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Some new developments on the Aircraft Design and Analysis System (ADAS)

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Abstract

The Aircraft Design and Analysis System (ADAS), developed by the Faculty of Aerospace Engineering of the Delft University of Technology, is a computer-based system for (conceptual) design and evaluation of aircraft configurations. Since the completion of the pilot-version (1988), additional enhancements have been implemented. For example, ADAS has been converted to UNIX operating system. Modifications and extensions have been made to the geometry definition protocol. ADAS has been integrated with a relational data base management system (INGRES) for design data storage and query. New analysis methods have been added to the program library. Appreciable progress has been made in the integration of numerical techniques for aerodynamic design of aircraft configurations. A procedure has been developed to automatically generate a panel distribution for a conceptual aircraft model defined with ADAS. The panel distribution format is compatible with the linear potential flow code NLRAERO. In this paper describes some of the new ADAS features and capabilities. The paper concludes with the presentation of a design study where ADAS was applied to evaluate conventional, canard and three-surface aircraft configurations using the potential flow code NLR-AERO.

Nomenclature

A - aspect ratio
b - span (m)
C - coefficient
c - chord (m), coefficient
c - mean aerodynamic chord (m)
l - length (m)
P - engine power (kW)
S - lifting surface (gross) area (m^2)
W - aircraft weight (N)
x - longitudinal distance from fuselage nose (m)

<u>indices</u>

c - canard
cg - center of gravity
D - drag
f - fuselage
L - lift
l - lift (2-dimensional)
m - pitching moment
max - maximum
t - horizontal tailplane
w - wing

1. Introduction.

The interest by the section of Aircraft Design/-Flight Mechanics in computer-aided aircraft design originated in the early 80's, when a research project was initiated to develop a computer-based system for conceptual aircraft design, designated as ADAS (Aircraft Design and Analysis System). A prototype was completed in 1988 (Ref. 1). Since that time, several student graduation projects have been conducted using ADAS as a design tool. The development of ADAS will continue as part of a larger CAD/CAM-project in which several Faculties participate.

ADAS was originally developed on the Interfaculty CAD-Installation (ICI) which consisted of a central PRIME 750 minicomputer and several remote MEDUSA-workstations (Ref. 2). The ICI will be phased out in the near future and is to be replaced by a Faculty-based network of engineering workstations. One cluster of workstations is intended specifically for CAD-applications in undergraduate training and exercises. A second cluster, referred to as the Faculty CAD-Installation (FCI), will consist of low-end and high-end (graphics) workstations (SUN-4, Silicon Graphics and HP) and is typically intended for graduate and research projects. Figure 1 schematically illustrates the hardware configuration of the FCI:

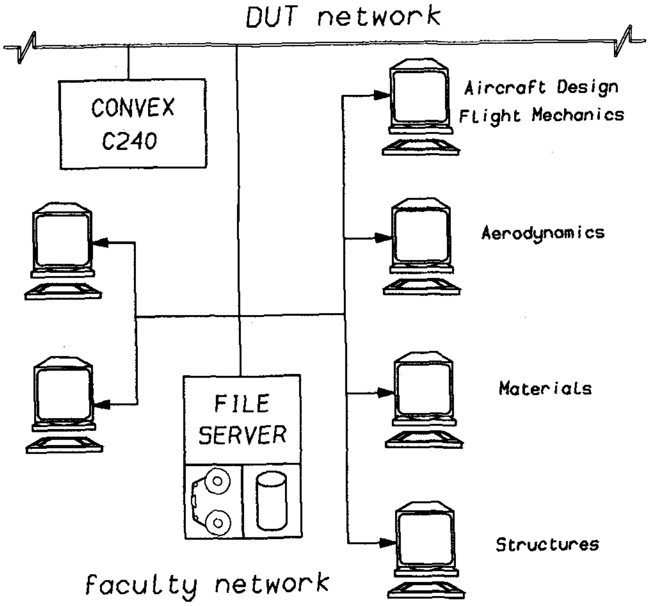

Figure 1: The Faculty CAE-Installation (FCI) hardware configuration.

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Phased acquisition and installation of the FCI commenced in 1989 and will cover about 3 years.

One major task was to convert ADAS to UNIX operating system. In conjunction, ADAS functionality has been enhanced based on new requirements and past experiences in practical design studies (Ref. 3). This paper reports on some recently added features and capabilities. In particular, the application of numerical techniques in the conceptual design of aircraft configurations will be discussed in detail.

2. The generic ADAS system organization.

The general philosophy behind the development of ADAS is that a useful design system should support, rather then control, the design process. The success of a design concept is closely related to the experience and ingenuity of the human designer. ADAS provides a working environment of computer tools in which design data and analysis methods can be easily manipulated. The generic ADAS organization structure is schematically illustrated in Figure 2:

