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Parametric Modeling of Movables for Structural Analysis

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In this paper a method is described with which structural models of aircraft movables can be generated using a knowledge-based engineering tool. First of all, a parametric definition of the movable family has been implemented in knowledge-based engineering software. The resulting model generates the geometry of, and information about, a movable, based on methods stored within the model and inputs provided by the user. The geometric layout of the movable can be adjusted by changing the input parameters used for generating the model. The information that is generated by the model is used in the second part of the knowledge-based engineering tool: the transformation of the geometrical model of the movable to a structural model. This transformation consists of segmenting the movable model into easily meshable surfaces and storing information about material properties of, and loads on, the movable in text files. The geometry and the text files are used in a finite element preprocessor to automatically generate the finite element model of a movable. In this way finite element models of movables of different configurations can be generated in a quick and consistent way.

Introduction

COMPETITIVENESS based on innovation combined with short time to market will be key to the continued success of Western aircraft manufacturers. Fast generation, analysis, and optimization of concepts supported by knowledge-based engineering (KBE) tools is one of the possibilities for achieving this. Capturing, reusing, and extending knowledge behind the companies' core competences is the objective behind the design and engineering engines (DEEs) under investigation by Delft University of Technology.[1–4] A DEE generates and analyses different solutions to a design problem.

A schematic outline of a DEE can be seen in Fig. 1. At the heart of the DEE is the multimodel generator (MMG). The MMG uses methods to generate the geometry of, and information about, the model. This geometry is based on input that is provided by the model user or an optimizer. This input comes in the form of a text file in which the data for generating the model are stored. The MMG also generates input data for the analyses that are performed by the different discipline silos. In this project the main focus is on the structural silo. Finite element (FE) models are generated as part of a DEE for aircraft movables. The time needed to create FE models will decreased significantly and therefore more concepts can be analyzed in depth, leading to a better trade-off between the different concepts.

Another objective of the DEE is that configurations can be changed quickly by changing design parameters. This is advantageous for aircraft parts because a conceptual design of the various aircraft parts can be made even when the final configuration of the aircraft is not fixed. Through parametric modeling the parts can be updated easily to design changes at a higher assembly level. Work done before the change can therefore be reused. This also works the other way a round: a lot of information about the different aircraft parts is available early on in the project; this can result in a different, more optimized, final aircraft configuration.

The DEE can be used on various scales of the design cube shown in Fig. 2. In previous projects,[2] it was used on the macro scale to evaluate aircraft configurations. For this project a lower level will be investigated: a family of aircraft parts, the movables.

The movables family was chosen because the model could be tested in the thermoplastic rudder project.[5,6] This project is currently running at the Delft University of Technology with the goal of developing a thermoplastic composite general aviation rudder. Furthermore, movables are usually designed and manufactured by subcontractors; therefore, in dealing with the different configurations of an aircraft manufacturer and similar designs for different aircraft manufacturers, a parametric model would be very advantageous. For example, in dealing with an aircraft family of different sizes but with the same basic configuration, a design conceived for one family member can easily be reused for another member by changing just a few parameters.

The MMG has been defined using the unified modeling language[7] (UML) and the MOKA modeling language[8] (MML) (see Parameterization of Movables) and is implemented using the ICAD software[9] of Dassault Systèmes. The ICAD system is a KBE tool; this means that instead of just generating a geometric model it also generates information about this model, which can be used in other analyses. How the model is built up and how the other information is used will be discussed in the rest of this article.

Parameterization of Movables

A generic model for a movable requires parameter definitions for the geometry, structural layout, and other properties of a movable. To identify the parameters, first the movable family and all its properties have to be defined.

The movable family consists of different members, as can be seen in Fig. 3; these members have different functions and therefore different layouts. Using UML and MML the different functions and parts of the movables can be identified and parameterized. In this article only the trailing edge movables will be treated.

UML is an object-oriented modeling language, which allows the model to be represented graphically in a standardized way. MML is an object-oriented modeling language and uses the UML graphical representation to represent its models. MML is especially developed to define engineering objects and processes and is therefore suited to represent the movable model. MML allows different views so that, for example, behavior, function, and structure of the part can be split in to different models.

A structural view of the movable using the MML language can be seen in Fig. 4. A part of this graph has been filled with the appropriate attributes and can be seen in Fig. 5; it represents part of the wing box structure of a movable. As can be seen in the structural

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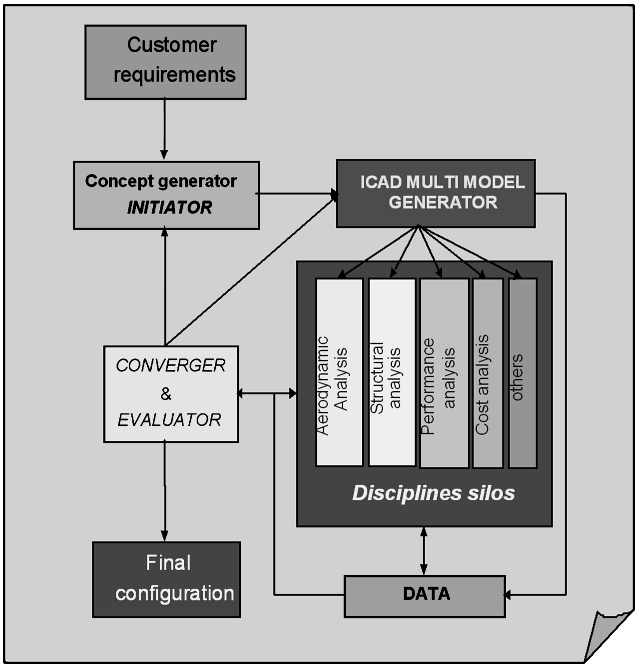

Fig. 1 Paradigm of a design and engineering engine.

