AN ALTERNATIVE PROCEDURE FOR FE-WING MODELLING

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1. INTRODUCTION

Higher order effects play an increasingly dominant role in the design of transportation aircrafts. Considering these effects requires high fidelity methods which base on explicit models. A popular approach for efficient model generation is relational modelling using commercial Computer Aided Design (CAD) software. This paper presents an alternative procedure for Finite Element Wing modelling which calculates the geometry based on a parametric description of the inner structure. As contour reference serve unstructured surface meshes which can be found in high fidelity aerodynamics or which can be generated easily based on structured grids or profile representations. Aiming at intermediate stages of design implying moderate levels of geometric complexity the prototype programme PARA_MAM (PARAmetric simple and fast Mesh based Aircraft Modelling tool) does not employ any CAD package but directly calculates the geometric keypoints using elementary mathematical operations. PARA_MAM is a very lean and fast code which can significantly reduce costs in intermediate design stages compared to CAD procedures. In this paper the principle approach of PARA_MAM is presented from user input till export to the Finite Element (FE) programme. The interfaces to the multidisciplinary design process are shown and the features of PARA_MAM for high fidelity aeroelastic simulations and structural optimisation are explained.

2. DESIGN PROCESS

The initial stage of aircraft design is characterised by a high number of variables to be optimised. Hence, pre-design relies on fast simulation techniques which go in line with empiric data mining and simulations based on simplified physical effects. This necessary simplification implies an unrealistic representation of higher order effects like transonic aerodynamics, which play an increasingly dominant role in the final design stages [6], [7]. But also unconventional configurations can only be evaluated on a reduced level of certainty.

An iterative use of variable fidelity tools could be established by knowledge based engineering techniques. Here the aircraft is not represented by disciplinary models but by databases containing the parametric aircraft object definition. While pre-design simulations can be set up easily based on numeric variables high fidelity simulations usually base on geometrically explicit models which classically are created by engineers using interactive computer interfaces.

To close the slow and expensive gap between pre-design and high fidelity methods, automatic modelling has been recognised to constitute a key feature in efficient design processes [4], [5]. In the recent years it has become popular to create associative models using commercial CAD programmes. Restraining the design space to a class of expected designs permits the creation of prototype models and components which can be aligned with the parametric model definition from the database. Thus, even complex models can be generated without the need for human operators. Variable fidelity optimisation in a closed loop is feasible.

But the speed-up of numeric prototyping is bought for the price of vast versatility the human designer provided operating the CAD software. The versatility in geometric design necessary in the final design stages was the reason for the introduction of CAD software which requires even today a reasonable effort in computational and human resources. Numeric prototyping increases the use of this software and with it the costs of the whole design process. But in the same time the software is trimmed by its justification to be used: versatility.

Making high fidelity simulations available for pre-design verification does not require high level modelling tools as long as detailed design is not intended. This paper presents an alternative procedure to create 3D Finite Element (FE) models of aircraft wings. The combination of elementary mathematical operations permits to calculate all geometric keypoints of medium complex wings by avoidance of CAD software. Indeed, the level of details which can be achieved ranges well beyond the requirements of pre-design. This alternate modelling process is aimed to improve the intermediate design stages concerning speed and costs.

3. ELEMENTARY MODELLING

The fundamental idea of the modelling engine is to take aerodynamic surface meshes as contour reference and to fit the parametric inner structure by efficient mathematical interpolation operations. For a lean and fast modelling process data handling is an important issue. All final model properties are organised in tables and finally exported into input decks for FE pre-processors.

PARA_MAM (PARAmetric simple and fast Mesh based Aircraft Modelling tool) is an operational prototype application realised as set of MATLAB macros. The reference mesh and the parametric structure definition are provided as ASCII files permitting batch operations and the use in closed multidisciplinary design optimisation (MDO) loops. The standard output is generated for ANSYS pre-processor but can be adapted to other formats like PATRANs PCL. With 250 kb inclusive comments and the standard user input the code is very lean and can be exported via the MATLAB compiler as stand-alone application.

3.1. Shape Representation

High fidelity aerodynamics design and mesh generation widely rely on sophisticated development performed by experienced engineers. Resulting shapes are often complex and can not be parametrically represented without enormous efforts and thus are not well suited for structural modelling. The CAD surfaces used in aerodynamic design can constitute the basis for structural models. But the usually not standardised geometric models have to be refurbished for the special needs of structural modelling going in line with costly design work. Alternative shape representations are aerodynamic surface meshes. Meshes are defined using standardised formats and provide versatile shape definitions appropriate for structural modelling. PARA_MAM bases on non structured grids input via the list of nodes and the connectivity list. Data handling is prepared for large meshes and has been tested up to 500k surface points without any problems what equals actual state-of-the-art fine CFD models. All attached elements like fairings, pylons or nacelles have to be removed from the mesh to ensure a well defined shape.

Early design stages do not provide finite volume meshes but elementary shape definitions based on profiles and translation- and scaling-factors. Allocating the same number of points on each profile permits the calculation of the nodes' 3D coordinates leading to a typical structured surface mesh representation of the wing. Although the relative node positions might not necessarily satisfy requirements of aerodynamic calculations, the shape representation is appropriate for structural modelling. The grid's structure permits to easily build the correlation list. This is important since the popular Delaunay triangulation method is error prone for this type of grids. Hence, simple wing representation can easily be transformed to unstructured tri mesh format.

