Chapter 9

Geometry Generator for CFD and Applied Aerodynamics

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9.1 Introduction

This chapter is intended to combine the knowledge bases of applied geometry with those of hydrodynamics and aerodynamics, including the modest additions presented in the two previous book chapters focusing on the interaction between compressible flow with shock waves and flow boundary conditions. The need to have flexible tools for effectively influencing the phenomena occurring in high speed flow calls for development of fast and flexible software to create shapes in a way to have easy access to the crucial shape-generating parameters controlling these flow phenomena, and at the same time observe the constraints given by structural and other practical limitations.

Renewed interest in Supersonic Civil Transport (SCT) or High Speed Civil Transport (HSCT) calls for extensive computational simulation of nearly every aspect of design and development in the whole system. CAD methods are available presently for many applications in the design phase. Nevertheless, work in early aerodynamic design lacks computational tools which enable the engineer to perform quick comparative calculations with gradually varying configurations or their components. To perform aerodynamic optimization, surface modelling is needed which allows parametric variations of wing sections, planforms, leading and trailing edges, camber, twist and control surfaces, to mention only the wing. The same is true for fuselage, empennage, engines and integration of these components. This can be supported in principle by modern Computer Aided Design (CAD) methods, but data preprocessing for numerical flow simulation (CFD) calls for more directly coupled software which should be handled interactively by the designer observing computational results quickly and thus enabling him to develop his own intuition for the relative importance of the several used and varied shape parameters. The requirements of transonic aerodynamics for transport aircraft in the high subsonic flight regime as well as more recent activities in generic hypersonics for aerospace plane design concepts have enhanced previous activities [113], [114] in the development of dedicated geometry generation [115]. Based on experience with the definition of test cases for transonic aerodynamics [116] and with fast optimization tools for hypersonic configurations outlined in the previous chapter, as well as taking into account new developments in interactive graphics, some fast and efficient software tools for aerodynamic shape design are already operational or under development. The concept seems well suited for application to various design tasks in high speed aerodynamics and fluid mechanics of SCT aircraft projects, especially with options to select suitable parameters for an application of optimization strategies which will be presented in following book chapters.

It is the author’s intention to illustrate the options of the proposed method for a systematical development of some of the required technologies for high speed aircraft design, at least those needed in aerodynamics, some for aeroelastics and for aeroacoustics. Computational simulations will have an ever increasing share in technology development though experiments are still needed; wind tunnel models are to be created by CAD systems for which the geometry generator as a preprocessor must provide data of exactly the same accuracy as for CFD.

Much use is made of graphic illustrations in this chapter which is natural for this topic and which may be more useful than much text. A powerful interactive fluid mechanics visualization software system [117] greatly adds to an efficient use of shape design methods: structured and unstructured CFD grids, shaded solid surfaces and isofringes depicting flow variables distribution results are displayed on a graphic workstation screen and for a few examples in the following pages.

9.2 Parameterized Curves and Surfaces

The geometry tool explained here has been developed in the years shortly before interactive graphic workstations became available, originally for input with data lists but increasingly laid out for interactive usage in the windows environment of the workstation. The list input still is the basic option and data for such usage will be presented here for explanation. Focusing on surface modelling of aerodynamically efficient aircraft components, we realize that the goal of shape 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 is gained with a set of simple analytic functions and the possibility is used to occasionally extend the existing collection of 1D functions, ground is laid to compose these functions suitably to yield complex 2D curves and finally surfaces in 3D space. This way we intend to develop tools to define data for airframe components with a nearly unlimited variety within conventional, new and exotic configurations. A brief illustration of the principle to start with 1D functions, define curves in 2D planes and vary them in 3D space to create surfaces is given:

9.2.1 Function Catalog

A set of functions Y(X) is suitably defined within the interval $0 < X < 1$, with end values at X,Y = (0, 0) and (1, 1), see Figure 53. 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. Four parameters or less were chosen to describe end slopes (a, b) and two additional properties (e_G, f_G) depending on a function identifier G. The squares shown depict some algebraic curves where the additional parameters describe exponents in the local expansion (G=1), zero curvature without (G=2) or with (G=20) straight ends added, polynomials of fifth order (G=6, quintics) and with square root terms (G=7) allowing curvatures being specified at interval ends. Other numbers for G yield splines, simple Bezier parabolas, trigonometric and exponential functions. For some of them a, b, e_G and/or f_G do not have to be specified because of simplicity, like G=4 which yields just a straight line. The more recently introduced functions like G=20 give 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. It is obvious that this library of functions is modular and may be extended for special applications, the new functions fit into the system as long as they begin and end at (0, 0) and (1, 1), a and b - if needed - describe the slopes and two additional parameters are permitted.

$$Y = F_G(a, b, e_G, f_G, X)$$

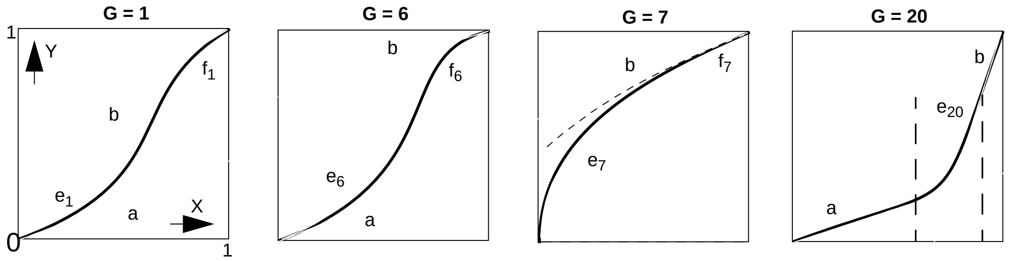
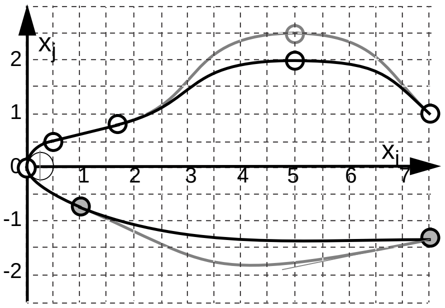


Figure 53 Selection of 4 basic functions F_G in nondimensional unit interval

9.2.2 Curves

The next step is the composition of curves by a piecewise scaled use of these functions. Figure