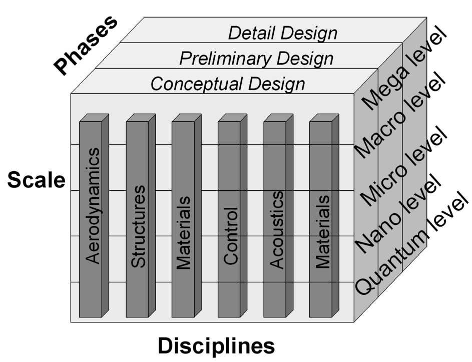

Fig. 2 The design cube.

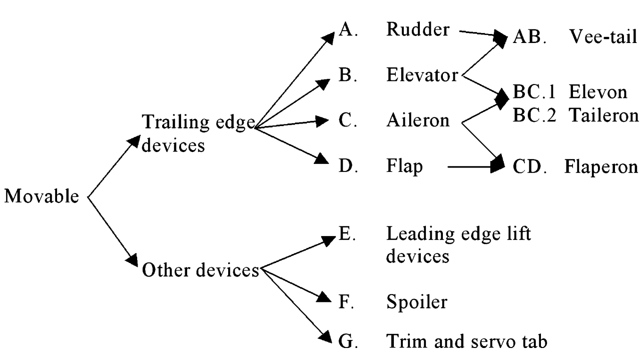

Fig. 3 Movable subdivision.

representation of the movable, the movable consists of four different parts: 1) the wing box (used in this paper for the central part of the movable, the part between the first and last spar); 2) the leading edge; 3) the trailing edge; and 4) the end caps.

The parts are built up of different panels, which consist of a web, the surface determining the shape of the panel, and girders at the edges of the web. This panel can also be used to model stiffeners; this is done by using only the girders of the panel and setting the web thickness at zero.

Shape Requirements

To be able to create sufficient variants of the trailing edge moveable family members, several features must be covered by the movable model. These features can be seen in Fig. 6. In this article all surfaces and features dealing with the outer shape or outer mold line of the movable will be called "shape" features or surfaces; all features in Fig. 6 are therefore shape features. These features are as follows:

1) The leading edge, the part of the movable in front of the main wing box, must have an aerodynamically smooth connection to the main wing box.

2) Cut outs and discontinuities are needed to accommodate, for example, trim tabs or to create a horn in which the mass balance of the movable can be positioned.

3) Arbitrary angles occar at the beginning and end of the movable and between the discontinuities.

4) Endcaps, aerodynamic fairings at the end of the wing box, ensure smooth aerodynamics of the top and bottom of the movable.

5) Skin continuity ensures that the movable lies flush with the wing surface to ensure good aerodynamic properties when the movable is not deflected.

Structural Options

To perform a structural analysis of the movable a structure within the movable has to be built up. Four main structural concepts for trailing edge moveables can be distinguished: a stiffened skin construction, a sandwich construction, a multirib construction, and the full depth foam/honeycomb. Three of these options have been incorporated into the model: the stiffened skin option, the sandwich option, and the multirib option. The difference between these three options is the way the skin surfaces are stiffened. Several different structural options can be combined in one instantiation of the movable model.

Stiffened Skin

The stiffened skin structure consists of two types of elements: shape surface elements and stiffening elements. The shape surface elements form the external shape of the movable. Shape surface elements are, for example, skins, leading edge, and end-caps. The stiffening elements make sure that the shape is kept when the movable is loaded; stiffening elements are, for example, ribs, spars, and stiffeners. The stiffened skin variant refers to the concept where most stiffening is provided by longitudinal stiffeners, as can be seen in Fig. 7.

Sandwich

With a sandwich construction shape and stiffening element are integrated in one element. The skin surface consists of two facings and a core. The distance between the two facings ensures that the skin surface has enough bending stiffness to prevent buckling. This principle can also be used for the other elements of the movable, such as leading edge and spar. An example of the sandwich construction used for the box skins can be seen in Fig. 8.

Multirib

The multirib construction is essentially a specific version of the stiffened skin construction. The main difference is that the stiffening elements consist of many ribs and that no stiffeners exist. The ribs divide the skin into many sections, which are short enough to withstand the loads that are exerted on them. An example of the multirib construction can be seen in Fig. 9.

The movable model must be able to generate movables containing all outside shape features and all three structural concepts. Furthermore, the configuration possibilities within the concepts, such as number of stringers, ribs, and sandwich configuration, should based on the input given by the user and must not be changed by rules hard-coded within the movable model. Therefore the movable model needs to be able to generate all shape elements plus the usual structural elements such as ribs, spars, and stiffeners and should be able to generate a sandwich construction when necessary. In addition the model should be built up in such a way that other features and structural concepts can easily be incorporated in the future.