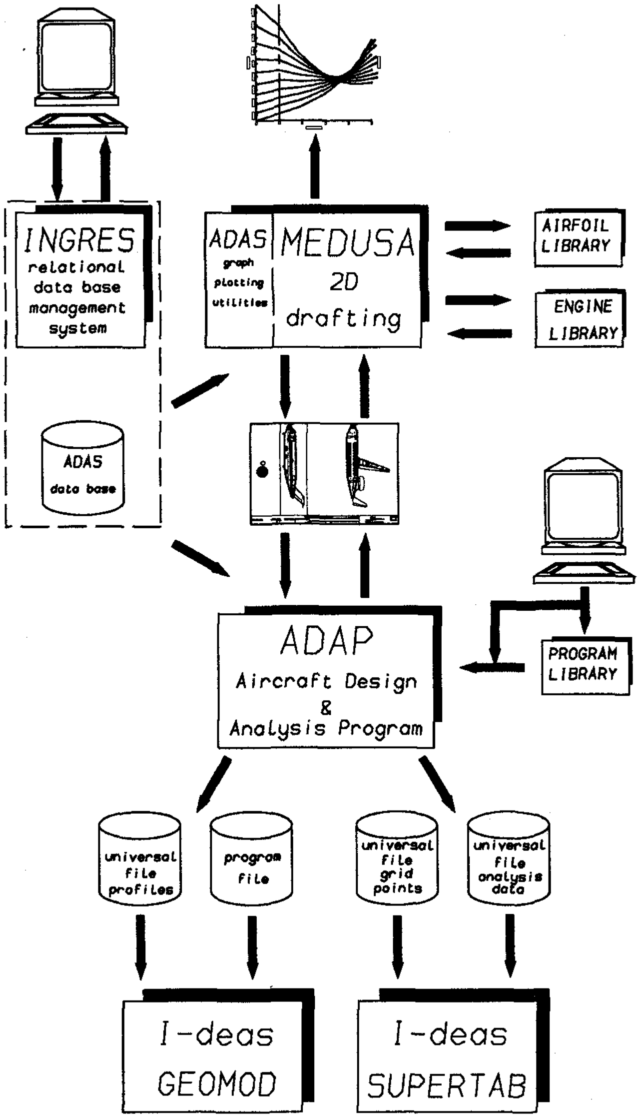

Figure 2: ADAS system organization structure.

The overall system comprises 3 major components:

- **MEDUSA** is a generally available system for design and drafting. MEDUSA is used to define and store the design geometry in the form of a 3-view configuration drawing.
- **INGRES** is a relational data base management system. It is used to manipulate and store numerical design data.
- **ADAP** is an executive program that controls the processing of user-defined analysis programs. ADAP incorporates options to perform sensitivity studies or multivariate optimization.

Some data bases/libraries are used to store generally available data:

- The airfoil and engine library, which are essentially MEDUSA symbol libraries and contain standard shapes of airfoil sections and engine nacelles respectively. The user can load symbols from these libraries directly into a drawing and vice-versa.
- The program library contains analysis methods in the form of FORTRAN-callable subprograms which can be incorporated into a user-coded analysis program, tailored to solve a particular design problem.
- A common INGRES data base is used to store user-specific numerical data. A user may set access-rights to share data with, or protect against, other ADAS-users.

In a typical ADAS design cycle, 3 consecutive steps can be distinguished, i.e. design definition, design analysis and design evaluation. First, an (initial) design is defined and subsequently analyzed with user-supplied or user-selected analysis methods. The design is evaluated and, if required, the design is changed. Within ADAS, the design can be changed either interactively by the designer (analysis mode), automatically under control of an optimization algorithm which attempts to optimize a specified objective function subject to constraints (optimization mode), or it can be changed by systematic perturbations of selected design parameters (parametric survey mode). These options are incorporated in the ADAP executive program.

3. Some new features in ADAS v2.0.

3.1 Fuselage geometry representation.

A more general geometry definition for the fuselage provides more flexibility in the definition of fuselage shapes, as shown in Figure 3. The fuselage is constructed from user-defined fuselage cross-sections. Each cross-section is a single, closed curve defined by 8 points including 4 B-spline control points with associated weight factors, as shown in Figure 3. In this way a wide range of different cross-sectional shapes can be defined, e.g. double-bubble, flat-bottom, circular and rectangular. Cross-sections should be placed at strategic locations to obtain a good approximation. In addition to the cross-sections, 4 longitudinal lines have to be defined. ADAS automatically scales the cross-sections according to actual dimensions defined by the contour lines.

3.2 Engine nacelles geometry representation.

In earlier ADAS-versions engine nacelles were modelled as a body of revolution. A convenient property being that only one profile line is required to define the nacelle shape. However, this approximation is not adequate for some turboprop arrangements. Therefore, a new method for nacelle geometry definition has been introduced which can represent both turbofan and turboprop engines. The procedure is essentially similar to that of the fuselage, except that an additional contour line must be defined as the nacelle does not necessarily have to be symmetrical in top view.

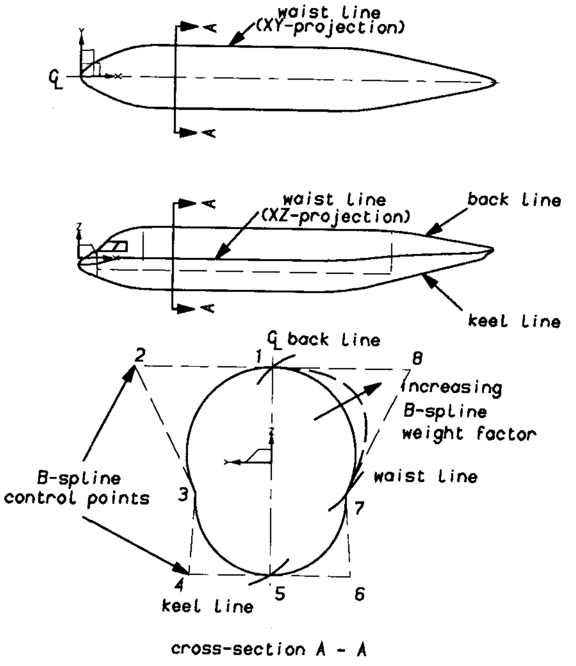

Figure 3: Fuselage geometry definition with ADAS.