54 illustrates this for an arbitrary set of support points, 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. Numbers serving as names ("keys") distinguish between a number of needed curves, the example shows two different curves and their support points. Besides graphs a table of input numbers is depicted, illustrating the amount of data required for these curves. Nondimensional function slopes a, b are calculated from input dimensional slopes s_1 and s_2, as well as the additional parameters e_G, f_G are found by suitable transformation of e and f. A variation of only single parameters allows dramatic changes of portions of the curves, observing certain constraints and leaving the rest of the curve unchanged. This is the main objective of this approach, allowing strong control over specific shape variations during optimization and adaptation.



key	u	F(u)	s_1	G	s_2	e	f
1	0.0	0.0	0.	7	0.25	4.	0.
1	0.5	0.5	0.	4			
1	1.7	0.8	0.25	6	0.	0.	-0.2
1	5.0	~~2.0~~ 2.5	0.	6	-0.8	-0.2	-0.2
1	7.5	1.0					
2	0.0	0.0	0.	7	-0.5	4.	0.
2	1.0	-0.7	-0.5	20	~~0.~~ 0.2	5.	
2	7.5	-1.3					

Figure 54 **Construction of arbitrary, dimensional curves in plane (x_i, x_j) by piecewise use of scaled basic functions. Parameter input list with 2 parameters changed (shaded curves).**

9.2.3 Surfaces

Aerospace applications call for suitable mathematical description of components like wings, fuselages, empennages, pylons and nacelles, to mention just the main parts which will have to be studied by parameter variation. Three-view geometries of wings and bodies are defined by planforms, crown lines and some other basic curves, while sections or cross sections require additional parameters to place surfaces fitting within these planforms and crown lines. Figure 54 shows a surface element defined by suitable curves (generatrices) in planes of 3D space, it can be seen that the strong control which has been established for curve definition, is maintained here for surface slopes and curvature.

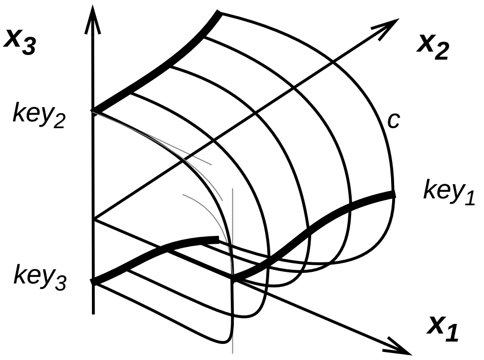


Figure 55 **Surface definition by cross sections c in plane (x_1, x_3) determined by generatrices (key_i), along x_2 and defined in planes (x_1, x_2) and (x_2, x_3).**

9.3 Aircraft and Aerospace Vehicle Components

So far the geometry definition tool is quite general and may be used easily for solid modelling of nearly any device if a mathematically exact description of the surface, with controlled gradients and curvatures, is intended. In aerodynamic applications we want to make use of knowledge bases from hydrodynamics and gasdynamics, i. e. classical airfoil and wing theory, as well as the classical results of slender body theory, transonic and supersonic area rule should determine the choice of functions and parameters. Surface quality should be described with the same accuracy as resulting from refined design methods outlined in the book chapter about the gasdynamic knowledge base. This is achieved by selecting suitable functions (G) when the 'key' curves are subdivided into intervals defined by support stations. Slope and curvature control avoids the known disadvantages of splines while at the same time the number of supports may be very low, if large portions may be modelled by one type of function.

In the process of making this generally described geometry tool to become dedicated geometry generator software for aerospace applications, a focusing on two main classes of surfaces has been found useful: There are classes of surfaces which are traditionally '*spanwise defined*' and others are '*axially defined*'. Lift-generating components like wings primarily belong to the first category while fuselages are usually of the second kind. With this distinction having led to several practical versions of geometry generators, it should not be considered too dogmatically: especially novel configuration concepts in the high Mach number flight regime are modelled without the above distinction as will be illustrated below, after describing the creating of conventional wings and fuselages.

9.3.1 Airfoils

In the case of wing design we will need to include 2D airfoil shapes as wing sections, with data usually resulting from previous development. Having gone through CFD design and analysis, sometimes also through experimental investigations, these given data should be dense sets of coordinates without the need to smooth them or otherwise make geometric changes which are not accompanied by flow analysis. Airfoil research has its main applications in high aspect ratio wing applications in the subsonic and transonic flight regime. Supersonic applications with low aspect ratio also need airfoils but their implementation to wing shaping requires mainly investigating the whole 3D problem. This leads to the option in the present geometry generator to provide again airfoil input data, but with only few coordinates: These can be used for spline interpolation in a suitably blown-up scale (Figure 56). For such few supports each point may take the role of an independent design parameter, wavy spline interpolation may be avoided if dislocations are small compared to distances to fixed points. Along one airfoil contour to be modified, portions of fixed contour with dense data distribution may be given while other portions may be controlled by only one or two isolated supports. This option was used in an early version of this geometry tool to optimize wing shapes in transonic flow [118].

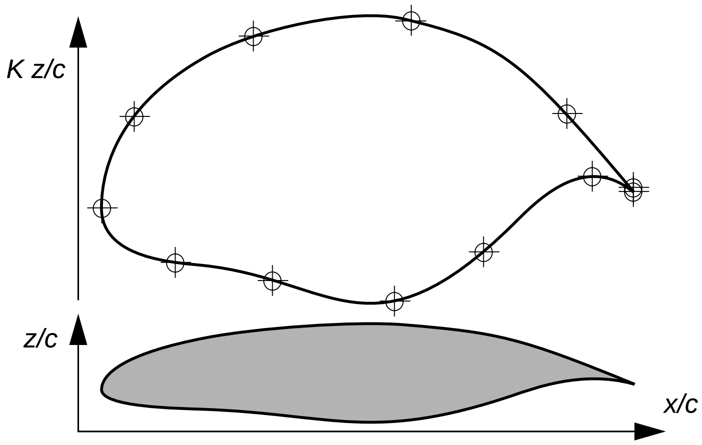


Figure 56 Spline fit obtained for airfoil in blown-up scale with few support points

Analytical sections and input for inverse design

Spline fits are well suited for redistribution of qualitatively acceptable dense data. The possible occurrence of contour wiggles has restricted their use in the geometry tool discussed here to the abovementioned option accepting external data, which is realistic for airfoils to be implemented in wing design. For a more independent approach we may ask for a more elegant analytical representation of wing sections, especially if these shapes still should be optimized. An important question arising is how many free parameters are needed for representation of arbitrary, typical wing sections, with the shape close enough to duplicate CFD or experimental results of aerodynamic performance with reasonable accuracy. Our successive refinement of airfoil generator subroutines using variously segmented curves as depicted in Figure 54 has shown that an amount of 10 to 25 parameters (numbers as listed in the table in Figure 54) may suffice for quite satisfactory representation of a given airfoil. The upper limit applies to transonic and laminar flow control airfoils with delicate curvature distribution as illustrated for a shock-free transonic airfoil, Figure 60 in chapter 7, where the influence of local curvature variations on the drag polar can be seen. The lower limit seems to apply for simpler yet practical subsonic airfoils and for most supersonic sections.