The parametric structure definition refers to the normalized coordinates relative span and relative local chord. Thus, leading and trailing edge slopes have to be detected. While structured meshes do not cause problems unstructured large meshes require an elaborate strategy: The wing is divided into an adjustable number of equal spanwise sections, in which the front-most and rear-most points are detected. Then the identified points are interconnected and a slope coordinate is introduced. The section boundaries for leading and trailing edge are adapted to establish equal sections in terms of the slope coordinates. The iterative application of edges search and boundary adaption increases the point density in areas of high curvatures leading to a good representation of the shape and resolving e.g. kinks and winglets. The number of edge points to search has to be suited to the mesh. Structured meshes automatically are evaluated at each profile whereas unstructured meshes have to be balanced to resolve the planform properly but not to obtain more points than edge elements risking unstable algorithm. Leading and trailing edge are used to determine the rib and spar slopes but do dot influence the contour of the resulting wing. Optionally PARA_MAM provides a graphical representation of the input mesh, the detected edges and the 25% chord line. Sweep, dihedral and twist distributions are displayed, too.

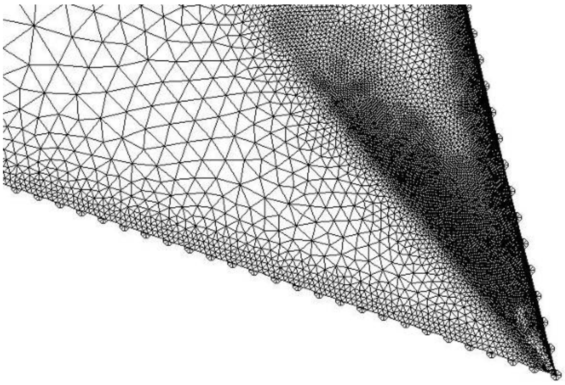

Figure 1: Unstructured CFD mesh with edge points

For later spar definition leading and trailing edge have to be provided also interior the fuselage. Multiple options can be chosen to extend the data provided by the aerodynamic grid. Typical are straight extension like common in some predesign tools and the projection of the inner most profile into the symmetry plane.

3.2. Parameterisation

The wing definition refers to the right wing with the X-axis in the symmetry plane aiming from the front to the rear, the Z-axis allocated in the symmetry plane aiming upwards and the Y-axis perpendicular aiming from the fuselage to the right wingtip. Rotation angles follow the rule of the right hand.

All structural definitions are made in the ASCII input file. Spars are defined as group of spars in only one matrix. The simple most group definition consists of a line vector containing four numbers whereof the first two numbers represent the relative chord position of the group's first and last spar in the aircraft's symmetry plane. Positions of other spars are interpolated linearly. The second number specifies the number of spars in that group. If the group contains only one spar the chord position defaults to the first definition number. The last number for the minimum definition is the virtual flag which will be explained later. PARA_MAM considers the specified points as hard points of the spars. If no more input is provided further hard points are created at the wig tip at equal chord positions. Hardpoints are linked using straight lines. Figure 2 shows the definition of one group of real spars between 25% and 50% chord.

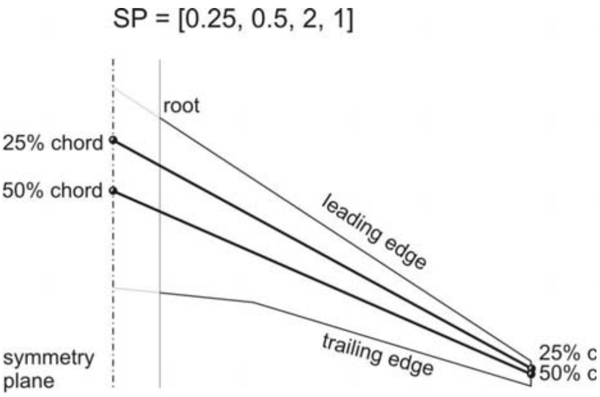

Figure 2: Elementary definition of spars

Additional groups of spars can be added by appending further lines to the matrix. If in spanwise direction further definition points are required, the matrix can be extended by groups of four rows. The first of the rows specifies the spanwise position of the additional hardpoint. The next two information define the chord position of the first and last spar of the group and the last number constitutes the virtual flag. Tip positions always refer to the group's last valid definition. Figure 3 shows an additional spar starting in the symmetry plane at 90% chord. At 35% wingspan a second definition point is set to 60% chord also defining the tip position. The information of the virtual flag are applied to the spar sections right of the definition point.

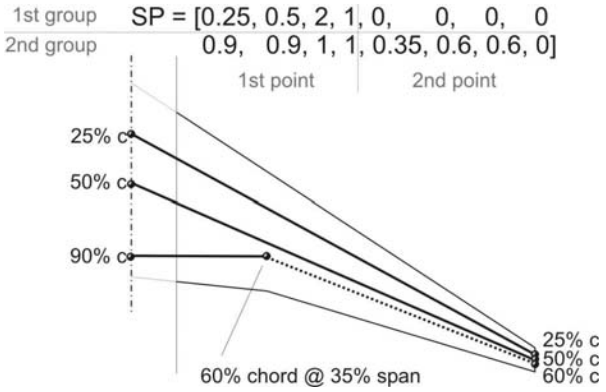

Figure 3: Extended definition of spars

Analogous to the spars also ribs are line-wise defined in groups. Their starting position at the leading edge is defined in relative span coordinate and the angle around the global Z-axis. Additional definition points do not refer to local chord but to intersection with the prior defined spars. At each definition point the angle around the Z-axis and the virtual flag can be changed.

The wing will built up on straight links between the intersections of ribs and spars. Thus, all geometric relevant points have to be represented by rib-spar intersections. If ribs or spars are required for geometric modelling only and are not intended to be part of the structure, the virtual flag can be set to zero. This causes that the later FE model contains data points on the surface of the wing where virtual entities are used, but in the inner neither areas nor elements are created. Virtual entities can be used to create arbitrary surface fragmentations or to adjust accuracy of shape representation. Especially if rounded wing tips or certain kinks have to be realised virtual entities are used.