3.3 New features provided with MEDUSA v7.0

ADAS requires MEDUSA 7.0 to run on the system. A new feature provided with this new MEDUSA version are user-definable attributes through which the user can associate non-geometric information with any graphical entity in the drawing. This information can be accessed with the DARS (Data Access RoutineS) FORTRAN subroutines. User-definable attributes greatly simplify the ADAS-MEDUSA interface as it reduces the number of required layer numbers. For example, all lifting surfaces are now placed in the same layer, while user-definable attributes are used to distinguish between separate lifting surfaces.

3.4 Solid modelling with I-deas GEOMOD.

The Faculty avails of the I-deas CAE-system on SUN, HP and Silicon Graphics workstations. GEOMOD is the I-deas interactive solid modeller. The ADAS-user can automatically create a solid model from a 3-view configuration drawing. This process takes place in two steps. First, the ADAP executive program is run which produces two files, i.c.: an I-deas universal file which contains the mathematical descriptions (NURBs) of all the cross-sections in the model, i.c. fuselage cross-sections, nacelle cross-sections and airfoil sections, and a command file which contains GEOMOD commands to construct individual components from the profiles and orient them to make up the complete aircraft model. The 3D model can be displayed and dynamically re-oriented, either as a wire-frame, with hidden line removal or a color shaded image.

3.5 INGRES relational data base management system.

Because a general engineering data base management system was not available at the time ADAS was developed, an ad hoc solution (direct access files) was implemented for management of design data. Recently, the INGRES relational data base management system was selected as the standard data base system at the Delft University of Technology. The current ADAS version can access design data stored in INGRES. INGRES data query language is based on SQL. INGRES provides a FORTRAN interface, referred to as Embedded SQL, which allows application programs to access design data retained in INGRES. An important advantage of a common data base system is that design data are stored in a uniform format (tables) and can be shared among users. User functions have been added to the basic MEDUSA drafting system to create engineering graphs from parametric data stored in INGRES. Graphs types include general XY-plots, 'carpet' plots, contour plots and surface plots (isometric XYZ-plots).

3.6 New analysis modules.

The programmability in ADAS introduces a high degree of flexibility, essential to make ADAS suited for many types of design studies. Therefore, it is expected that the ADAS organization structure will not change significantly in the future. However, updating the program library will be an on-going effort to keep up with the state-of-the-art in design technology.

Some new analysis modules have been added to the program library. A new module has been developed to estimate wing weight, according to a station-by-station analysis. The structure is sized for the most critical load case. Empirical relations are used to estimate the secondary structure weight, e.g. leading and trailing edge structure, high-lift devices, spoilers and speedbrakes. Initial ADAS-versions could only accommodate turbofan engines. A new engine performance module has been developed that can be used for turboprop and turbofan engines (Ref. 4). The designer can combine any propeller and engine for which the efficiency map and performance deck are available. The performance module can interpolate for a given power rating P/P_{max} or for a given thrust level. Simple scaling rules have been derived for the propeller and engine for "rubberizing".

4. Conceptual aerodynamic design and optimization.

The program library should ideally contain analysis modules that cover a wide range of design disciplines and methods that vary is terms of complexity, sophistication, computer-time required, amount of input data, etc. The designer should have the option to select more accurate methods as the design evolves and more information becomes available. For aerodynamic design the ultimate in computer simulation is generally referred to as computational fluid dynamics (CFD).

Currently, a research project is conducted to determine if potential flow codes can be practically applied to aircraft configuration development. Utilities have been developed to perform numerical aerodynamics calculations to an aircraft configuration defined within ADAS. This module comprises a set of semi-independent routines, that can be called from the user supplied analysis program, tailored to investigate particular design parameters. Some major features are:

- A semi-automatic paneling scheme to create a suitable grid for numerical aerodynamic calculations.
- Pre- and post-processing facilities for modification of the (baseline) geometry and visualization facilities for panel distributions.
- A general potential flow method (NLRAERO) which builds the resulting aerodynamic influence coefficients matrix and subsequently solves the system of equations in terms of a source and doublet distribution over the geometry surface.
- Post-processing facilities, such as drag and lift analysis, calculation and visualization of pressure distributions, aircraft trimming procedure, viscous drag and pitching moment analysis.
- A constrained Lagrange optimization procedure to obtain favorable circulation distributions.

Major components of the aerodynamic module will be discussed in the following sections.

4.1 Automatic paneling scheme for numerical aerodynamic analysis.

The module DXGRID can be integrated in the user-supplied analysis program DSPROG which is subsequently run under ADAP control. DXGRID derives the geometry from a MEDUSA configuration drawing and produces a 3-dimensional model representation of quadrilateral panels over the "wetted" surface. In addition, internal panels for lift-carry-over effects and for representing the wake, are also generated. The grid is hierarchically structured, as shown in Figure 4:

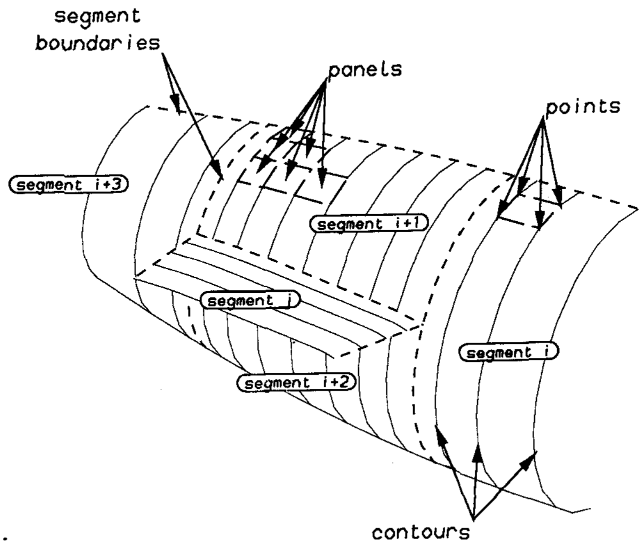

Figure 4: Definition of grid points, panels, contours and segments.