With a library of functions applied to provide parametric definition of airfoils, another application of this technique seems attractive: new inverse airfoil and wing design methods need input target pressure distributions for specified operation conditions and numerical results are found for airfoil and wing shapes. The status of these methods is reviewed in the next book chapter. Given the designer’s experience in aerodynamics for selecting suitable pressure distributions, choice of a few basic functions and parameters may provide a dense set of data $c_p(x/c)$ just like geometry coordinates are prescribed, the amount of needed parameters for typical attractive pressure distributions about the same as for the direct airfoil modelling.

Variable camber sections

Lifting wings need mechanical control devices to vary their effective camber. Geometrical definition of simple hinged and deflected leading and trailing edges are defined by airfoil chordwise hinge locations and deflection angles. A more sophisticated mechanical flow control includes elastic surface components to ensure a certain surface smoothness across the hinge, such devices are called sealed slats and flaps (Figure 57). Spline portions or other analytical connection fits may suitably model any proposed mechanical device, an additional parameter is the chord portion needed for the elastic sealing.

Multicomponent airfoils

While sealed flaps and slats are suitable for supersonic wings, the much more complicated multicomponent high lift systems have been developed for current subsonic transport aircraft. In addition to angular deflection of slat and flap components, they require kinematic shifting devices housed within flap track fairings below the wing. For a mathematical and parameter-controlled description of slat and flap section geometries within the clean airfoil, the richness of our function catalog provides suitable shapes and track curves for a realistic modelling of these components in every phase of start and landing configurations. Figure 58 illustrates a multicomponent high lift system in 2D and 3D.

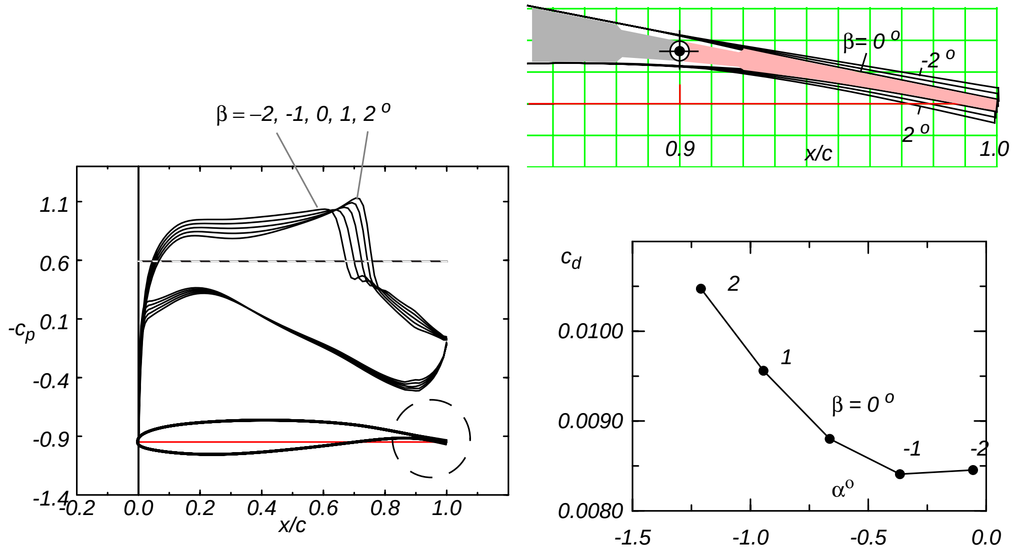


Figure 57 Variable camber sealed flap example. Flap deflection as a function of angle of attack variations, for constant lift. Airfoil in transonic flow, $M_\infty = 0.75$, Re = 40 Mill., $c_l = 0.7$, (MSES [93] analysis)

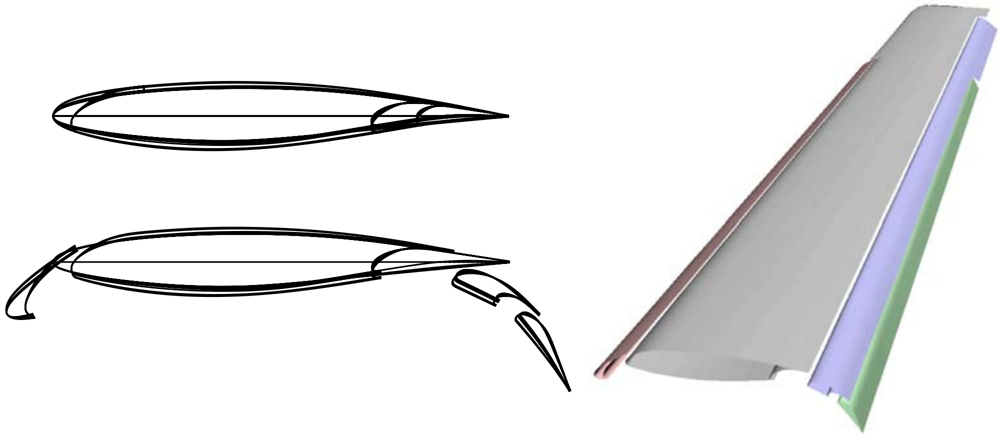


Figure 58 Wing sections for multicomponent high lift system, 3D swept wing with slat and flaps.