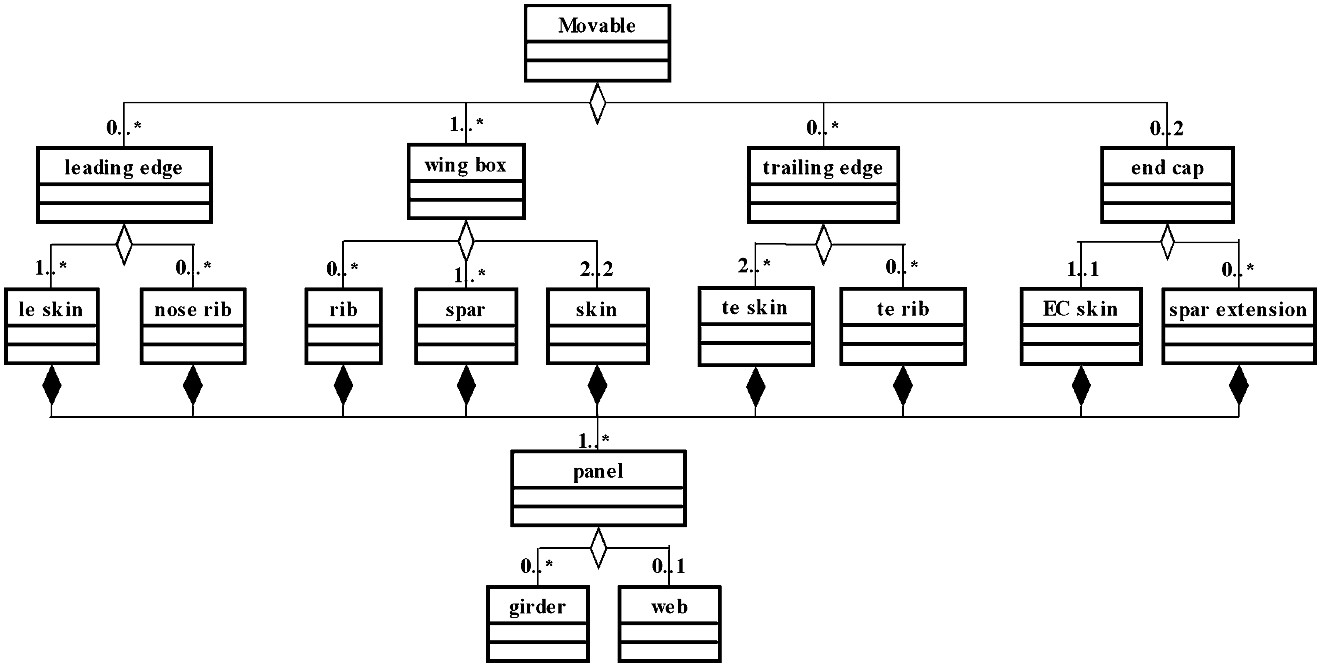

Fig. 4 MML structural representation of a movable.

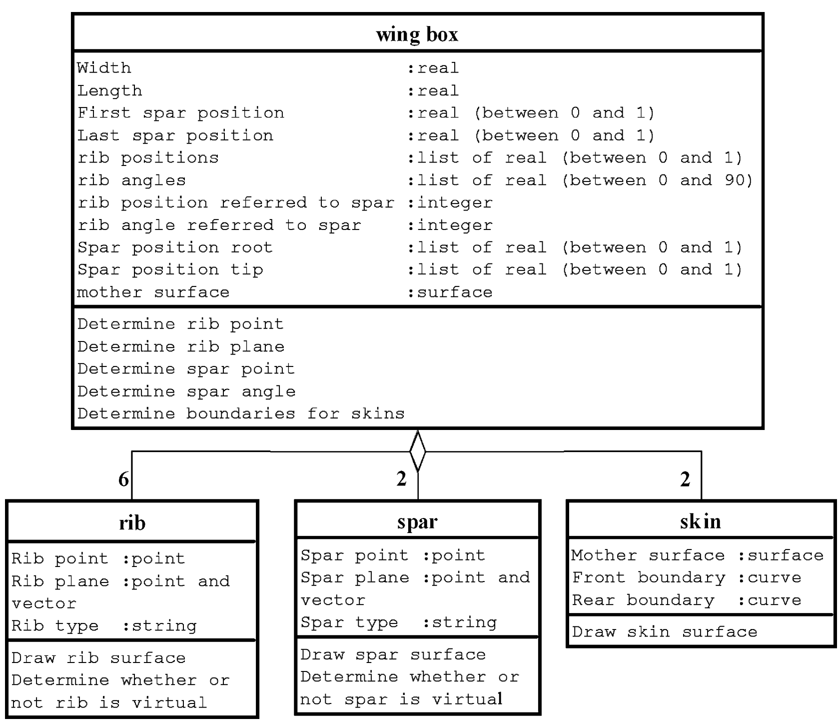

Fig. 5 Part of the structural MML diagram worked out for the multirib construction of Fig. 6.

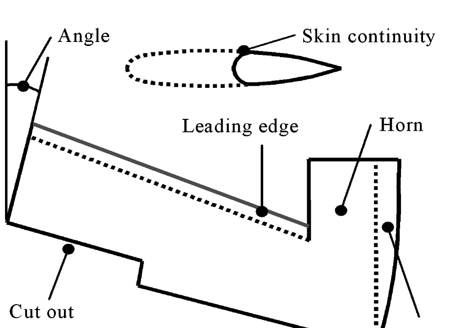

Fig. 6 Shape features.

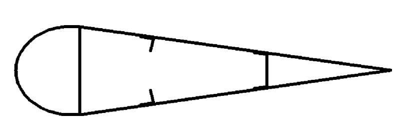

Fig. 7 Stiffened skin example.

Fig. 8 Sandwich example.

ICAD Movable Model

The movable model consists of a basis module and added shape parts. The basic module consists of a set of wing trunk primitives, which is a modified version of the wing trunk model developed at the Delft University of Technology.[2] Several parts can be added and deducted from the basic module. The shape parts are not integrated into the wing trunk module and are therefore added to the basic module. Taking advantage of the contextual instantiation feature of ICAD, which means that different objects belonging to the same class can look different based on the context or inputs of the class, the wing trunk element, which is a class, is used (and reused) to generate the different movables. The wing trunk element makes possible the generation of a large family of movables within the same configuration by simple modifications of the basic parameters (span, chord length, angles, etc.). The number of wing trunks can be determined by the user, giving a maximum degree of design freedom.

All input parameters that determine the shape and structure of the movable are stored in an input file; this is a text file and can be updated or changed by the designer using the movable model. A small piece of such a text file can be seen in Fig. 10.

Wing-Trunk Primitive

The instantiation of a wing trunk (Fig. 11) element requires a set of parameters that unambiguously defines external and internal (structure) shape, orientation, and positioning in space. For the movable the leading edge of the original wing trunk model is not used; it is replaced by a shape part.

