

Automatic generation of rib mould for rubber forming of thermoplastic composites, using knowledge based engineering

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ABSTRACT

In today's competitive market place it is important for manufacturers of aircraft parts to be able to respond quickly to the demands of your customer. This requires flexibility and speed in the development of new or redesigned aircraft parts. One way to achieve this is to develop Knowledge Based Engineering (KBE) tools that shorten the design and production lead-time. In this paper a KBE tool is described with which geometry of moulds used for rubber forming of thermoplastic composite movable ribs can be generated. This KBE tool is part of a larger Design and Engineering Engine of an aircraft movable.

The KBE tool uses information stored within the tool to generate the mould geometry and information about the mould. People not familiar with mould design can operate the KBE tool, making mould design a cheaper and, because the mould design is automated, less time consuming process. The knowledge stored in the tool consists of expert knowledge on the positioning and sizing of critical features of the rib mould. This knowledge is transformed from raw knowledge into practical design rules and practical models. Finally the models and knowledge are packaged in a KBE tool.

The KBE tool consists of several features that together form the rib mould. Negative or positive mould can be modeled by changing just one input parameter. The features needed for using the mould in the rubber forming process are also positioned using user-defined parameters. This results in a tool that is flexible but fast in generating rib moulds. Generation of a rib mould typically costs 2 minutes.

1. INTRODUCTION

In today's competitive market place it is important for manufacturers of aircraft parts to be able to respond quickly to the demands of your customer. This requires flexibility and speed in the development of new or redesigned aircraft parts. One way to achieve this is to develop Knowledge Based Engineering (KBE) tools that shorten the design and production lead time. These KBE tools capture and re-use the knowledge behind core competences of the company. Different KBE tools can be collected to form a Design and Engineering Engine (DEE)[1][2][3][4]. Such a DEE generates and analyses different solutions to a design problem.

A schematic outline of a Design and Engineering Engine can be seen in Figure 1. At the heart of the DEE is the Multi Model Generator (MMG). The MMG uses methods to generate the geometry of and information about the product. This geometry is based on input that is provided by the model user or an optimiser. This input comes in the form of a text file in which the data for model generation is stored. The MMG itself generates input data for the analyses that are performed by the different discipline silos. These silo's can contain for example structural analysis, aerodynamic analysis and tooling design. In this project the main focus is on tooling design. Rubber forming moulds for ribs of aircraft movables will be generated using the information generated by the multi model generator. These rib moulds will be used in the thermoplastic General Aviation (GA) rudder project of the TU Delft [5].

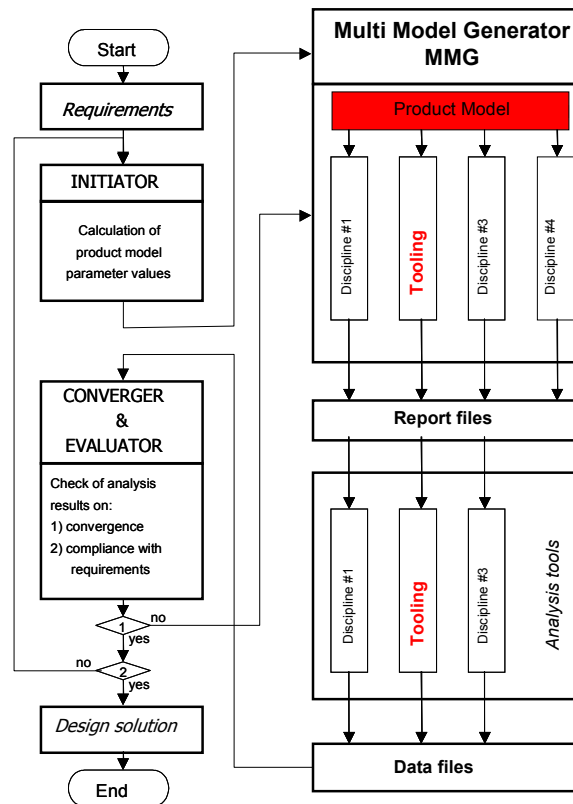


Figure 1 DEE focussing on the tooling discipline silo

In the thermoplastic rudder project a GA rudder is under development. The design will be based on thermoplastic composites and incorporates several ribs. These ribs all have approximately the same shape and will be manufactured using the rubber forming manufacturing technique[6].