9.3.2 Spanwise defined components

Aircraft wings

Aerodynamic performance of aircraft mainly depends on the quality of its wing, design focuses therefore on optimizing this component. Using the present shape design method, we illustrate the amount of needed “key curves” along wing span which is inevitably needed to describe and vary the wing shape, Figure 59. The key numbers are just identification names: span of the wing y_o in the wing coordinate system is a function of a first independent variable $0 < p < 1$, the curve $y_o(p)$ is key 20. All following parameters are functions of this wing span: planform and twist axis (keys 21-23), dihedral (24) and actual 3D space span coordinate (25), section twist (26) and a spanwise section thickness distribution factor (27). Finally we select a suitably small number of support airfoils to form sections of this wing. Key 28 defines a blending function $0 < r < 1$ which is used to define a mix between the given airfoils, say, at the root, along some main wing portions and at the tip. The graphics in Figure 59 shows how the basic airfoils, designed with subsonic or with supersonic leading edges, may be dominating across this wing. Practical designs may require a larger number of input airfoils and a careful tailoring of the section twist to arrive at optimum lift distribution, for a given planform.

Recent updates to the wing generation include a spanwise definition of the previously mentioned 10 - 25 airfoil parameters as additional key functions, replacing given support airfoils and the blending key 28. Because of an explicit description of each wing surface point without any interpolation and iteration, other than sectional data arrays describing the exact surface may easily be obtained very rapidly with analytical accuracy.

Wings with high lift systems are created using multicomponent airfoils either for unswept wings with simply their varied deflected 2D configurations as illustrated in Figure 57, or in the more practical case of swept components (Figure 58) rotation axes and flap tracks need to be described as lines and curves in 3D space. The clean airfoil configuration of the system is then changed observing the given 3D kinematics.

Other components with wing-type parameterization

Besides aircraft wings the tail and rudder fins as well as canard components are of course treatable with the same type of parameters and key functions. Highly swept and very short aspect ratio wing type components are the pylons for jet engines mounted to the aircraft wing; they need to be optimized in a flow critically passing between wing and engine. Generally any solid boundary condition to be optimized in flow with a substantial crossing velocity component is suitably defined as a spanwise defined component with a parameter set as illustrated for the wing.

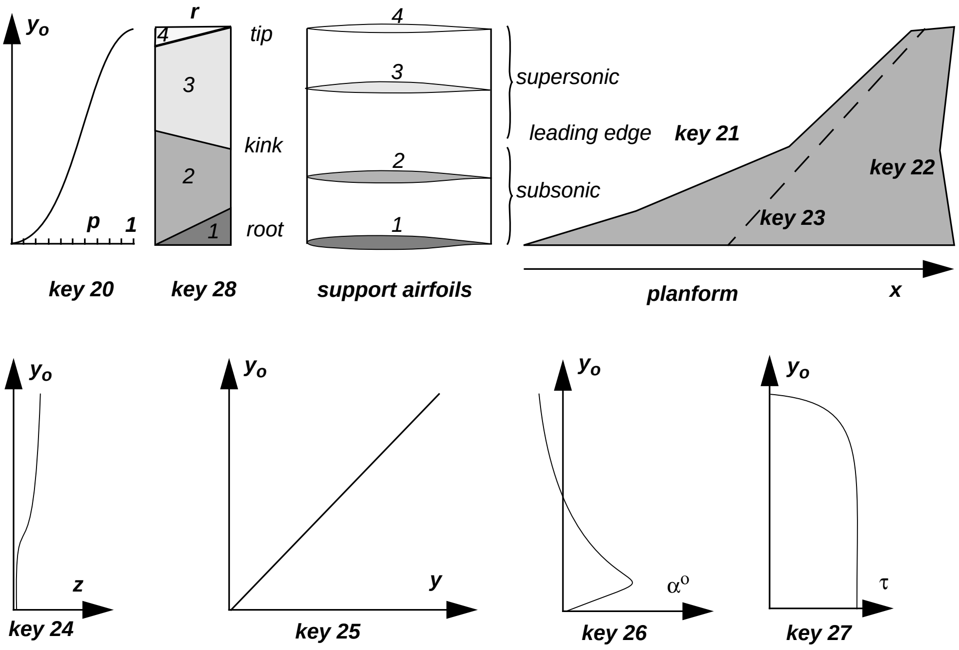


Figure 59 **Wing parameters and respective key numbers for section distribution, planform, an/dihedral, twist, thickness distribution factor and airfoil blending.**

9.3.3 Axially defined components

Fuselage bodies, nacelles, propulsion and tunnel geometries

This group of shapes is basically aligned with the main flow direction, the usual development is directed toward creating volume for payload, propulsion or, in internal aerodynamics (and hydrodynamics) the development of channel and pipe geometries. The parameters of cross sections are quite different to those of airfoils; the quality of their change along a main axis with constraints for given areas within the usually symmetrical contour is the design challenge. Fuselages are therefore described by another set of “keys” which is defined along the axis. This axis may be a curve in 3D space, with available gradients providing cross section planes normal to the axis. For simple straight axes in the cartesian x-direction key 40 defines axial stations just like key 20 defines spanwise x-stations. With the simplest cross section consisting of superelliptic quarters allowing a choice of the half axes or crown lines and body planform, plus the exponents (with the value of 2. for ellipses), 8 parameters (key 41 - 48) are given (Figure 60). Basic bodies are described easily this way, with either explicitly calculating the horizontal coordinate y(x, z) for given vertical coordinate z, or the vertical upper and lower coordinate z(x, y) for given points y within the planform, at each cross section station x = const.

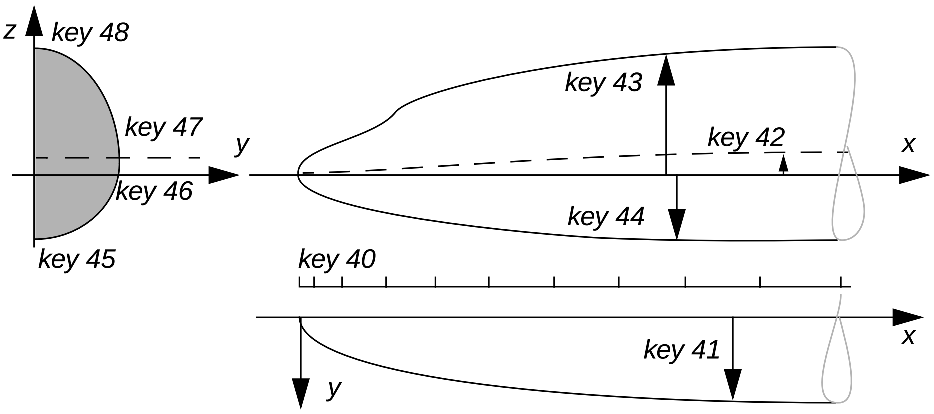


Figure 60 **Fuselage parameters and respective key numbers for cross section definition, planform and crown lines, superelliptic exponents.**

More complex bodies are defined by optional other shape definition subprograms with additional keys (49 - 59) needed for geometric details. These may be of various kind but of paramount interest is the aerodynamically optimized shape definition of wing-body junctures. In the following a simple projection technique is applied requiring only a suitable wing root geometry to be shifted toward the body, but more complex junctures require also body surface details to suitably meet the wing geometry.