To define the shape of the wing-trunk airfoil curves are constructed, which are defined in a library. These curves can be stretched to fit the designer's needs, and new profiles can be added to the library. As an addition to the original wing-trunk module the option has been implemented to put the curves at angles with respect to the flight direction. These angles facilitate even more design freedom for the movable. Another option added to the original wing-trunk model is the possibility of throwing away the trailing edge of the wing trunk. This enables the user to create a cutout in which, for example, a trim tab can be positioned.

Wing-Trunk Primitive Structure Generator

The contextual instantiation principle has been applied to the structural elements to make the tool able to generate the complete structure automatically within any given wing-trunk surface. In this way there is an efficient (re-)use of the code modules. This option makes the tool powerful and very flexible at the same time. The structure is always tailored to the outer aerodynamic surface as can be seen in the Examples and Results section.

The number and position of ribs and spars is determined by input values. The orientations of these elements can also be determined by input values, enabling the user to generate the complete internal structure of the wing-trunk module. Different "smart" input options have also be incorporated to simplify the user's task. These options include:

1) Optional variables for the input that result in ribs being placed at the edges of the wing trunk.

2) The incorporation of a variable calling the flight direction of the aircraft and thereby disconnecting the orientation of the ribs from the orientation of the wing trunk.

The user has the possibility of assigning to each placed rib a label indicating the actual structural functionality (virtual rib, hinge rib, light rib, etc.). A virtual rib is present in the movable model; however, the physical representation of the rib, the rib web, is not exported to other analysis tools and thus not incorporated in the analyses. Once the ICAD tool detects a hinge rib, a routine automatically generates a slot in the leading edge (see Shape Requirements and Fig. 6). This slot is essentially a hole in the leading edge in which a hinge can be placed. Additional input parameters determine the position and size of the slot. The ICAD tool also adds a virtual rib on each side

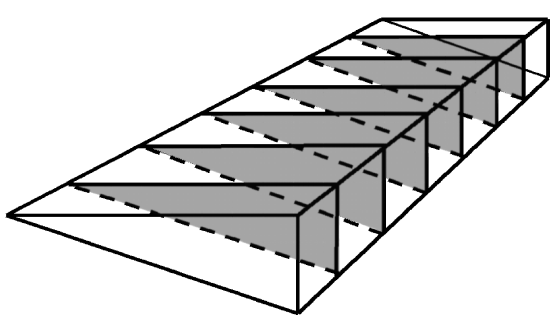

Fig. 9 Multirib example.

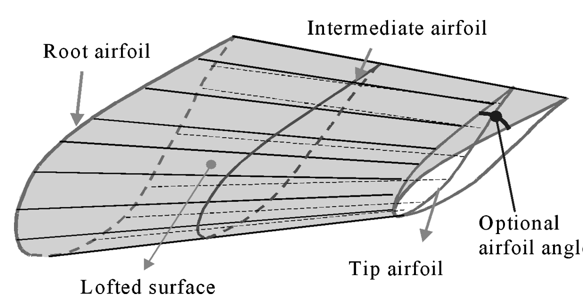

Fig. 11 The wing-trunk element.

```
(defpart spars-ribs ()
  :optional-inputs
  (
   :spar-offset-list-root       (list (list 0.247   0.6916  0.93)  (lis
   :spar-offset-list-tip        (list (list 0.346  0.6916   0.93)  (lis
   :type-of-spar                (list (list  'h     'r        'v)  (lis
   :cap-sparlet?                (list (list  t      nil      nil)  (lis
   :production-group-spars      (list (list  6      7        nil)  (lis


   :hinge-cut-rel-hinge-pos             (list (list     0   ) (list
   :hinge-cut-width                     (list (list     0   ) (list
   :type-of-rib                         (list (list    'l   ) (list
   :rib-positioning-referred-to-spar    (list (list    'root) (list
   :rib-orienting-referred-to-spar      (list (list    'root) (list
   :rib-positioning-offset-list         (list (list     0.00) (list
   :rib-orienting-angles-list           (list (list     0   ) (list
   :le-riblet?                          (list (list     t   ) (list
   :le-riblet-angles-list               (list (list     0   ) (list
   :te-riblet?                          (list (list     t   ) (list
   :hinge-middle-or-side                (list (list    's   ) (list
   :hinge-side-displacement             (list

   :production-group-ribs               (list (list     0   ) (list
```

Fig. 10 Part of the input file containing the data for the ICAD model.

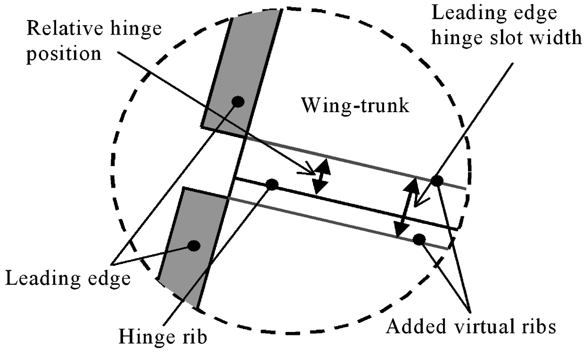

Fig. 12 Leading edge slot layout.

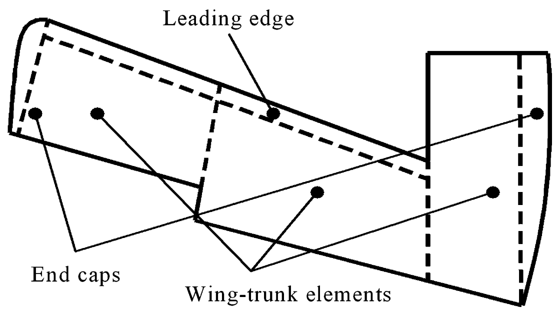

Fig. 13 Shape elements of the model.

of the hinge rib to ensure the proper segmentation, which is needed for the link to FE tools. An example of a leading edge slot can be seen in Fig. 12.

