (see also: Springer Eurographic Seminar Series, Springer 1991)

8. Sobieczky, H., Dougherty, F. C., Jones, K., 'Hypersonic Waverider Design from Given Shock Waves', paper at 1st International Hypersonic Waverider Symposium, University of Maryland, Oct. 1990

9. Center, K., Sobieczky, H., Dougherty, F. C.,'Interactive Hypersonic Waverider Design' , AIAA 91-1697 (1991)

10. Müller, B., Niederdrenk, P., Sobieczky, H., 'Simulation of Hypersonic Waverider Flow', paper at 1st International Hypersonic Waverider Symposium, University of Maryland, Oct. 1990

11. Pagendarm, H. G., ' "HIGHEND", A Visualization System for 3D Data with Special Support for Postprocessing of Fluid Dynamics Data', Proc.Eurographics Workshop on Visualization in Scientific Computing, Springer, (1990)

12. Niederdrenk, P., 'Solution-adaptive Grid Generation by Hyperbolic / Parabolized Hyperbolic PDE's, Third Intl. Conference on Numerical Grid Generation in CFD and Related Fields, Barcelona, June 3 - 7, 1991

13. Kandebo, W., 'Lifting Body Design Is Key to Single-Stage-to-Orbit', Aviation Week and Space Technology, Oct. 29, 1990