9.3.4 Component intersections and junctures

The usual way to connect two components is to intersect the surfaces. Intersection curves are found only by numerical iteration for non-trivial examples. Most CAD systems perform such task if the data of different surfaces are supplied. Here we stress an analytical method to find not only the juncture curve but also ensure a smooth surface across the components avoiding corners which usually create unfavorable aerodynamic phenomena. Sketched in Figure 61, this can be applied generally to two components F_1 and F_2 with the condition that for the first component one coordinate (here the spanwise y) needs to be defined by an explicit function $y = F_1(x,z)$, while the other component F_2 may be given as a dataset for a number of surface points. Using a blending function for a portion of the spanwise coordinate, all surface points of F_2 within this spanwise interval may be moved toward the surface F_1 depending on the local value of the blending function. Figure 61 shows that this way the wing root (F_2) emanates from the body (F_1), wing root fillet geometry can be designed as part of the wing prior to this wrapping process. Several refinements to this simple projection technique have been implemented to the program.

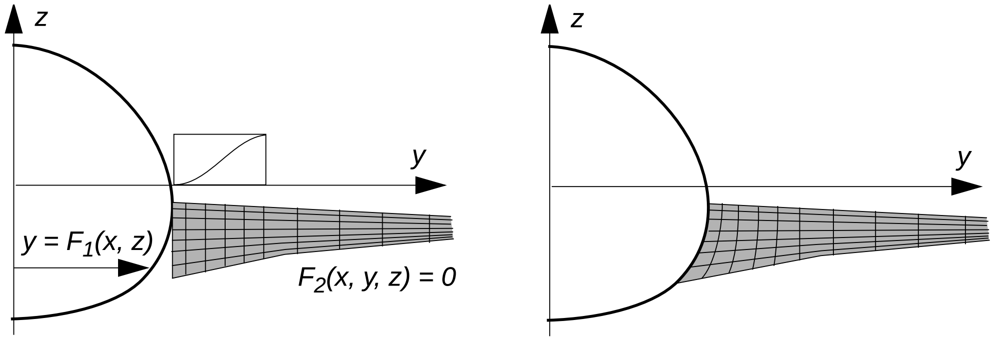


Figure 61 **Combination of two components by a blended projection technique**

9.3.5 Extensions to the fourth dimension

The outlined geometry generator based on this explicit mathematical function toolbox allows for creating models for nearly any aerospace-related configuration. The next step is to provide a whole series of shapes which result from a controlled variation of a parameter subset key_j, with the option to create infinitesimally small changes between neighboring surfaces. This requires the introduction of a “superparameter” t, its variation within a suitable interval Δt and a general variation function f(t). Variated parameters result then to

$$key_j(t) = key_j(0) + f(t)\ \ \Delta key_j \tag{71}$$

with Δkey defined by the chosen extreme deviation from the starting values. Obtaining a series of surfaces calls for suitable computergraphic animation technology [119]. There are three major applications of introducing the 4th dimension (t) to the presented geometry generator for the development of design concepts:

Numerical Optimization

The success of optimization performing variations of a set of parameters small enough to enable the designer to control and understand the evolutionary process toward improved performance, but large enough to most likely include a global optimum, depends on selecting the parameters by knowledge based criteria. Simple first applications include the calibration of surface modifications as experienced from shock-free transonic design [118], [120].

Adaptive Devices

A mechanical realization of numerical optimizing processes is the use of adaptive devices controlled by flow sensors [121]. Experiments are needed for the development and understanding of the dynamics of such processes, as they are already routine for adaptive wind tunnel walls. Adaptive configuration shape simulation by the geometry generator will require a series of shapes generated by selected functions equivalent to the mechanical model for elastic or pneumatic devices.

Unsteady configurations

Finally there is time, the natural role of the superparameter t. Configurations may vary with time, especially if there is aeroelastic coupling between structure and flow. Periodically varying shapes are generated to study the influence of moving boundary conditions on the flow. Modelling buffeting in the transonic regime is a wellknown goal, application of periodic geometries for a coupling of numerical structure analysis and CFD seems timely. Shape changes to model an adaptive helicopter rotor section with a sealed slat periodically drooped nose have been carried out and the results of unsteady Navier Stokes analysis suggest a concept for dynamic stall control [122].

9.4 Applications

Case studies for new generation supersonic transport aircraft have been carried out through the past years in research institutions and in the aircraft industry. Our present tool to shape such configurations needs to be tested by trying to model the basic features of various investigated geometries. Knowing that the fine-tuning of aerodynamic performance must be done by careful selection of wing sections, wing twist distribution and the use of sealed slats and flaps, with initial exercises we try to geometrically model some of the published configurations, generate CFD grids around them and use optimization strategies to determine the sensitivity of suitable geometry parameters. This is still a difficult task but tackling its solution greatly contributes to building up the knowledge base of high speed design.

9.4.1 Example: Generic High Speed Civil Transport Configuration

Figure 62 and Figure 63 illustrate data visualization of a generated configuration derived from a Boeing HSCT design case for Mach 2.4 [123]. The configuration consists of 10 components, engine pylons are not yet included. Wing and horizontal and vertical tail components are spanwise defined, fuselage and engines are axially defined components. The wing has a subsonic leading edge in the inner portion and a supersonic leading edge on the outer portion.