- A point is defined by a set of 3 coordinates (X,Y,Z).
- An ordered set of points is called a contour.
- An ordered set of contours having the same number of points and a consistent ordering of points is called a segment.
- A set of segments, having the same function, i.c. lift generating or non-lifting, can be grouped into a part.
- A complete set of parts form the aircraft geometry.
- Two successive points on two neighboring contours, within the same segment form a panel.
- Two adjacent contours within the same segment form a strip.

To improve the accuracy of aerodynamic results, some automatic grid refinements are implemented in DXGRID based on the following considerations:

- Regions where large gradients in the computed flow are anticipated, e.g. strong surface curvatures or at junctions of components (wing/fuselage, wing/nacelles, etc.), will have small panel sizes in the direction of the flow.
- In general, large surface curvatures result in smaller panels in order to maintain an acceptable approximation of the actual geometry.
- No attempt is made to close "leaks" at locations where panels do not match properly, as this would affect the orientation of the vector normal to the panel.

The panel generation process takes place in three steps:

1. The aircraft geometry is deduced from a MEDUSA configuration drawing through the MEDUSA-ADAS interface module DXMEDG.
2. The paneling module DXGRID generates a suitable grid for numerical aerodynamic analysis. First, DXGRID identifies parts, i.c. fuselage, lifting surfaces and engine nacelles. Parts are automatically subdivided into segments. For lifting surfaces, segment definition is governed by identifying "wetted" and "non-wetted" regions (the "non-wetted" region serve to incorporate lift-carry-over effects), breaks in leading and/or trailing edges, thickness distribution of airfoil sections and engine locations (if mounted to the lifting surface). Body segment definition is governed by body/lifting surface intersections. At each intersection two new segments are defined, one located above and one below the lifting surface. Otherwise only one segment exists. Engine nacelles differ from standard bodies, because of the flow through surfaces at the fan face and the exhaust plume with jet entrainment effects with the (non-zero) normal velocity. This velocity can be calculated by a suitable design program or specified by the user. Spinner, fan, inner and outer cowling are identified as separate segments. For each segment, the user has to specify the number of contours and the number of points on the contours and the normal velocity if non-zero.

   The paneling module positions the panel corner points on the external surface of the aircraft and automatically orders the points into contours and contours into a segments. The location of points depends on the kind of segment:

- On lifting surfaces, a cosine distribution of the panel corner points in chord direction is applied to accommodate for relatively large flow gradients at the leading and the trailing edge. In spanwise direction a similar approach is used.
- On body components the location of the panel corner points in longitudinal direction is governed by the location of the points on the intersecting lifting surface contour. In case the boundary of the segment does not coincide with a lifting surface-body intersection, the longitudinal location of the panel corner points is governed by the size of the adjacent panels of the neighboring segments and the number of specified panels. In circumferential direction the location of the panel corner points is governed by the B-spline weight factor and the number of circumferential panels. The automatic paneling scheme allows the user to analyze or optimize a number of designs, using the parametric variation option in the ADAP program, without the need for a user re-specification of the panel distribution over a derivative design. Once the user has specified the panel distribution over the baseline design, the paneling module automatically adjusts the panel distribution over derivative designs. The average panel length and width are kept constant for each segment as well as the distribution over the contour within each segment.

The results from DXGRID are stored in an intermediate file for subsequent processing.

3. In the third step, the user typically inspects the generated panel distribution, prior to any aerodynamic calculations. An interactive viewing program can be used to rapidly visualize the panel distribution. This program is produces output directly into a MEDUSA drawing. Major viewing options are:

   - Rotation and projection of the 3-dimensional geometry.
   - User specification of parts and segments to be viewed.
   - Hidden line removal and zooming facilities.
   - Inspection of the orientation of panels, using the normal vector representation.
   - Contours only versus panels plotting option.
   - Graphical output is stored into a MEDUSA drawing, therefore all MEDUSA facilities are available for editing and hardcopy plots.

Once the user is satisfied with the panel distribution, the DXGRID output file can be redirected to a potential flow code for aerodynamic analysis. For this purpose, the Faculty avails of the linear potential flow code NLRAERO (Ref. 5). DXGRID and NLRAERO may serve as a stand-alone design program or alternatively may be integrated into a multidisciplinary design program.

5. Potential flow code NLRAERO.

NLRAERO has been developed by the National Aerospace Laboratory in the Netherlands. Minor modifications have been implemented to make NLRAERO more suitable for integration into the ADAS environment. The integration and functionality of ADAS/NLRAERO are shown in Figure 5:

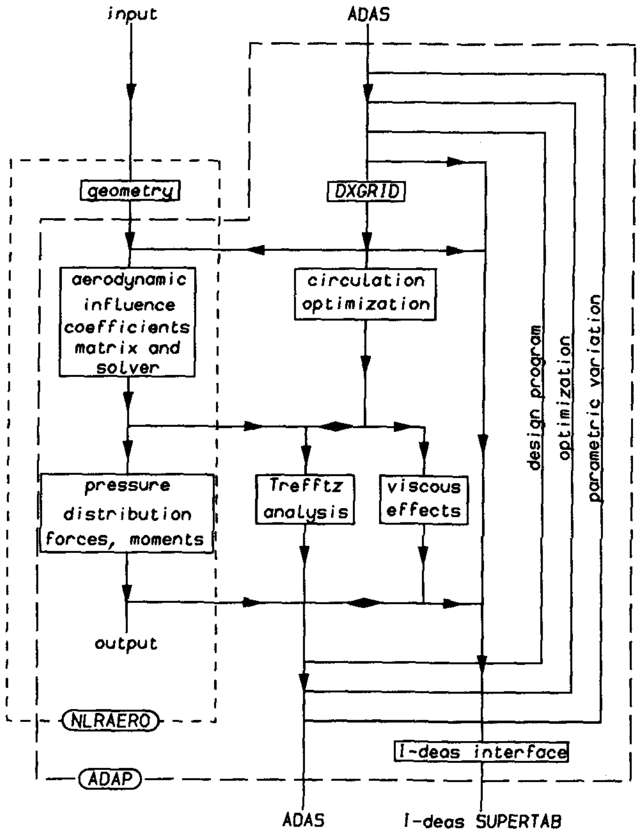

Figure 5: NLRAERO-ADAS integration.

Only the construction of the aerodynamic influence matrix, the solver and optionally the pressure distribution module are retained from NLRAERO. The code solves the linear compressible potential flow, either subsonic or supersonic, governed by the first-order Prandtl-Glauert equation. A normal velocity boundary condition is imposed at the "wetted" side of the geometry surface (Neumann boundary condition). The Prandtl-Glauert equation can be transformed into an integral using Green's theorem. The integral can be solved by introducing a combination of a doublet and a source distribution. In order to solve the integral for the boundary conditions, a computational grid is required (panel distribution), together with a discretization of the source and doublet distribution. At the panel centroids and the Kutta locations at the lifting surface trailing edges, the velocity contributions of the source and dipole distribution is computed in terms of the unknown source/doublet parameters. At these locations the normal flow boundary condition is imposed. This leads to a system of linear equations with an equal number of unknowns.

Panels on body components have a constant source distribution. Lifting surfaces are assumed to be thin and moderately cambered. This allows simplification of the boundary conditions and a significant reduction in the number of unknowns to be solved. For lifting surfaces, the zero normal flow condition is not applied at the actual geometry surface, but at the projection onto a reference plane. This reference plane is aligned with the x-axis, passing through the leading edge. The lift effects are accounted for by a panel-wise quadratic dipole distribution and a linearly varying source distribution accounts for thickness effects.

5.1 Modifications to NLRAERO.

In general, the conceptual designer is primarily interested in global drag and lift characteristics of the complete aircraft configuration. Detailed knowledge of local flow is of less importance at this stage. Some modifications have been incorporated into the basic NLRAERO code to make it more suitable for conceptual aerodynamic design:

- In NLRAERO, drag and lift are calculated by integration of local pressures over the surfaces. Summation of pressures in order to obtain global forces and moments can lead to inaccurate results because of summation of small contributions with different signs (roundoff and cancelation errors). To improve lift and drag calculations, a Trefftz-plane analysis method has been developed and integrated with NLRAERO.
- Viscous drag analysis has been included. For lifting surfaces viscous drag is predicted using an extended DATCOM-Hoerner technique, based on the flat-plate analogy with corrections for lift and thickness effects, and accounting for a mixed laminar and turbulent boundary layer. Viscous drag contributions are computed in chordwise direction and subsequently integrated along the span.
- Flow separation effects on body components are considered. First, a simple streamline pattern is assumed over the body surface. Separation and laminar-turbulent boundary layer transition is estimated using the local pressure values and their gradients along these streamlines. In areas of separation the local pressure coefficients are set to zero. The pressure distribution is integrated over the surface to compute the pressure drag and pitching moment coefficient. In addition, the local friction coefficient is calculated along these streamlines and integrated to give total friction drag.
- A method to optimize the circulation distribution in the Trefftz-plane has been developed. One can either minimize induced drag or induced + viscous drag for a given total lift. In addition, a trimming constraint can be imposed ($C_m = 0$). This requires some knowledge of the pitching moment distribution along the span of the lifting surfaces. A schematic representation for the pressure distribution in chordwise direction has been adopted, as depicted in Figure 6:

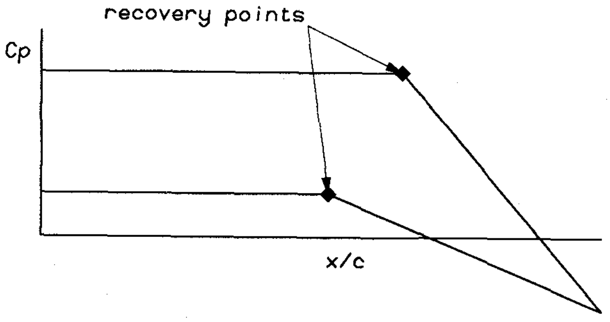

Figure 6: Recovery points for chordwise pressure distribution representation.

The shape of the pressure distribution is defined by two parameters (recovery points). A similar approach is used in the SAMID-program (Ref. 6).

This optimization module computes the optimum lift distribution for minimum induced drag at a given design point, i.e. a given planform but for variable twist and camber distribution. Clearly, a check must be made to verify that the resulting lift distribution can indeed be obtained with a practical wing structure. The circulation distribution can subsequently be input into the analysis module to compute associated aerodynamic properties, i.c. drag and pitching moment. allows the user to explore the minimum attainable drag of an aircraft configuration, and, in combination with the analysis module, the quality of the design can be judged and improved. Moreover, combining the analysis and optimization module allows the user to design the aircraft for a given design requirements, and subsequently analyze the design in off-design conditions.