The general principle of rubber forming is that a thermoplastic laminate is heated until a certain temperature is reached. This must always lay considerably higher than the glass transition or melt temperature of the thermoplastic. Once the temperature is reached, the laminate is being transported to a press, where the hot, and therefore mouldable laminate is formed between a rubber mould on one side and a hot metal die on the other side. The blanks that are used are plates build up from carbon fibre fabric and thermoplastic resin. The rubber used in the process is usually a silicone rubber that can resist the heat, approximately 200° C encountered during the process.

For this process moulds are needed. Because all ribs have approximately the same shape and are produced using the same production process, the mould geometry will also be approximately the same. Therefore a parametric knowledge based design tool that can create all these moulds will be very useful. This design tool will automate the mould design process and will generate the moulds using input parameters and the MMG of the movable DEE[7], which has already been partly developed. This movable model uses methods to not only generate the geometry of a movable but also to generate information about this movable that can for instance be used in generating a rib mould.

By automating the design process of the rib moulds the design lead-time and thereby the design cost will be reduced. This is especially useful when there are design changes, because these changes will automatically update the designs of the different moulds. On the other hand the mould shape can be determined early on in the project. Cost of the mould and difficulties with the mould are known at an early stage in the design process. In this way the manufacturability of the design can be monitored and design changes, when necessary, can be made at an early stage in the design process.

2. THE MOVABLE ICAD MODEL

The rib moulds that will be generated are based on the geometry of a movable. A movable is an aircraft part that can be moved in flight of the aircraft to disturb the airflow around the aircraft. Movable parts are for example, the elevator, the rudder, ailerons, flaps etc. The movable MMG creates this geometry and also information about the movable. This information consists of information about the structure, such as the thickness of certain parts, and also other information about for example the loads acting on the movable. The MMG is built using the ICAD software package. The ICAD system is a knowledge based engineering tool produced by Dassault Systèmes. The MMG creates a model, in this case of a movable, using methods stored in the model and input provided in a text file by the user. The movable model works in such a way that an outer shape and an inner structure of any movable can be built up by the model. The movable in the model consists of:

- The wing box
 - Outer skins
 - Spars
 - Ribs
- The leading edge
 - Outer skin
 - Nose ribs
- The trailing edge
 - Outer skin
 - Trailing edge ribs
- The end caps
 - Outer skins
 - Sparlets
- Hinges

How the outer shape surfaces and internal structure are created is described in [7]. An example of a movable created by the movable model can be seen in Figure 2, this is a model of the rudder of a GA composite aircraft. For the creation of the rib moulds only the ribs from the wing box are used. However with a few adjustments the rib mould module that is going to be developed can also be used for other parts of the movable model such as the spar.

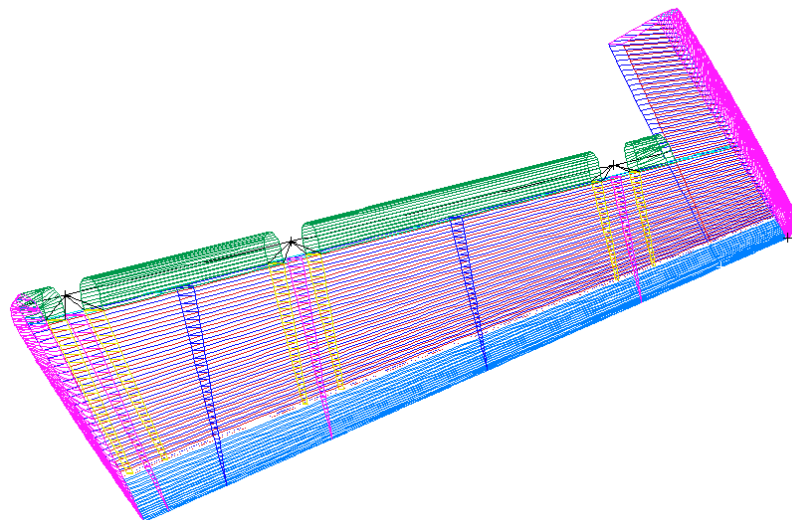


Figure 2 GA aircraft rudder built by movable model

3. CAPTURING AND FORMALIZING THE RIB MOULD KNOWLEDGE

To create a mould creation tool the knowledge of creating such a mould has to be captured in a computer tool. This can be done using Knowledge Based Engineering (KBE) methodologies [8]. The KBE process consists of several steps that cover the complete life cycle of the KBE application. This life cycle can be seen in Figure 3. Start point is identifying the possibility and justifying the need for a KBE application. The next step is capturing the knowledge available. In this case capturing the knowledge available about a thermoplastic composite rubber forming rib mould. Once the knowledge has been captured the knowledge has to be filtered and translated into a model on which the actual KBE application is based, this step is called formalizing. Next step is building the actual KBE application by using specialist software for instance ICAD, this step is called packaging. Once the application has been written it has to be put to use in the activation stage of the life cycle. Finally, new issues are identified and the KBE application must be updated, closing the KBE application life cycle.