The spars also get a label determining the structural functionality (real spar, virtual spar, stringer, etc.). In the case of a stringer label, curves are created on the top and bottom skin. These curves are exported and can be converted into stringers in the FE tools. The cross section of the stringer is defined by the property the stringer gets in the FE analysis tool. How this property is created can be seen in the Creation of Patran Session Files section. The web of such a stringer spar is considered virtual and therefore not exported.

Shape Features

The shape features that are added to the wing-trunk model are the leading edge and the endcaps. The position of the leading edge is determined by the first spar of the movable. Endcaps can be added at both tips. The features can be seen in Fig. 13.

Leading Edge

The leading edge of the movable is a surface that has been added in front of the first spar. It ensures good aerodynamic properties and can also be used to enclose mass balance elements that are located in front of the first spar.

The leading edge consists of several different surfaces that are based on one virtual mother surface. The mother surface is generated by lofting a surface through two curves at the end and beginning of the relevant section. The curves for the mother surface are built by lofting a curve through points. The position of these points is determined by offset values stored in the input file, which is controlled by the user. The profile point's offset is always related to the upper point of the spar to which the leading edge is connected and the offset lengths are also based on the height of this spar. During the surface loft the upper and lower spar curves of the front spar are used as guide curves to ensure a good connection to the wing box. The definition of the points and curves can be seen in Fig. 14.

The number of different leading edge surfaces is dependant on the number of hinges. At each hinge there is an opening to accommodate the hinge. This opening is cut from the mother surface, resulting in several smaller surfaces. Finally, nose ribs are added to the leading edge. These are basically extensions of the ribs in the wing trunk. However, input parameters are available to control whether or not

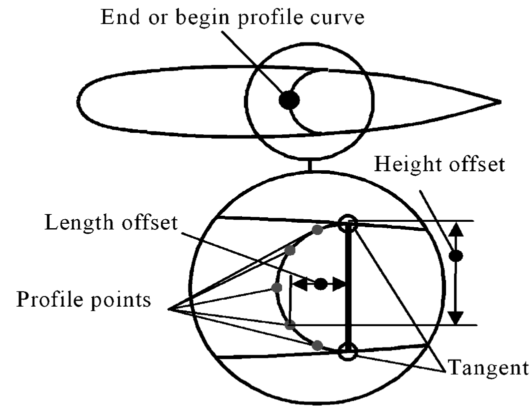

Fig. 14 Leading-edge profile layout.

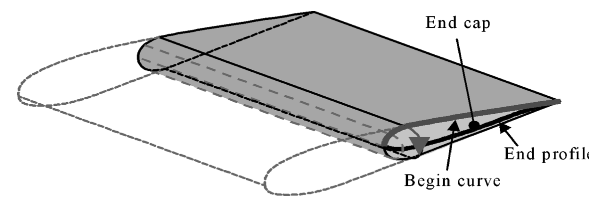

Fig. 15 Endcap definition.

they should be created and whether or not they should have an angle to the relevant rib in the wing trunk. A nose rib can also be added without adding a rib; this is done by specifying the relevant rib to be virtual. When a hinge rib is detected a nose rib is created on each side of the hinge slot.

Endcaps

The endcaps are parts that can be added to the tips of the movable. The endcaps consist of a surface that ensures the aerodynamic properties and optional sparlets, extensions of the spars that exist in the wing-trunks. For the creation of the endcap the first two curves are created at the lower and upper part of the movable to which the endcap is connected. These curves are built up by merging curves from the wing-trunk and leading edge into one. Another curve is created at the tip of the endcap. This curve is based on a profile that is stored in a library and is called through the input file. The end cap is created by blending a surface through the three curves. This blending is influenced by three control surfaces that determine the tangency of the endcap to the wing box and the direction of the endcap at the end profile. The influence these control curves have on the endcap is determined by several input values, giving the user extra control over the shape of the endcap. Finally, sparlets can be created; these are extensions of the spar that extend from the spar to the endcap skin. These sparlets are optional; whether or not to create them is determined in the input file. An example of an endcap can be seen in Fig. 15.

Segmentation of the Model Surfaces

The surfaces, including all surfaces representing structural members, created by the movable model will be used in Patran,[10] which is used in the DEE as a preprocessor for Nastran, in which the actual FE calculation is performed. The main issue here is the definition of a proper strategy to build up a direct and smooth link between the movable model and the FE analysis environment. The main requirement for this smooth link will be that the surfaces must be easily meshable to eliminate the time-consuming splitting of the surfaces in the FE program. This can be achieved by segmentation of the surfaces. A special procedure has been programmed in the ICAD tool to automatically split all the structural surfaces (spars, ribs, skins) along their intersections. Spars are split along the intersection with all ribs, ribs are split along the intersection with all spars, and skin panels are split in patches along the intersections with both the ribs and the spars. This segmentation is continued in different shaped parts. Virtual ribs and spars are also added in places where extra

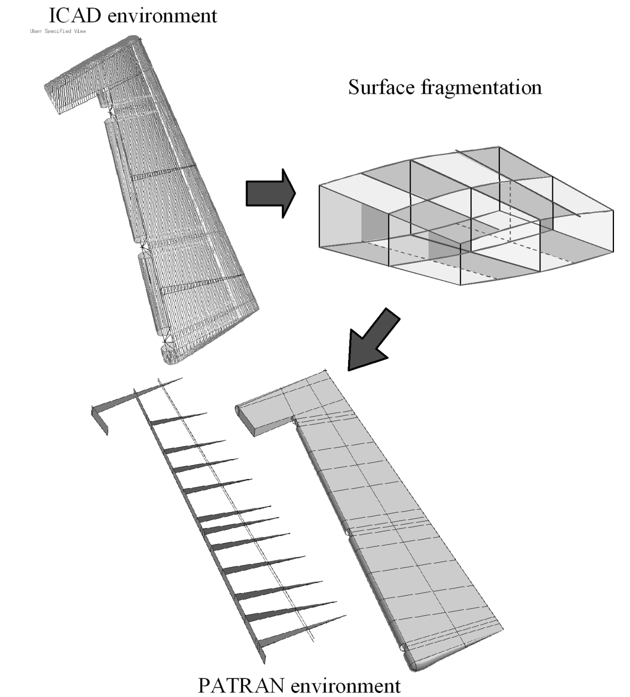

Fig. 16 The ICAD model surfaces are split into small patches before being imported into Patran.