Ribs and spars constitute the primary definition of the structure. Optional information refers to a numbering system explained in the next paragraph. All entities like shell element thickness are entered via one scalar variable defining the default value and one matrix aligning designated areas with non-default values. If the matrix definition is empty all areas take the default value. The skin thickness definition is, for example, a five row matrix. Each line initialises one group of areas with the thickness specified in row five. Row one and two define the spars constituting the borders of the area. Row three and four designate the left and right bordering ribs. Setting the thickness to minus one flags to remove that area. Other secondary definitions like tank volume allocation and distribution of stringer properties are made equivalently.

3.3. Numbering and Name Conventions

Spars and ribs form a grid which lenses itself to be used for formatted designation of items. Assumed that not more than 100 ribs and 100 spars are required a six digit numbering system was chosen. The first digit is an object reference handle permitting to operate multiple objects in the same namespace. This is useful if PARA_MAM creates wing plus flaps which shall be merged in the later FE model. The second digit decodes the type of object numbered. Digits three and four form the dedicated rib in the range of 1 to 100 and the last two digits designate the dedicated spar in the range of 1 to 100. Figure 4 shows the numbering of keypoints. Digit two can take the value 1 for upper surface keypoints and 2 for lower surface keypoints.

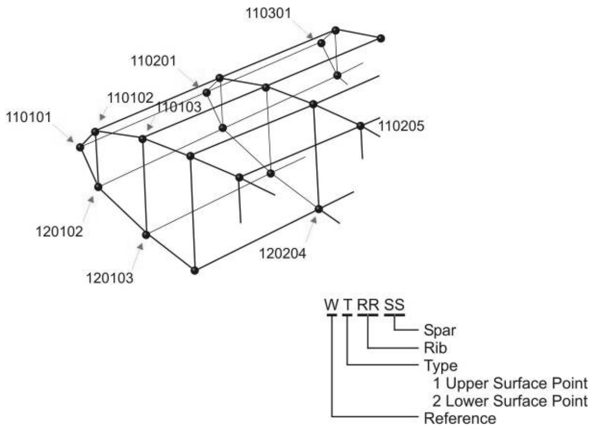

Figure 4: Numbering of keypoints

Lines are numbered accordingly with adapted meaning of the second digit. The numbering of areas is equivalent to the introduced alignment of properties in the input file. Figure 5 illustrates the numbering of areas.

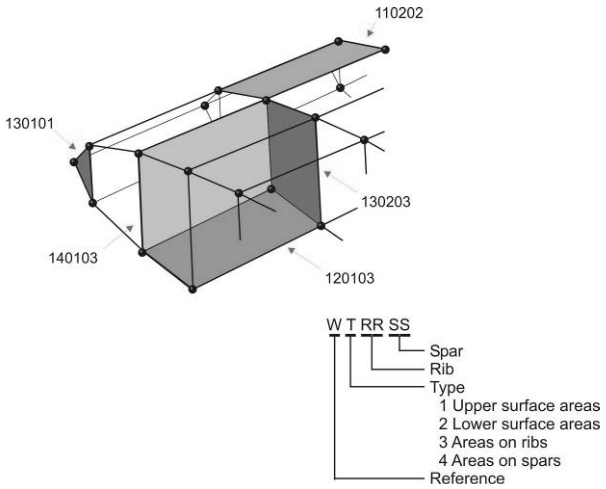

Figure 5: Numbering of areas

3.4. Computing Keypoints

Wing geometry is built up on straight interconnections between the rib-spar intersections. With the detected leading and trailing edge the calculation of all spar hardpoints in the wing's chord plane can be realised easily based on elementary trigonometry. Then, rib slopes starting from the leading edge are calculated and rib-spar intersections are determined. The intersections of the flat wing in 3D space are basis for the calculation of volumetric wing's keypoints.

Points of the volumetric wing are located on lines which are the intersection lines of rib and spar areas. Additionally these points have to be allocated at the defined contour. Hence, the volumetric keypoints are the intersection points of these intersection lines with the aerodynamic surface mesh. One point of the rib-spar intersection lines is known from the flat wing definition. The lines' inclination angles are defined in the input file by rib and spar pitching angles. Angles can refer to the global coordinate system or the chord plane's local normal vectors.

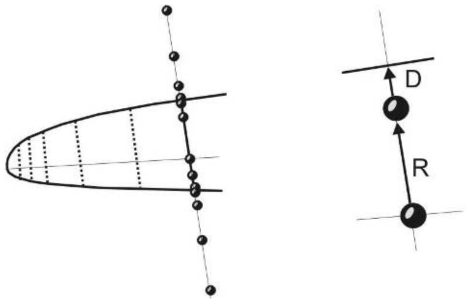

Figure 6: Intersection point search algorithm

Finding the intersection points is not a trivial task since the surface is expected to be arbitrary. Here the DLR developed MATLAB routine GRIDAPPROX plays a central role. GRIDAPPROX was initially designed for cross-grid-interpolations between dissimilar meshes in weakly coupled interdisciplinary analysis. Based on a branch-and-bound method adopted from computer graphics ray-tracing routines the programme provides outstanding speed and robustness especially with very large meshes. A detailed presentation of GRIDAPPROX is given in [3]. One return value is the distance of the target mesh points from the source mesh. This is used in PARA_MAM to determine the line-surface intersections. Starting from the points of the flat wing the length on the lines R is guessed and the distances to the surface D are evaluated using GRIDAPPROX. In the correlation between R and D zero points of D are searched to obtain the two Rs of intersections. Since GRIDAPPROX has to create a bounding-box tree every time it is called multiple guesses are passed for evaluation at every call of the routine.