In the optimization module, the representation of the (input) geometry and the internal representation of the circulation distribution as well as the methods for calculating viscous pressure and induced drag are fully compatible with the modified NLRAERO-program. Since the Prandtl-Glauert equation is linear in the source and doublet strengths, combination of optimized and analyzed circulation distributions is permitted. This allows to optimize the configuration for a given set of design conditions (Mach number, altitude, weight, cg-location), and subsequently analyze the aircraft at off-design conditions. Design considerations like trimming with fixed incidence surfaces or all-moving surfaces can be easily addressed to. The optimization and analysis module can be used to evaluate the actual and potential performance of the design or to make a first estimation of the twist and chamber distribution along the span.

Some modifications to NLRAERO were required to properly integrate the program into the ADAS environment:

- The tedious and cumbersome task to manually prepare input files that describe the geometry and the panel distribution is avoided with the introduction of a convenient and user-friendly graphics interface (ADAS/MEDUSA) in combination with the automatic panelling module DXGRID (see section 4.1).

- Intermediate files created during the execution of ADAS/NLRAERO are retained, so that other analysis programs may use these files to calculate additional properties.

- The NLRAERO program has been divided into several logical subprograms which have been added to the ADAS program library. A user-supplied analysis program may call these routines in a certain sequence, tailored to solve a specific design problem. Although a more flexible design program can thus be made, some basic knowledge of each separate routine is required. However, the routines automatically perform input and consistency checks and are well documented.

The optimization and parametric variation capabilities of the ADAP executive program can be used in combination with NLRAERO to analyze different designs in one job. For example, multivariate optimization can be used to optimize the geometry or flight condition for a given objective function subject to constraints. An example of such an application will be discussed in section 6.

5.2 Post-processing of aerodynamic data with I-deas SUPERTAB.

Currently, an interface is being developed to transfer panel distribution data and analysis results from ADAS/NLRAERO to the I-deas pre- and post-processing program SUPERTAB. This program can be used to display the panelled geometry or to generate color-coded pressure distributions, velocity vectors at panel collocation points, isobars, etc. This gives a global impression of where geometry modifications are required to improve flow characteristics. Real time rotation and shading capabilities reduce the time required to access aerodynamic characteristics. This project is still in progress, but preliminary results are promising.

6. Aerodynamic design and optimization of three-surface configurations for minimum cruise drag.

The interest in unconventional aircraft configurations, i.e. canard "tail-first" and three-surface layouts, has revived in the last decade. The homebuilt canard aircraft designed by Burt Rutan are well-known. Examples of unconventional designs in the business aircraft category are the Beech Starship I (canard) and the Piaggio P-180 Avanti (three-surface). Many studies have been performed to explore the aerodynamic merits of different aircraft configurations. A classical method to estimate induced drag of multiple lifting surfaces is the Prandtl-Munk equation (Refs. 7,8,9 and 10). This theory assumes an elliptical circulation distribution over all lifting surfaces. The induced drag is solely dependent on lift, the gaps and the spans of the lifting surfaces. Some more in-depth studies have been made using vortex-lattice methods (Refs. 11 and 12), while others use a combination of both methods or give a comparative description (Refs. 13 and 14). All these studies show that a final selection for a particular design configuration depends strongly on the design requirements considered, e.g. low-speed characteristics, stability and handling, structural implications, cg-travel, passenger comfort, powerplant and undercarriage location. The pros and cons of conventional and unconventional aircraft configurations is still highly debated.

A contribution to this discussion is given in this section by presenting the results of a comparative study using ADAS/NLRAERO with the objective to assess the aerodynamic implications of a conventional, canard and a three-surface configuration layout for a small turboprop business aircraft. This study is part of a larger project conducted at the Faculty of Aerospace Engineering (Ref. 16). Figure 7 gives an ADAS/MEDUSA 3-view configuration drawing of the subject aircraft (baseline design). The first part of the study (section 6.1), involves the sizing of lifting surfaces and variation of wing location to determine the optimum configuration for minimum cruise drag (trimmed). In the second part (section 6.2), the effect of cruise lift coefficient and cg-travel on trim drag for a selected configuration is assessed.

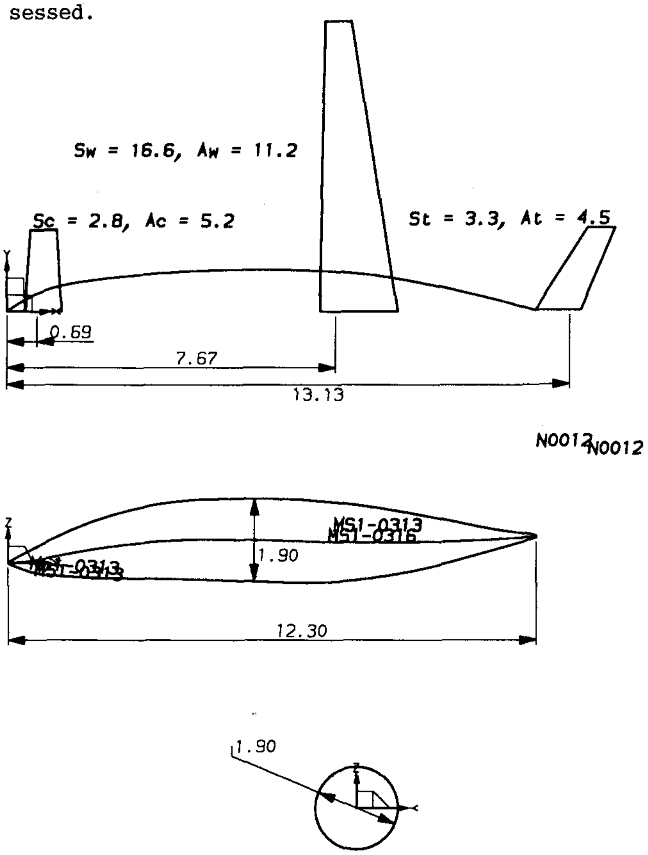

Figure 7: 3-view configuration ADAS/MEDUSA drawing for a three-surface aircraft (baseline).