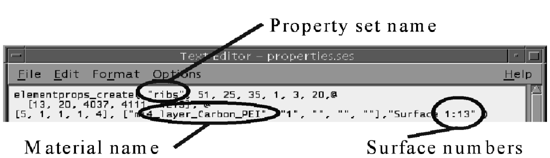

Fig. 17 Session file defining variables.

segmentation is needed, such as the leading edge slots. Finally the segmented surfaces are stored in several iges files. In each of the iges files a group of surfaces is stored with the same structural function. During loading into Patran the grouping remains the same, enabling a clear representation of the different groups in Patran. A visualization of the segmentation can be seen in Fig. 16.

Creation of Patran Session Files

Segmentation is done within the movable model prior to exportation of the FE. If only the geometry were transported, all other information present in the movable model would be lost. Therefore a method was devised to transport other information stored in the movable model to the FE analysis tool.

The FE preprocessing tool used for the movable DEE is Patran. In working with Patran all actions are stored in so-called session files. These session files are basically text files that can be written by every text writer and also by ICAD. Previously these session files have been written by ICAD to aid meshing in Patran.[11] In the current DEE session files are used to transfer specific other information on the movable model, such as material properties and loads, to Patran.

Generating the Properties Session File

In the movable model material properties can be allocated to the different parts. These properties are exported to the FE model using a Patran session file in which the properties are linked to the appropriate surfaces.

Patran session files are basically recorded sessions of using Patran. In these session files, defining variables can be identified, as can be seen in Fig. 17. For example, when a property set is generated, there are two variables determining which surfaces should be included in the property set. These two variables are identification numbers of the first and last surface to be included in the property set. In ICAD these variables can be determined for different property sets such as spars and ribs.

To allocate the right property set to the parts the surface numbers of the surfaces created by segmenting the model have to be known. This is achieved by standardizing the way the different groups of surfaces are loaded into Patran. The sequence of loading of the different iges files containing the geometry of the model is standardized by using a standard session file. Because the sequence of loading is known, the surface numbers of the different parts can also be determined. For this the number of surfaces in each group has to be determined, this is done by scanning the segmented movable model. The counting is done automatically within the ICAD tool. The principle of determining all the surface numbers can be seen in Table 1.

Table 1 Parts surface numbers

Parts	Begin surface number	End surface number
1. Ribs	1	Number of rib surfaces
2. Spars	Number of rib surfaces + 1	Number of spar surfaces + previous end surface number
3. Covers-up	Number of spar surfaces + 1	Number of cover-up surfaces + previous end surface number
Etc.	Etc.	Etc.

Finally, using the surface numbers, a session file is automatically written, which will generate the physical properties of the different surfaces in Patran. The curves used to generate stiffeners are handled in the same way; here the properties session file also determines the cross section of the stiffener.

Generating the Loads Session File

To make a useful finite element analysis the loads acting on the movable have to be determined. For the analysis of the rudder in the thermoplastic rudder project a pressure load distributed according to JAR 23 (Ref. 12, Appendix A23.11) is used. In the conceptual design phase this is a useful and fast way to define load cases. In later stages pressure fields from aerodynamic tools can be used or data from experiments.

The shape of the pressure load on the movable (rudder or elevator) resembles a triangular pressure load with the maximum pressure at the hinge line of the movable and a pressure of zero at the trailing edge. The maximum total force that is exerted on the rudder is dependent on the configuration of the rest of the aircraft and should therefore be determined by the user by altering the input for the movable model.

In Patran the pressure is put on the model by a square area pressure defined by the pressures at the four corner points. It is therefore necessary to determine these corner point pressures. This is done in the following manner:

1) First, using the total force acting on the movable and the geometry of the movable, a pressure calculation factor is determined.

2) Second, the pressures at the four corner points are determined by the ICAD tool using the pressure calculation factor and geometric data retrieved from the movable model.

3) Third, the pressures are stored in a session file that can be used by Patran.

All these actions take place in the ICAD environment. The resulting pressure fields and the resulting pressure in Patran can be seen in Figs. 18 and 19.

To generate a proper analysis of the model in Patran it is necessary to prohibit movement of the model at the hinges. In the movable model the hinges are modeled as four curves running from the hinge point to the four corner points of the leading edge slot. The hinge point is the point where the hinge rib plane cuts the hinge line. In this point displacement in the three translation directions is prohibited. The hinge layout in Patran can be seen in Fig. 20. One of the hinges will also act as an actuator; this means that for this point rotation in any direction is prohibited. Which of the hinges also acts as actuator is determined by the user in the input file. The creation of the hinge and actuator constraints is performed by the loads session file.

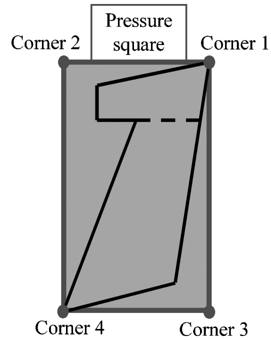

Fig. 18 The pressure square defined by ICAD.