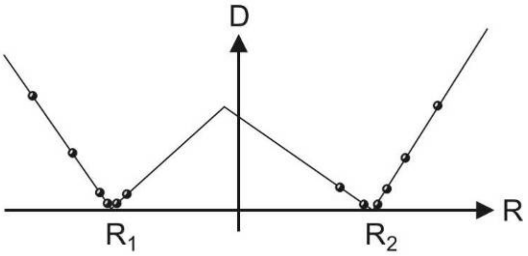

Figure 7: Correlation R ~ D

A three stage search algorithm is used. R is guessed first with relative large absolute values. The resulting correlations sometimes do not resolute the typical w-shape but degenerate to v-shapes. This first result is only used to determine the magnitude of R for an evaluation with refined R limits and with a higher number of points. The second calculation provides the w-shape and permits to roughly determine the two R values of intersection per line. Subsequently the estimated R are separated in two zones and again refined guessed points are evaluated. In this final stage each R is calculated from the v-shaped correlation as minimum problem. Using cubic spline interpolation the resulting intersection points match the target surface with a tolerance which is in the magnitude of material's roughness.

The search algorithm is tolerant to starting points which lie outside the convex hull what can occur at the trailing edge of wings with sigmoidal chord. Interpolating exactly at leading and trailing edge arises multiple numerical problems. However, interpolation is not necessary here since leading edge and trailing edge are known. Thus, chord positions equal zero and one default to local leading respectively trailing edge coordinates.

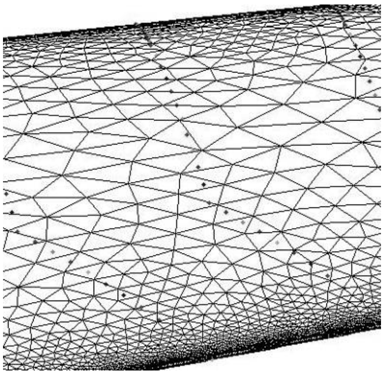

Figure 8: CFD mesh with structural keypoints on upper surface

3.5. Build the Wing

The user input file contains a compressed description of the wing. With the calculated keypoints a detailed and explicit knowledge base is created. Based on the introduced numbering system lists of items are created similar to the tables used in FE codes. The initial lists of keypoints, lines and areas are straight forward but have to be reduced due to removed areas of virtual entities or -1 thickness. Further list operations are necessary for coincident keypoints arising from intercepting or branching ribs and spars. A further array contains the properties associated to the areas. Besides thickness, material number and material orientation also stringer properties are aligned. For pre-design calculations an implicit stringer representation is advantageous. For each skin area the mechanic properties of a continuous layer is calculated with elastic properties equal to the defined stringers. Explicit stringer modelling for more detailed stressing is discussed later. The lists constitute a complete knowledge base of the wing and all of it's components in explicit form.

3.6. Export Pre-Processor Inputdeck

All wing properties have been calculated inside PARA_MAM and are available in the database. The creation of FE models bases on the script languages available with pre-processors for batch runs. Due to the high programming efficiency ANSYS with its parametric design language (APDL) was chosen to be linked to PARA_MAM first. An ASCII file is initialised with a header containing all relevant input data comprising besides others input mesh name, scaling factors and date of creation.

Since all geometric keypoints are already available, model generation can be realised used elementary commands exclusively. Geometric modelling uses only thee commands:

- create keypoint # at position x,y,z
- create line # between keypoint #1 and keypoint #2
- create area # from lines #1, #2, #3, (#4)

Building the model bottom up prevents slow and error prone higher order functions, especially interceptions and Booleans. The numbering system can be directly applied to the FE code or a correlation list can be transferred to save memory.

For structured meshing opposed lines of areas have to hold the same number of nodes. The assembly of multiple areas implies a system of corresponding lines which have to hold the same number of nodes. The numbering system permits efficient selection of line groups, determine the average line length and calculating the appropriate number of nodes to meet a predefined element size best in average. PARA_MAM standard elements are of layered shell type (SHELL 99 in

ANSYS). Each area has an own element definition comprising an individual real data table defining e.g. stacking sequence, layer thickness and orientation and an individual material definition for the local implicit stringer representation. With well defined boundary conditions the meshing operation is straight forward.

Combined with geometric modelling, material and element initialisation and meshing also clamping is enclosed in the pre-processor input file. Optionally nodes of the symmetry plane and the root ribs can be restrained in their degrees of freedom.

Automatic modelling was introduced aiming at interdisciplinary simulations which will be discussed in chapter 5. PARA_MAM creates named components in ANSYS. Stringent name conventions permit fast access on e.g. the aerodynamic-structural interface area or keypoints representing force introduction points. The surface description necessary for aeroelastic coupling can be automatically generated, too.

Comments are automatically generated in the input-deck. The typical size of resulting input-decks for detailed pre-design models ranges from one to thee Megabytes equivalent 30k to 100k lines of commented ASCII code. With an appropriately high number of virtual entities PARA_MAM could also be used for explicit modelling. Keypoints are then directly used as nodes; areas are replaced by elements. This technique permits to create models without separate pre-processor but requires high resources in PARA_MAM especially with irregular geometries like branching ribs or spars.

3.7. Computational Effort

PARA_MAM is set to enable fast and lean FE modelling. Following the computational effort to generate a medium complex FE wing model based on a fine CFD mesh is presented exemplary. The used computer is an average office PC. Processing times do not include MATLAB and ANSYS programme launch.
Computer: P4 3,4GHz, 2GB ram, 1 IDE HDD
CFD surface: 125k nodes, 250k elements
ANSYS input deck: 34k lines, 1088kb
FEM model: 2.283 keypoints, 5.622 lines, 4.422 areas
PARA_MAM processing time: 161s
ANSYS (interactive) pre-processing time: 129s
Although PARA_MAM is still a prototype application and not yet explicitly optimised for computation speed the performance is competitive to CAD techniques.