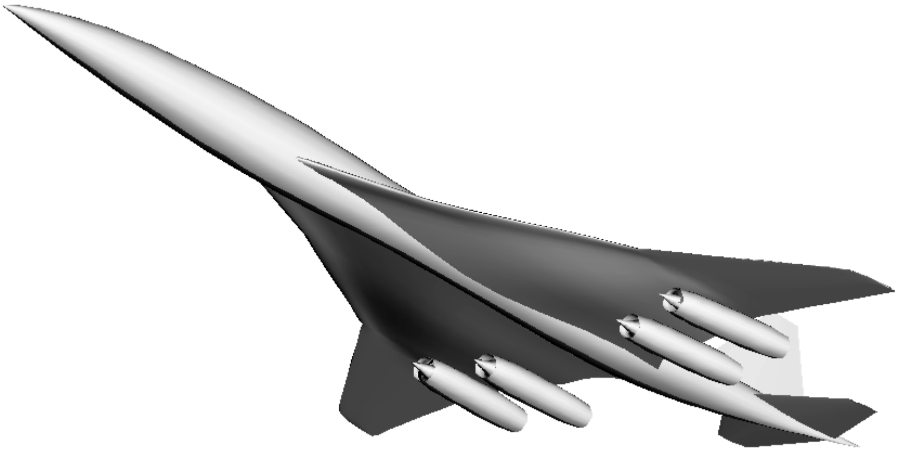


Figure 62 **Generic HSCT configuration derived from Boeing Mach 2.4 case study: shaded graphic visualization of geometry modelling result**

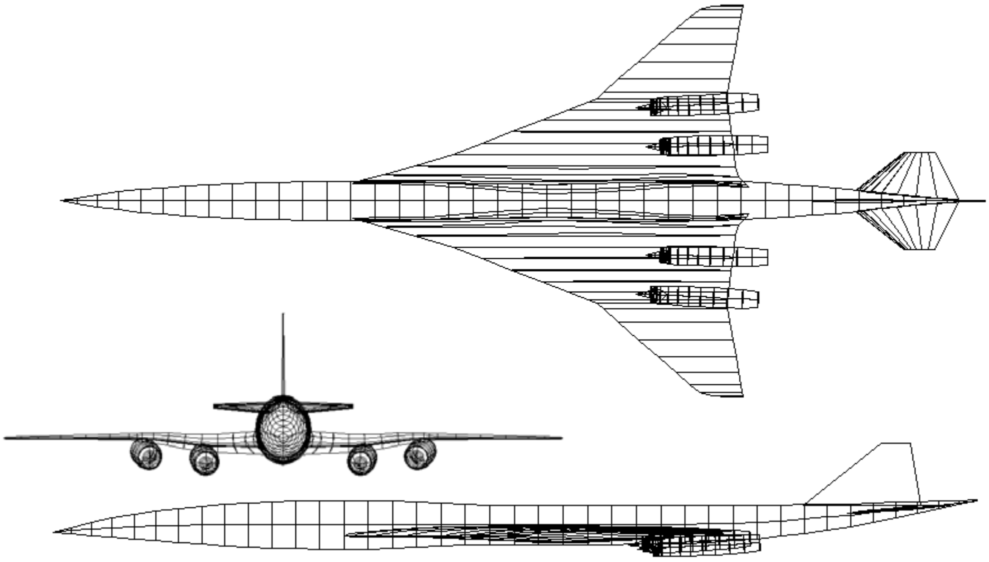


Figure 63 **Generic HSCT configuration: Three-view wireframe model**

For this study a minimum of support airfoils (Figure 58) is used to get a reasonable pressure distribution: a rounded leading edge section in most of the inner wing and a wedge-sharp section in the outer wing portion define the basic shape of the wing. Wing root fillet blending, the smooth transition between rounded and sharp leading edge and the tip geometry are effectively shaped by the previously illustrated wing keys, the fuselage here is a simple slender body requiring just the baseline body tool with elliptical cross sections.

Preprocessing input data for CFD requires providing a grid surrounding the configuration. For application of either structured or unstructured grids additional geometric shapes need to be provided. In the case of the generic HSCT with given supersonic flight Mach number the farfield boundary is chosen to engulf the expected bow shock wave (Figure 64a) and a cross sectional grid for both wing and body is generated, either as simple algebraic trajectories or using elliptic equations.

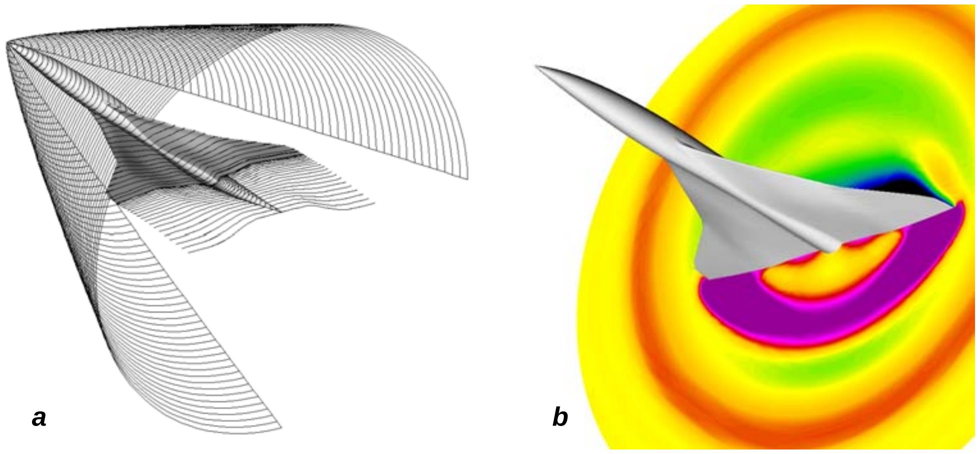


Figure 64 CFD grid boundaries, result for Euler analysis of HSCT wing-body in supersonic flow $M_\infty = 2.4$

Short runs using an the inviscid flow Euler option of a flow solver [124]were carried out on a coarse (33 x 81 x 330) grid, here only to get an idea about the needed wing section and twist modifications for acceptable pressure distributions. Visualization of the results in various grid surfaces is needed, like pressure distributions in cross section planes as shown in Figure 64b.

Coupling with visualization tools

Postprocessing of CFD results with a powerful graphic system [117] shows detailed display of flow variables distribution along the configuration and in the flow field. Selected cross section pressure checks allow for an assessment of chosen airfoils and twist distributions before refined grids and longer Euler or Navier-Stokes runs are executed. Though areas of necessary local grid refinement are spotted, some basic information about needed airfoil changes is already provided by such short runs; the refinement of geometry and CFD analysis may begin.