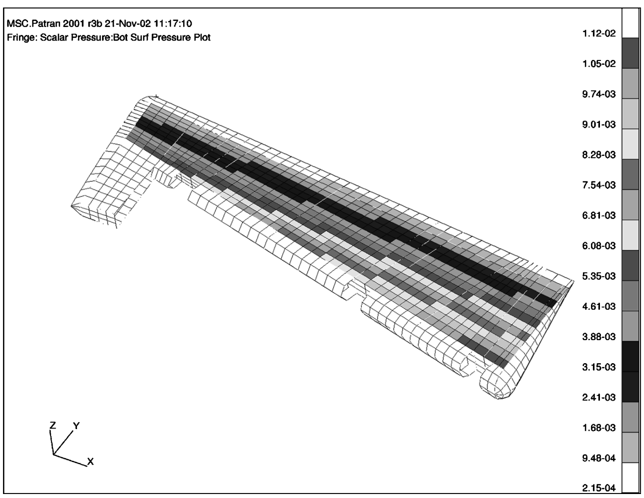

Fig. 19 JAR 23 Appendix A23.11: pressure contour in Patran.

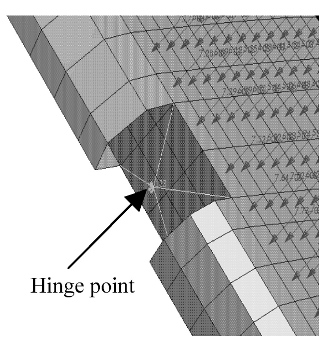

Fig. 20 Hinge layout in Patran.

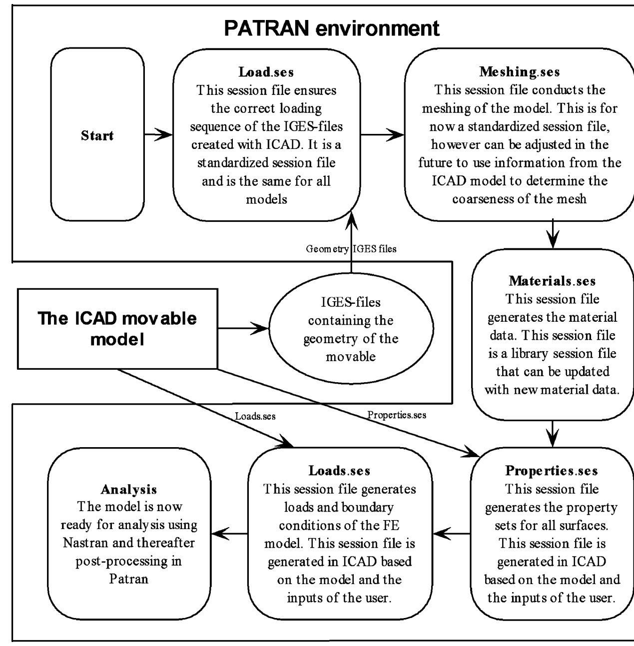

Fig. 21 Diagram showing the function and flow of all session files.

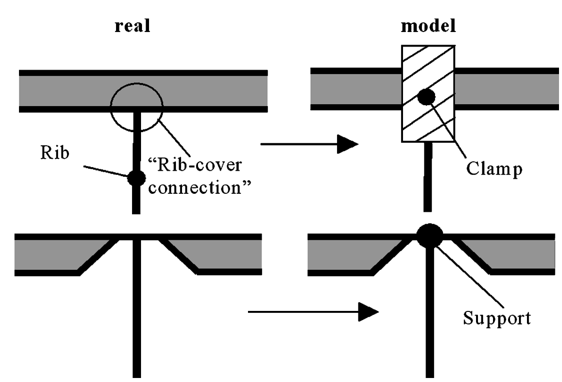

Fig. 22 Different sandwich skin-rib connection options, real and how they should be modelled.

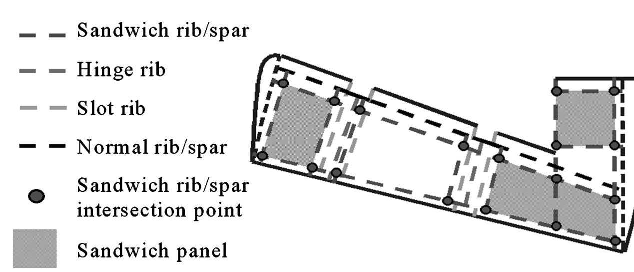

Fig. 23 Sandwich panel determination.

Using the Session Files to Create a FE Model

With the session files discussed previously and standard session files that stay the same for all the movables, an FE model can be created in Patran. This process involves the running of the different session files in a particular order, resulting in an FE model that is ready for FE analysis. How this process works and where the session files are generated can be seen in Fig. 21.

Implementation of Structural Options

The stiffened skin and multirib structural options are implemented by using the standard spar, stiffener, and rib elements available in the wing trunk structure generator. The sandwich structural option cannot be implemented in this way; for this option another implementation method was devised.

Sandwich panels are created by adjusting the properties of the relevant surfaces in Patran; this is done automatically by the properties session file. The sandwich properties are used in Patran during the FE analysis. One option to define the sandwich panels in the movable model is to give all surfaces in the skin surface group a sandwich panel layout. This will result is a "rib-cover connection" as represented in the upper part of Fig. 22. For certain constructions this definition suffices. However, in converting the movable model to an FE model, this definition of the rib-cover connection will result in a clamped cover connection. For certain structural options, this is not a truthful representation of reality.

The constructions shown in the lower part of Fig. 22 must be modeled in the FE-model with a simply supported joint between cover and spar/rib. In the movable model this is made possible by splitting the covers in sandwich and non-sandwich. This splitting is done by adding virtual ribs and spars, which determine the boundaries of the sandwich areas, and by collecting the surfaces within these sandwich areas in a different surface group, which is given a sandwich layout.