4. ADVANCED MODELLING TECHNIQUES

The previous chapter presented the elementary strategy to create FE wing models. The following paragraphs discuss some detail solutions and relevant exceptions.

4.1. Explicit Stringers

For more detailed stressing stringers can be modelled explicitly. The spanwise stringer slope has to be input as spar. Values greater one for the virtual flag designate I, T or L shaped stringers. To generate the stringers additional keypoints have to be created offset to the inner of the wing by the specified stringer height. Doing this in global Z-direction is trivial, in direction of the opposing surface stringer or in the wings local normal vector requires elementary interpolation only. For T and L stringers the sideward shift usually is directed parallel to the local skin. The additional geometric entities are considered by an extended namespace in numbering.

4.2. Branching Ribs and Spars

Branching ribs can occur e.g. at the kinks of larger wings where ribs in flight direction interface ribs perpendicular to the wing axis. This situation appears e.g. when PARA_MAM spar definitions are used to represent stringers which taper off in other spars. Branching is realised by merging neighbouring ribs or spars at defied rib-spar intersections. In the PARA_MAM input file keypoints to be merged are listed. In the model generation discussed in chapter 3.5 the removed keypoints are replaced by a pointer aiming at the remaining keypoint. The pointer system permits to realise merging multiple keypoints. Lines with identical start and endpoint are not generated in the lists as well as areas with less than tree lines.

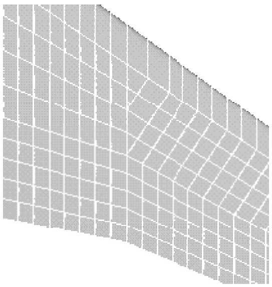

Figure 9: Branching Ribs

4.3. Nose and Trailing Sections

The wingbox is assumed to solely bear the aerodynamic bend and twist loads. Nose and trailing sections contain the retracted high lift devices. If those are not intended to be modelled explicitly in pre-design, dummy structures have to be created which do not contribute to the wing's geometric moments of inertia but return realistic deflection fields for aeroelastically coupled simulations. This is realised by very elastic skin and very stiff rib elements in these regions, whereby *very* means a modification of proper material data by three orders of magnitude. On the skin areas nodes are only permitted at the rib intersections to prevent local large deflections. This can lead to non matching meshes at the front and rear spar. Since loads shall not be transferred to the front and rear dummy sections anyway, from structural point of view this situation does not imply any disadvantages. Discontinuous displacement fields are eliminated during the interpolation process.

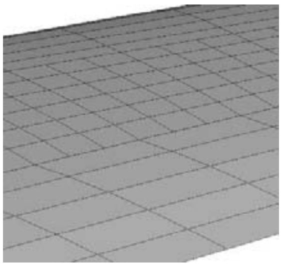

Figure 10: Discontinuous Mesh at Front and Rear Spar

4.4. Splines

The volumetric wing was introduced build up on keypoints and straight connection lines. The number of nodes per line can be adjusted to refine the structural representation. But the nodes which are not located at the keypoints do not provide an exact shape representation. Besides an increased number of virtual entities improved accuracy can be obtained using the PARA_MAM spline option. Intermediate the user-defined keypoints additional points are calculated exactly on the CFD surface and in the rib or spar areas. For the keypoint interconnections splines can be fit through the two intermediate points. Intermediate points are created as serving entities for the temporary creation of splines and deleted afterwards. Hence, no further extension of namespace is necessary.

4.5. Grids with Holes

Very detailed CFD models can contain fairings and pylons. If these items are removed to ensure a well defined structural surface, holes are created in the mesh. The presented calculation of geometric keypoints returns the same position for upper and lower surface keypoint. After the regular interpolation the results are checked for coincident keypoints. If this occurs both points are checked if they lie on splines fit through the neighbouring correctly interpolated keypoints. The points not satisfying this criterion are recalculated using spline fits through the regular structural keypoints.

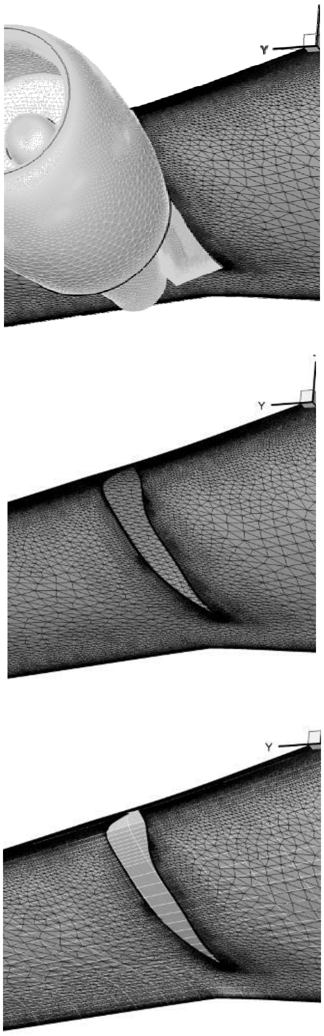

Figure 11: CFD mesh a) with engine b) showing the hole and c) FEM mesh bridging the hole

4.6. Winglets

Wing tip design plays an important role in exploiting aerodynamic potential. Tip geometry is usually complexly shaped in the wing plane or elevated as e.g. winglet. Using virtual ribs and spars nearly arbitrary shapes can be realised. Referring rib and spar inclination angles to the wing plane permits efficient modelling also with wing tips of varying dihedral. Problems occur if the tip is bended outside the XY-plane by 90 degree or more since the structural definition referring to the span is no longer unique. A work-around is rotating the CFD mesh around the X-axis to make the tip the position of maximum Y-coordinate again and rotating back the structural keypoints in PARA_MAM after data processing.