Visualization of the shock waves system emanating from the body tip and the wing is shown in Figure 65. A new visualization technique [125] allows for analyzing shock waves found by CFD analysis in 3D space: their quality near the aircraft, as shown, or with refined CFD analysis in larger distances to investigate sonic boom propagation, may be a useful help to assess this environmentally important aspect of supersonic transport. The figure shows a cut-off domain of the shock surfaces: A shock strength threshold allows analysis of local sonic boom quantities.

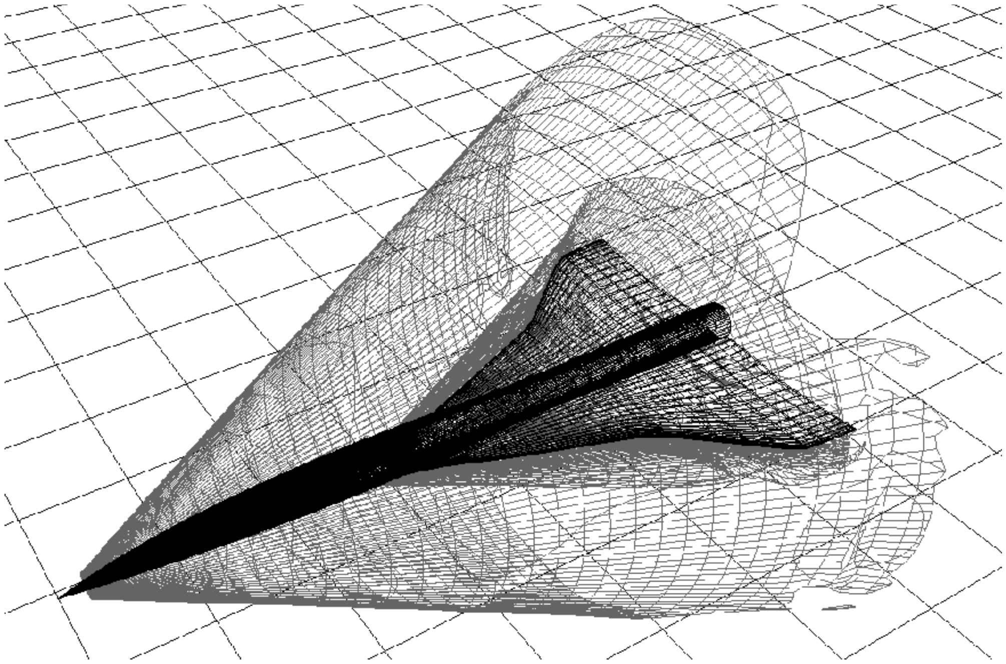


Figure 65 Visualization of CFD results: Shock system emanating from body tip and wing root, cut-off at threshold for selected sonic boom strength.

9.4.2 Software development for CFD and CAD preprocessing

The above case study, to be further used for a refined analysis and design parameter identification, is just a modest example compared to the needed studies in the development of industrial software suitable for the envisioned multidisciplinary quality as outlined in the first book chapters. With the proven flexibility of the ideas developed here, a larger scale software development at industry, aerospace research establishment and university institutes has picked up the basic elements and merged them in their applied software systems:

At Daimler Benz Airbus aircraft industry a software system was developed as a preprocessor for multiblck structured grid generation around complete aircraft [126]. The fast algebraic definition of arbitrary surface metrics is ideal for application in multiblock/multigrid CFD analysis; many case studies exploiting the richness of possible configuration topologies with this approach have been carried out. Refinements in the algebraic grid generation tools for optimum multiblock grid spacing have been implemented and complex transonic transport aircraft configurations with suitable grid blocks have been generated and used for CFD analysis.

Parametric studies of supersonic transport aircraft wings have been performed at DLR German Aerospace Research Establishment [127]. Sensitivity studies are carried out and a multi-point optimization design method is being worked on using some of our basic functions and curves. Results are obtained for conventional and new configurations, with optima found for relative positioning of the different components.

The emergence of new programming languages and faster and more powerful graphic workstations with larger storage capacity gave rise to the development of a new and completely interactive version of this geometry generator [128]. Definition of a complex case study for a combined theoretical, numerical and experimental investigation sets various tasks for the new system to serve as a preprocessor for different CAD systems. These systems are needed for wind tunnel model construction (CATIA) and for unstructured CFD grid generation (ICEM). The latter is needed for performing Euler and Navier Stokes analysis with a new analysis code using unstructured grids [129]. Figure 66 illustrates a result of this analysis.

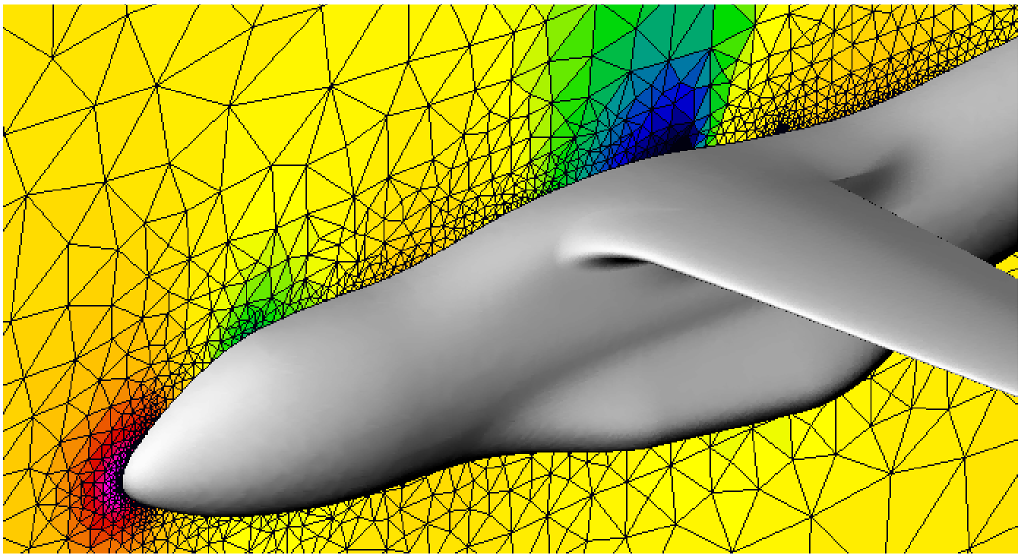


Figure 66 **Generic high wing transport aircraft geometry model for Euler CFD analysis with unstructured grid code; grid and pressure isofringes in center plane**

9.4.3 Novel Configurations

The development of conventional high speed transport configurations like the generic HSCT configuration may still face crucial technology problems resulting in reduced chances to operate economically, as it is critically reviewed in various chapters in this book. New concepts, on the other hand, are emerging, but they must be studied in great detail using reliable theoretical, numerical and experimental analysis tools before any project can be laid out for development of a first aircraft.