In Fig. 23 a schematic model including the sandwich spars and ribs can be seen. In the figure the intersection points of sandwich

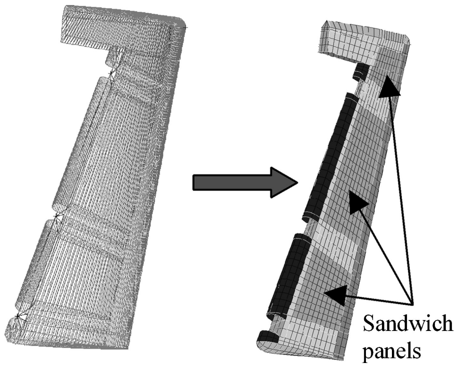

Fig. 24 ICAD to Patran sandwich properties (not the same model as Fig. 23).

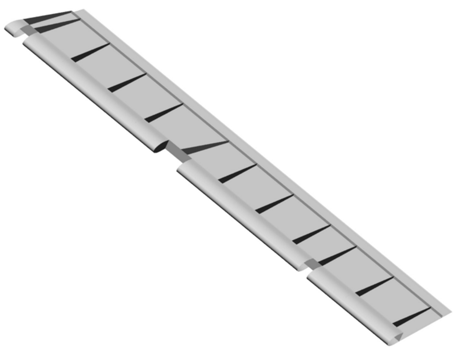

Fig. 25 Airbus A320 aileron.

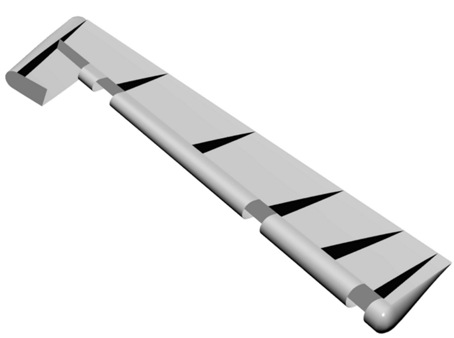

Fig. 26 General aviation rudder.

ribs and sandwich spars are indicated by a dot. To determine if a panel is a sandwich panel all four corners of the panel are compared, automatically, with a list of all intersection points of sandwich ribs and spars. When all four corners of the panel coincide with an intersection point the panel is marked as a sandwich panel and collected and exported as such. In Patran the panels are awarded the proper property, as can be seen in Fig. 24.

Examples and Results

The movable model that has been created has been tested on a number of example movables. This has shown that a majority of the structures occurring in real life can be recreated with the movable model. It has also shown that the movable model can be used as a module in other ICAD models. Some examples of instantiations of the movable model are shown in Figs. 25–28.

Parts of the movable model were used in projects conducted with industry. One of these projects was the design of a vertical and horizontal tail for a large civil airliner. The model used was created using the building blocks from the movable model. With this vertical/horizontal tail model, FE representations of tail configurations could be generated within 1 h. This compares to 1 day or 8 h for the creation of a FE model in the traditional way. The traditional way in this case meant using a CAD model and cutting this up into meshable segments in a FE pre-processor.

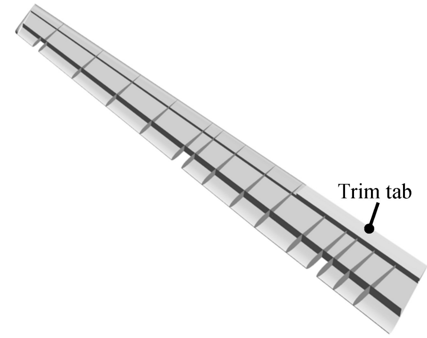

Fig. 27 Elevator example: trim tab is modeled using a simplified movable model.

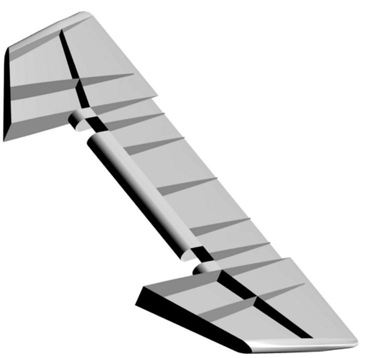

Fig. 28 Movable with an imaginary configuration.

Conclusions and Future Developments

A generative model of a family of movables has been created using KBE software, in this case ICAD. This model can be used to create FE models using text session files for the transfer of the model properties to the FE software. The work has been used in the design and analysis for a general aviation rudder.

Significant time reductions for the creation of the FE model have been accomplished. These time reductions are on the order of 80%. Because of the reduced time it takes to analyze a movable configuration, more configurations can be analyzed in the conceptual design phase. This can result in a better more optimized design.

The product knowledge of the movable and the process knowledge of creating a movable structural model have been captured in different ways:

1) The product knowledge is captured in an input file in which knowledge about geometry, structural functions, and material properties is stored.

2) The knowledge of segmenting the geometric model for meshing has been captured in a module that uses KBE software; this ensures that segmentation can be done for all movable models in a similar method.

3) The knowledge of how to create the pressure load on a movable defined by certification authorities has been stored in a module using KBE software. This module writes a text file, a so-called session file, that can be read and used by the FE software. In this way the load can always be determined even when the layout of the movable is changing.

4) The knowledge of building the FE model has been stored in text files, so-called session files, that are used by FE software to build an FE model. This will result in a similar FE model for each instantiation. The results from a FE analysis using this model will therefore be comparable and can be used in a trade between the different concepts.

With some modifications the movable model can also be used for vertical or horizontal tails in combinations with the rudder of elevator. Because the ICAD model is build modularly, this can be achieved in a relatively simple way.

Future developments will include the creation of a tooling module to be linked to the movable model, with which tooling will be automatically generated, and a cost module, which will provide a smooth link to a cost calculation program.

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