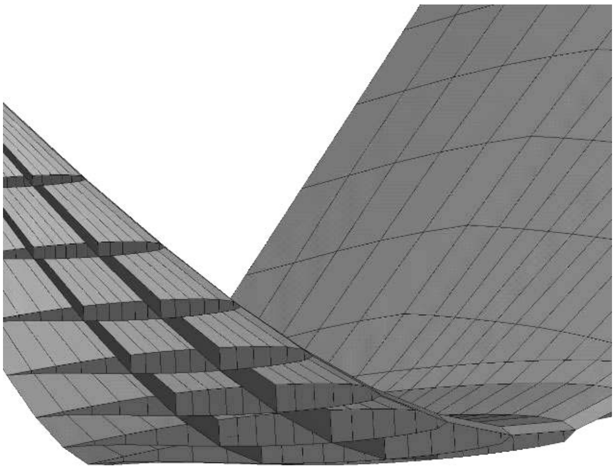

Figure 12: Wing tip spherically bent up

Devices which split the wing like Tip Fences can not be modelled directly. Then the wing has to be separated into the core wing and the tip device.

4.7. Multiple Wing Objects

The wing object handle in the numbering system permits merging different models. Two components like wing and winglet can be created with equal interface areas and directly merged or with a gap and the use of special interface sections. On a higher level of details also the movables can be modelled explicitly. For this purpose, PARA_MAM has to be run with the individual CFD meshes and object handles higher one. This flags additional objects which can be added by simply calling the individual input decks one after the other. The interconnection between the objects is currently introduced to PARA_MAM aiming at fast modelling of complete high lift configurations. Further wing objects may be e.g. stabiliser and elevator.

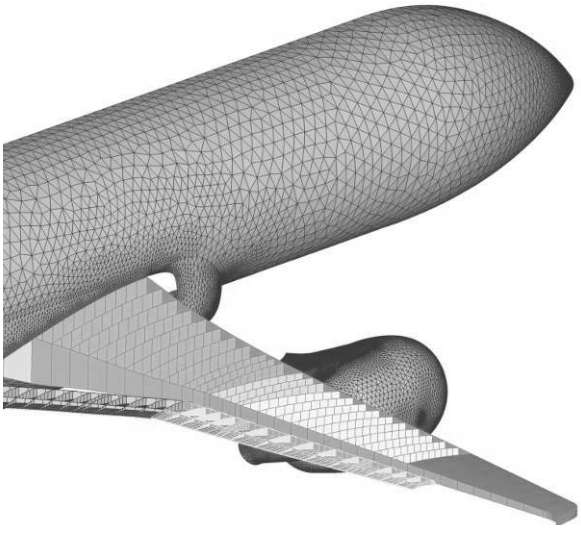

Figure 13: FE wingbox with flaps, CFD body and nacelle (unstructured source mesh)

4.8. Engines

Engine thrust and mass are evident for the design task. Prototypes of engines inclusive defined load introduction points, nacelles and pylons are defined and can be modelled as additional objects. The location of the engine reference point is defined by relative span and offset to the leading edge. Attachments to the wing are foreseen at one or two load introduction ribs and two or thee discrete attachment points each. The definition of attachment in the PARA_MAM input file refers to the numbering convention. Nacelles are necessary in coupled simulations since extrapolating the displacement field for the CFD nacelle based on wing deformations is problematic. There are no high requirements concerning the shape representation for coupling. Currently the definition bases on three diameters, three lengths and two orientation angles. Namespace conventions limit the maximum number of engines to nine per wing object. Gears and gear-spars are modelled equivalently.

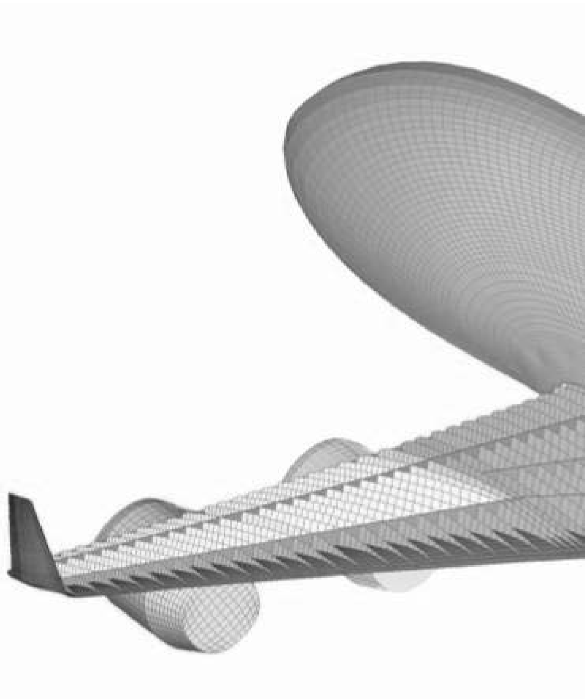

Figure 14: Wing with winglet and two structural engine dummies, CFD fuselage (structured mesh)

4.9. Fuselage

The PARA_MAM modelling engine can be used to generate fuselage sections, too. For this, the points of the surface mesh have to be transferred to cylinder coordinates R, phi, Z. Unwinding the surface and plotting R over phi and Z in a Cartesian coordinate system creates a smooth surface which can be interpreted as upper surface of a wing. Then phi corresponds to the wings X-axis, Z to the Y-axis and R to the Z-axis. Spar definitions for wing generation create stringers in the fuselage analogon, ribs correspond to frames. Ribs and Spars have to be flagged as stringers which require modified generation rules.