All-body and all-wing configurations

From the viewpoint of using the presented geometry generator for support of such new concepts, it seems that promising new configurations can be generated if the two types of shapes, axially and spanwise defined components, are not any longer restricted to their traditional roles of representing fuselage and wing, respectively. There is rather an attractive alternative emerging by either type of component taking over both functions:

All-body aircraft as well as all-wing configurations are limiting cases where either wing or fuselage is vanishing and the remaining component taking over both functions which are providing volume as well as lift. Waveriders as illustrated in the previous book chapter are fully integrated configurations; guided by the outlined knowledge base of inverse design it is now relatively easy to create arbitrary direct design cases with waverider characteristics [115], there is just no “on-design” condition flow field coming with the design geometry. Suitable choice of geometry parameters to simulate inverse design cases but allowing a 4D optimization extension as outlined above most likely will lead to further improvements. Generic hypersonics asks for integrated configurations, favorably based on the waverider concept: Direct geometry generation using either the wing tool (Figure 67a) or the body tool (Figure 67b) for the integrated wing body components can solve this task.

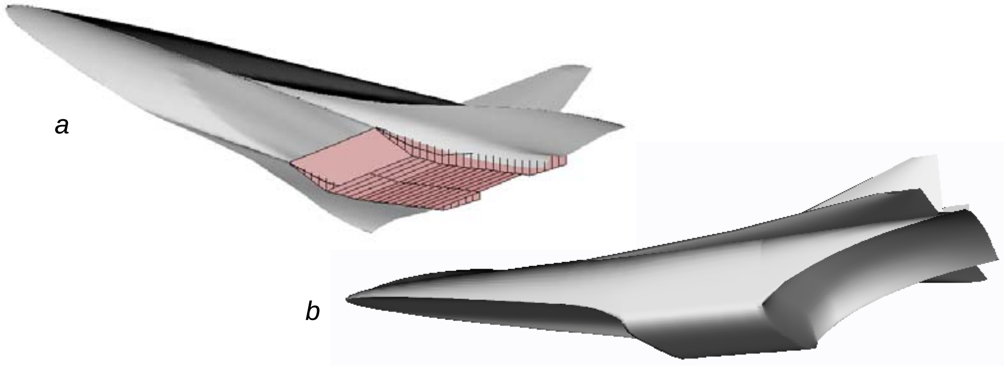


Figure 67 **Aerospace plane configuration geometry models with wing-body-propulsion integration.**

All-wing or Flying Wing aircraft has several advantages reviewed in other chapters of this book; here its attractivity for both aerodynamics and structures in high speed flight just means that we may focus on case studies to model a variety of such Flying Wings as input for detailed analysis in a multidisciplinary approach.

Oblique Flying Wing

A shape with a relatively simple geometry at first sight is the Oblique Flying Wing (OFW), an ultimate example of adaptive geometry by adjusting the yaw angle of the whole configuration (exept the engines and control surfaces) to the varying flight Mach numbers (Figure 68). After several conclusions about the attractivity of this concept in this book, the two final chapters are entirely devoted to the OFW. In the last chapter some studies are presented using our geometry software for OFW definition. Challenging tasks for systematic geometry parameter fine tuning emerge from the obtained results. Ongoing work will profit from a combination of this geometry generator with optimization tools as outlined in the following chapters.

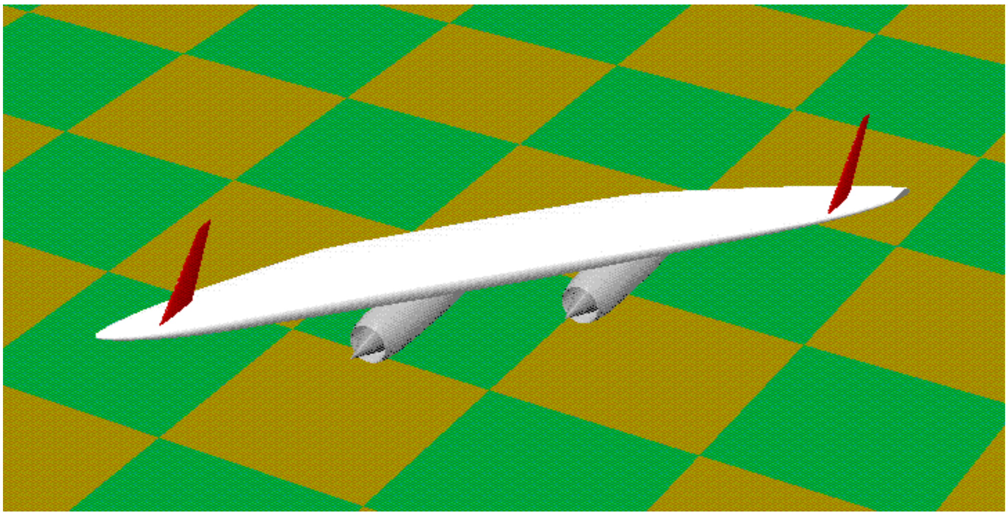


Figure 68 Oblique Flying Wing model, with control surfaces and propulsion adjusted to the flight direction.

9.5 Conclusions

Software for generic aerodynamic configurations has been developed to support the design requirements in the high speed regime. Based on simple, explicit algebra a set of flexible model functions is used for curve and surface design which is tailored to create realistic airplanes or their components with various surface grid metrics. The explicit and non-iterative calculation of surface data sets make this tool extremely rapid and this way suitable for generating whole series of configurations in optimization cycles. The designer has control over parameter variations and builds up a knowledge base about the role of these parameters influencing flow quality and the aerodynamic performance coefficients. Gasdynamic relations and other model functions allow for the gradual development of our design experience if generic configurations are used as boundary conditions for numerical analysis with mature CFD codes. Experimental investigations are supported by CAD data which are delivered from the same geometry inputs as used for preprocessing numerical simulation. With efficient geometry tools available to the designer, the development of interactive design systems for not only aerodynamic but multidisciplinary optimization gets additional momentum.

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