Different trim procedures are considered for the canard and/or horizontal tailplane.

6.1 Sizing of lifting surfaces for minimum cruise drag.

Using ADAS parametric survey option, different configurations were analyzed by systematic variation of wing location (x_w) and canard area (S_c). As each configuration represents a new aircraft geometry, it has to be re-panelled using DXGRID. Figure 8 illustrates the grid distribution for the baseline design:

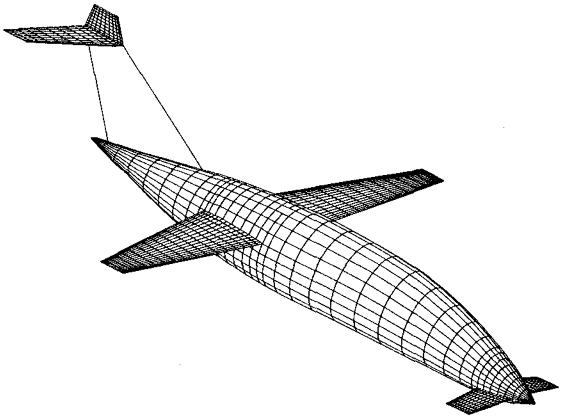

Figure 8: Panel distribution for a three-surface aircraft configuration (baseline design).

The following simplifications have been made to reduce the number of design parameters:

- For all configurations the sum of canard and wing area is held constant, i.c.:

  $$S_c + S_w = \text{constant} \qquad (1)$$

  If $C_{L_{max}}$ of canard and wing are assumed equal, eq. (1) assures that a given maximum lift can be obtained for low-speed performance.
- A relation between the canard area and tail area has been introduced, based on a alternative volume coefficient:

  $$S_c(x_c - x_{cg}) + S_t(x_t - x_{cg}) = \text{constant} \qquad (2)$$

  where x_c and x_t define the longitudinal location of the canard and horizontal tailplane (quarter-chord point of mean aerodynamic chord) respectively. Eq. (2) assures that a given pitching moment can be obtained for controllability at low speeds.

Cruise weight and cg-location were calculated with (semi-)statistical methods given in ref. 15. Fuel and payload weight were fixed. The drag contributions of the vertical tailplane and engine nacelles have been ignored to reduce the complexity of the aerodynamic model. However, their effect on weight and cg-location have been incorporated. For each configuration, an optimal circulation distribution for minimum drag for all lifting surfaces is computed using a Lagrange optimization technique. The governing constraints are a given total lift which follows from vertical force equilibrium ($L = W$) and zero pitching moment $C_m = 0$ (trimmed condition). Figure 9 gives the optimal c_l- and $c_l c$-distribution for the baseline design:

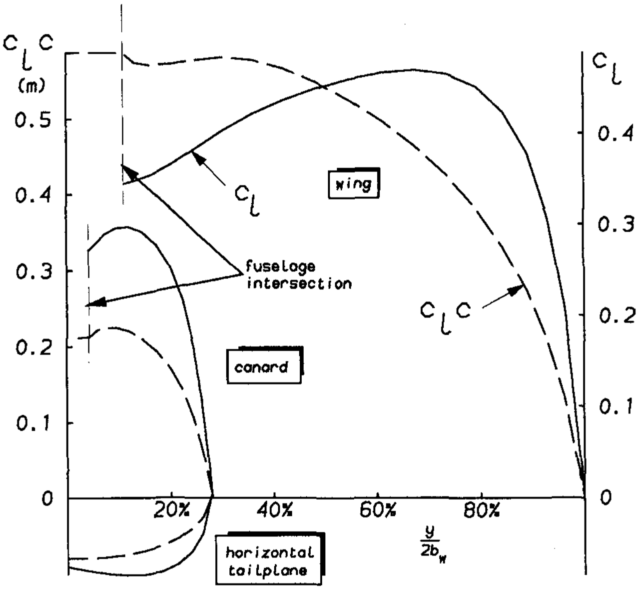

Figure 9: Optimal lift distribution for a three-surface aircraft configuration (baseline design).

It is assumed that the resulting circulation distribution can be obtained by a suitable twist and chamber variation along the span. For each design, the static stability margin dC_m/dC_L is also computed to verify if the configuration is inherently stable design. Figure 10 gives contour lines for constant $(C_DS)_{trimmed}$ and contour lines for constant stability margin as a function of canard area and wing location:

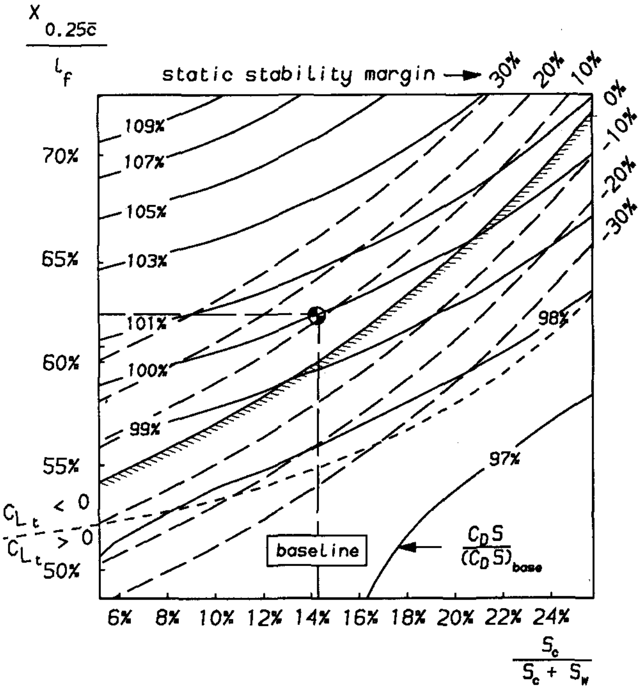

Figure 10: Cruise drag area (trimmed) and static stability margin for different canard area and wing location (optimal lift distribution).