Floors can be introduced as interconnected stringers. Supporting structure is then generated similar to the stringers in the wing. The versatile rib stringer definition permits also for the fuselage flexible structure definition. Today the fuselage module of PARA_MAM is a feasibility study showing the further potential.

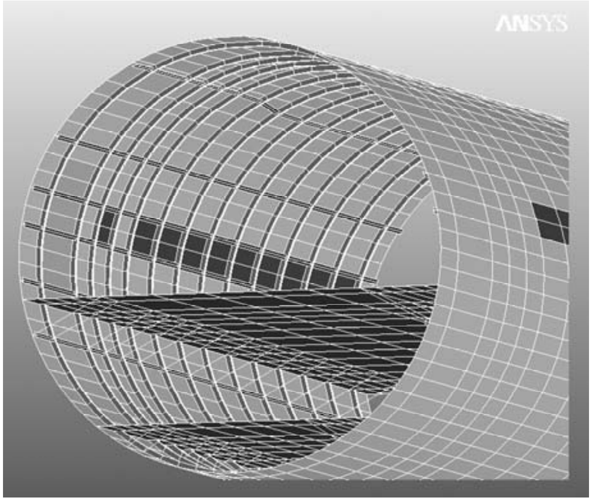

Figure 15: Fuselage section with stringers, frames and floors

5. STRUCTURAL SIZING

The previous chapters presented a procedure to automatically generate FE models. The following paragraphs show how PARA_MAM is integrated into the design process. Studies using PARA_MAM are presented in [1], [2], [7].

5.1. Interdisciplinary Design

Fibre reinforced polymers (FRP) are materials which provide an enormous potential for light weight structures. But this can only be achieved if the fibres are well tailored for the loads in the laminate. Thus, high fidelity methods are mandatory to calculate stress vectors rather than scalar stress levels what was sufficient with metallic structures. Prior to calculating internal loads and discussing appropriate failure criterions, the external loads need to be determined reliably.

Wings of high aspect ratio and slim profiles, like prevalent in actual transportation aircrafts, show significant interactions between aerodynamic forces and structural deflections. In stationary flight wings take shapes of aeroelastic equilibriums assigned to structural loads which can significantly differ from loads calculated based on the jig geometry. Equilibrium shapes depend on the structure's elastic properties. Hence, loads vary in the course of the structural sizing and optimisation process. This effect is pronounced with CFRP material since exploiting the fibres' potential necessarily leads to anisotropic properties and subsequently structural couplings.

The utilisation of anisotropic coupling effects to influence aeroelastic states of equilibrium usually aiming at drag reduction or spanwise shift of sizing loads is known as Aeroelastic Tailoring. In multi loadcase design optimized composite structures necessarily show coupling effects, hence Aeroelastic Tailoring is inextricably associated with FRP lightweight design.

The consideration of aerodynamic performance in structural optimisation is self-evident. But for transonic transportation aircraft high fidelity methods are necessary to reliably calculate especially drag and maximum lift. The state-of-the-art constitute Finite Volume Methods solving the 3D Reynolds averages Navier Stokes equation (RANS). DLR uses mainly the self-developed RANS codes FLOWer for structured grids and TAU for unstructured grids.

5.2. Aeroelastic coupling

The highly-developed tools for structural and aerodynamic analysis can be merged in a sequential process for calculating stationary states of aeroelastic equilibrium. After an initial aerodynamic simulation of the reference shape the resulting pressure at each node of the CFD mesh is exported to a file. Then, an interpolation routine has to transfer the pressure from the CFD nodes to the nodes of the FEM mesh which is of significantly different mesh topology. Interpolation is the critical point of this weak coupling called procedure, since forces and moments have to be maintained and possible geometrical discrepancies between the meshes have to be bridged. The DLR used interpolation module uses volume spline techniques and requires descriptions of the interface areas of both meshes. All data interchange is currently realised using ASCII files and the versatile AMIF format. After the interpolation to the FE mesh a structural simulation returns the displacement field of the interface area which is interpolated back to the nodes of the CFD mesh. Following the aerodynamic mesh is deformed to the new shape and the process is iteratively run until deflections and pressure distribution converge.

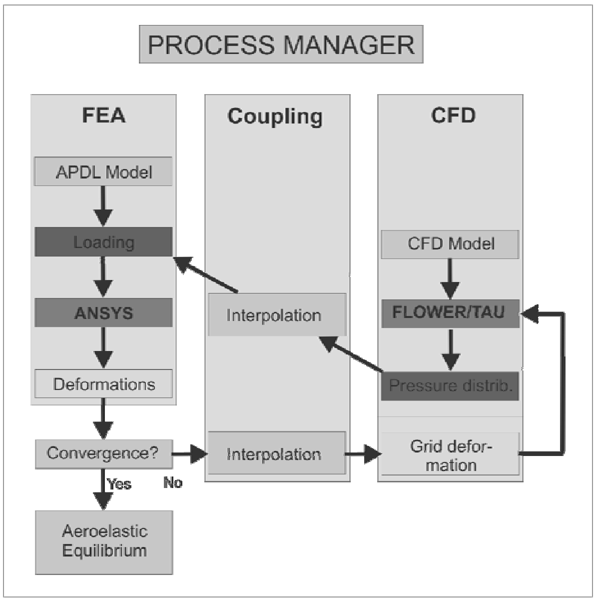

Figure 16: Sequential coupling process

PARA_MAM can be used to automatically generate FEM models for a given CFD mesh. At initial model generation in the FEM pre-processor the structural description of the interface area necessary for interpolation is written in an ASCII file. Based on this information the interpolation module calculates the nodal forces and directly aligns them to the node numbers in the surface description. Hence, the process manager only needs to launch the FEM code, load the model, apply the forces and start the solution process. The automatic post processing to write out displacements refers to the PARA_MAM generated component A_AERO, which comprises all areas of the coupling surface. Thus, whole the structural part of the aeroelastic process chain can be initialised automatically using PARA_MAM.