The following conclusions can be made:

- If the static stability requirement is not taken into account, the canard configuration is favorable with regard to minimum cruise drag.
- If a limited amount of static instability is permitted, a three-surface configuration may be the most favorable option.
- If an inherently stable design is required, a conventional configuration may be the best alternative.
- For a fixed wing location, e.g. in the case that for comfort sake the wing must be located behind the passenger cabin, and a positive stability margin, the three-surface aircraft is the best configuration.
- The tail load is negative (downward) for all stable designs.

The analysis took about 8 hrs. of computing time on a CONVEX C-240 (single CPU with vectorization) for a matrix of 10 x 10 design configurations.

6.2 Optimal trimming procedure for minimum cruise drag.

In the following part of the study, the effect of variation in cg-location and C_L on $C_{D_{trimmed}}$ was investigated. The cruise drag was computed for different trimming procedures, i.c.:

- Trimming with only the horizontal tailplane.
- Trimming with only the canard.
- Trimming with horizontal tailplane and canard.

The analysis was applied to the baseline configuration indicated in Figure 8. The cg-travel is indicated relative to the average cg-location used the parametric study (section 6.1). The results are given in Figure 11:

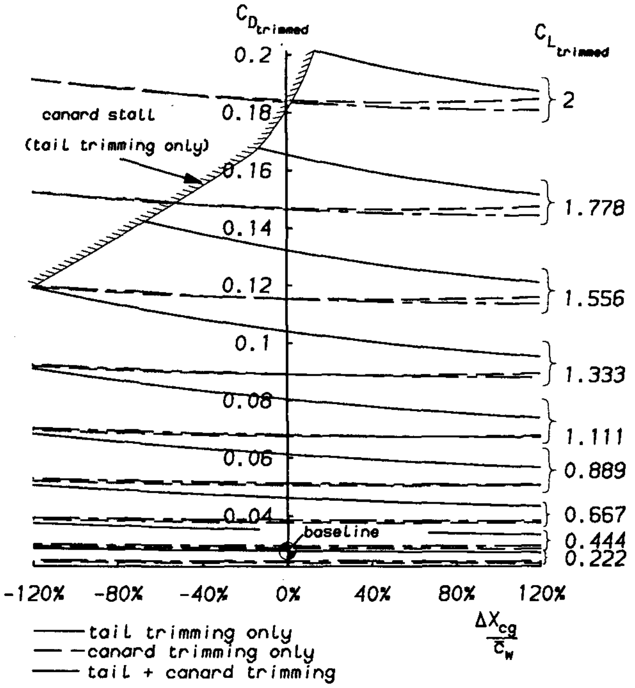

Figure 11: Cruise drag (trimmed) for different cg-locations and lift coefficients. Canard and/or tail trimming are considered.

The following conclusions can be made:

- Trimming with only the horizontal tailplane causes a relatively high drag penalty. At extreme forward cg-locations and high C_L, the large down-load on the tailplane and consequently a high angle of attack to compensate for a given C_L, may cause the canard to stall.
- For all conditions, trimming with horizontal tailplane and canard is most favorable in terms of minimum drag in trimmed cruise condition. Trim drag is practically independent of the cg-location.

This analysis required about 20 min. for the 3 trim procedures. The aerodynamic influence coefficient matrix had to be computed only once as the geometry was fixed in this case.

8. Conclusions.

Some recent improvements to the Aircraft Design and Analysis System (ADAS) have been discussed. ADAS has been converted to UNIX operating system which is considered as the standard operating system in a technical-scientific environment. A more general geometry definition has been introduced for the fuselage to accommodate double-bubble and flat-bottom cross-sections. A similar approach has been adopted for the engine nacelles to accommodate various nacelle configurations for turboprop engines. User-definable attributes in MEDUSA v7.0 have been used to simplify and extend the ADAS-MEDUSA geometry exchange interface. In particular, the number of layers required has been reduced considerably. Use of a standard relational data base management system (INGRES) provides the option to store and query design data in a uniform fashion.

New analysis modules have been added to the program library. In particular, substantial progress has been made in the development of software tools that provide the ADAS-user the capability to perform numerical aerodynamic analysis on an aircraft configuration defined in ADAS. First, the module DXGRID automatically generates a panel distribution over the aircraft surface. The panelled model can subsequently be analyzed with the linear potential flow code NLRAERO, developed by the National Aerospace Laboratory in the Netherlands. Post-processing can be carried out with I-deas SUPERTAB. As an example, ADAS/NLRAERO has been employed in a design study to investigate the effect of different aircraft configurations, i.c. conventional, canard and three-surface layout, on cruise drag (trimmed). The integration of ADAS/NLRAERO brings modern CFD-techniques within the reach of the ADAS-user. The results of ADAS/NLR-AERO can be used for example to verify (semi-)-empirical methods typically used in conceptual design or to analyze unconventional configurations for which first-level methods are not available. However, for a typical analysis task several hours of computing time have to be expected on a mini-supercomputer.

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