5.3. Structural Sizing

Detailed FEM models from PARA_MAM and the aeroelastic process chain constitute the basis for reliable structural sizing. The challenge arises from the enormous number of variables which might be changed independently. Each element is built of up to 250 layers with individual material, orientation and thickness. These real data constitute the primary variables. One common procedure is the local grouping of elements which share a set of real data. Variables are determined using mathematical optimisation strategies and evaluation of stress levels employing the FEM code. Aerodynamic quantities can directly be considered as optimisation target or boundary condition. PARA_MAM provides a feature to designate areas being part of certain optimisation groups using the name convention of areas.

Reduction of variables using grouping leads to coarsely sized structures. But the concept of shell based light weight structures base on distributed bearing properties and local optimisation. A smart arrangement of optimisation groups can account for local effects and provide very good results but either pre-existing knowledge has to be introduced for group allocation or grouping has to be added to optimisation increasing the number of design variables.

An alternative is a two stage optimisation process based on element-wise application of design rules and super-ordinate optimisation of the design rule parameters. The automatic application of design rules like realised in the DLR S_BOT (Sizing roBOT) programme is schematically presented in figure 17. S_BOT is a suite of ANSYS macros performing analyses with given FE models. All element results are stored in variables and are post-processed to determine the best properties for each individual element. After modification of real data the internal structural loads will change. Hence, the process has to be repeated iteratively until internal loads and properties converge.

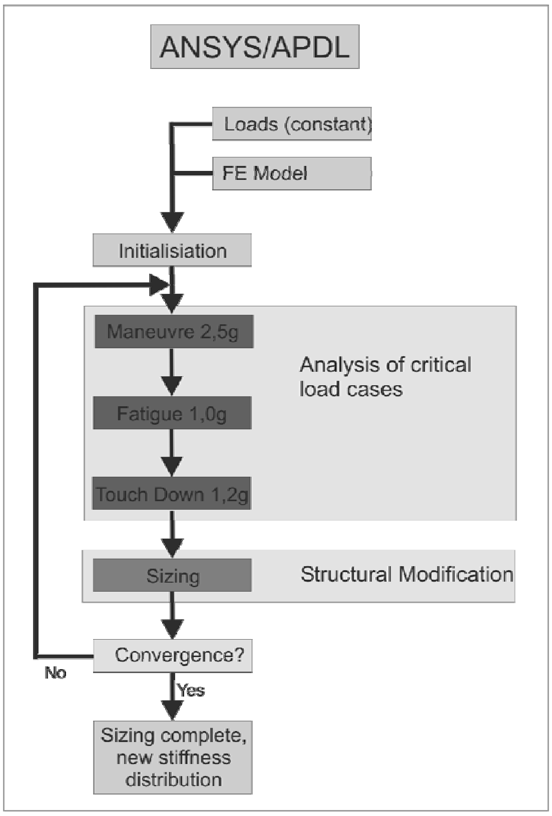

Figure 17: S_BOT sizing process

New properties are calculated using user specified design rules like 'align the fibre axis with principal stress'. These rules represent the typical engineering work of designers and permit automating of classical sizing process. For multiple loadcases and complex targets it is hard to predict which might be the best strategy for sizing. Rules might be of the type 'orient the fibres with an offset of X degree to the mean stress direction', where X is one parameter of all elements to be mathematically optimised. Thus, sizing rules are an alternative for variables reduction. Here only a brief introduction to S_BOT is projected. Detailed information especially about sizing strategies is presented in [1].

S_BOT and PARA_MAM share common name conventions. Engines e.g. are defined in the user input and modelled by PARA_MAM. The load introduction points are designated using the component option with unique name for each engine. In the S_BOT input thrust and mass of engines can be specified as scalar variables. Due to the name convention S_BOT can directly apply the input to the model. Further on surface pressure loading is harmonised with the aeroelastic process chain. In the S_BOT inputfile only the names of the aerodynamic load files need to be specified. S_BOT automatically applies the forces to the nodes. The sized model remains appropriate to be used in the aeroelastic process chain.

6. CONCLUSION

Higher order effects play an increasingly dominant role in the design of transportation aircrafts. Considering these effects requires high fidelity methods which base on explicit models. The MATLAB programme PARA_MAM was presented in this paper for the automatic generation of FE wing models in a detailed shell representation. Unstructured surface meshes serve as contour reference which are common in high fidelity aerodynamics and can easily be created from structured meshes or profile data. The structural model can be elementary simple up to a realistic complex multi body configurations exploiting shell theory. Hence, PARA_MAM covers the range from elementary pre-design verification up to the high fidelity sector of complete wing simulations. The outstanding characteristic of PARA_MAM is the avoidance of CAD packages to generate the structural model but the use of elementary mathematical functions. Thus, the PARA_MAM code is very lean and fast. Due to the batch capacities it is well suited for multidisciplinary optimisation up to medium levels of complexity. CAD programmes using relational modelling do not offer advantages in the intermediate design stages PARA_MAM aims at but are indispensable in the final design stages. PARA_MAM is programmed to suit interdisciplinary design processes and provides interfaces for high fidelity aeroelastic simulations and structural optimisation. Further development of PARA_MAM could extend structural shell representation to solid modelling and further increase the level of details. Due to computational effort this approach might be restrained to component analysis and design. Another development direction is improvement of the fuselage module and the creation of wing-fuselage interfaces to model whole aircraft configurations.

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