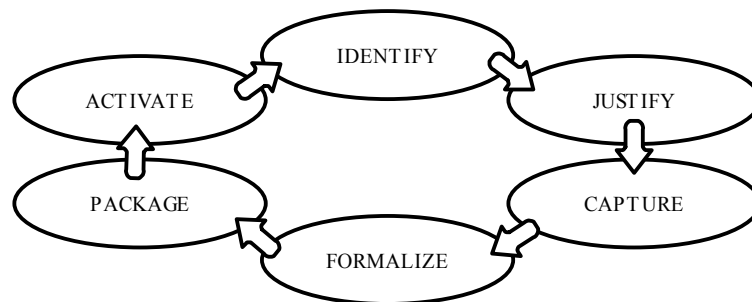


Figure 3 KBE application life cycle[8]

In this paper 3 steps of the KBE application life cycle will be described: capture, formalize and package. With these three methodologies the knowledge available is transformed in a tool that can be used by people not having knowledge about moulds in general and more specifically rib moulds.

First of all the knowledge about rib moulds has to be captured. This knowledge consists of:

- Functional knowledge, what should the mould do.
- Product shape knowledge, what it should look like.
- Process knowledge, in what process will the mould be used.
- Mould technology, what materials are going to be used and how is the mould going to be manufactured.
- Communicational knowledge, how is the information about the mould communicated between the different actors involved.

The knowledge about these items is available or has to be developed. When it is available it is usually not stored in a format that can be easily used for formalizing the knowledge. Therefore a translation of the knowledge has to be made into rules that can be used for the formalizing process. The knowledge and translations used for the formalization process of the rib mould structural model can be seen in Table 1. This table is not complete; it only shows the knowledge that is used for the product model rib mould tool.

Table 1 Knowledge and translation of the knowledge

| Knowledge | Translation |
|---|---|
| Rib mould shape should be based on the outer mould line of the complete movable minus the material thickness of for instance skin and flanges. | As a basis for the rib mould a shape resembling the outer mould line of the movable should be used. The user of the tool can determine offsets from this outer mould line. |
| To ensure that the rubber mould will not tear during forming, sharp edges have to be avoided. Radii of the rounds depend on the rubber properties. | All sharp edges that are in contact with the rubber should be rounded with a radius determined by the tool user. |
| The forming can be either positive or negative. The difference lies in the choice of which mould should be the rubber one and which the metal one. | Tool should have the possibility to create negative and positive moulds. |
| Rib mould has to be fitted to the rubber press using bolts, position of these bolts depends on the rubber press used. | In the rib tool the holes that have to be created can be placed using inputs at arbitrary place with an arbitrary diameter. |
| The blank must be positioned with respect to the mould. Current technology is using pins to position the blank. These pins are circular but have steps in the diameter. | In the rib tool the holes that have to be created can be placed at arbitrary place. A hole can have height steps with different arbitrary diameters at arbitrary positions. |

Now that the knowledge is captured it has to be formalized meaning that the knowledge from the capture stage is used to create product models and process models. These product model are created using Moka Modelling Language (MML)[8], which is an object oriented modelling language that uses the Unified Modelling Language (UML)[9] graphical representation to represent its models. Because the output of the tool has to be a rib mould, the most important model is the structural view of the MML model of this rib mould. In this view all features that have to be incorporated in the physical rib mould tool are represented and also the methods, which are the result of the implemented knowledge, are shown. The structural view of the MML model of the rib mould can be seen in Figure 4. In this view all structural items of the rib mould are represented.

In the figure each structural element has three items. Top item is the name of the structural feature. In the middle item the input parameters that are used for seizing the structural element are shown. The lower item contains the methods stored in the structural element that generate parameters for other structural elements that depend on it. On top of each structural element the possible number of the specific structural element in the rib mould is shown. A diamond representing a constraint is also incorporated in the model, at this constraint a critical decision about the mould is made. All these elements together form the MML structural view of the rib mould.

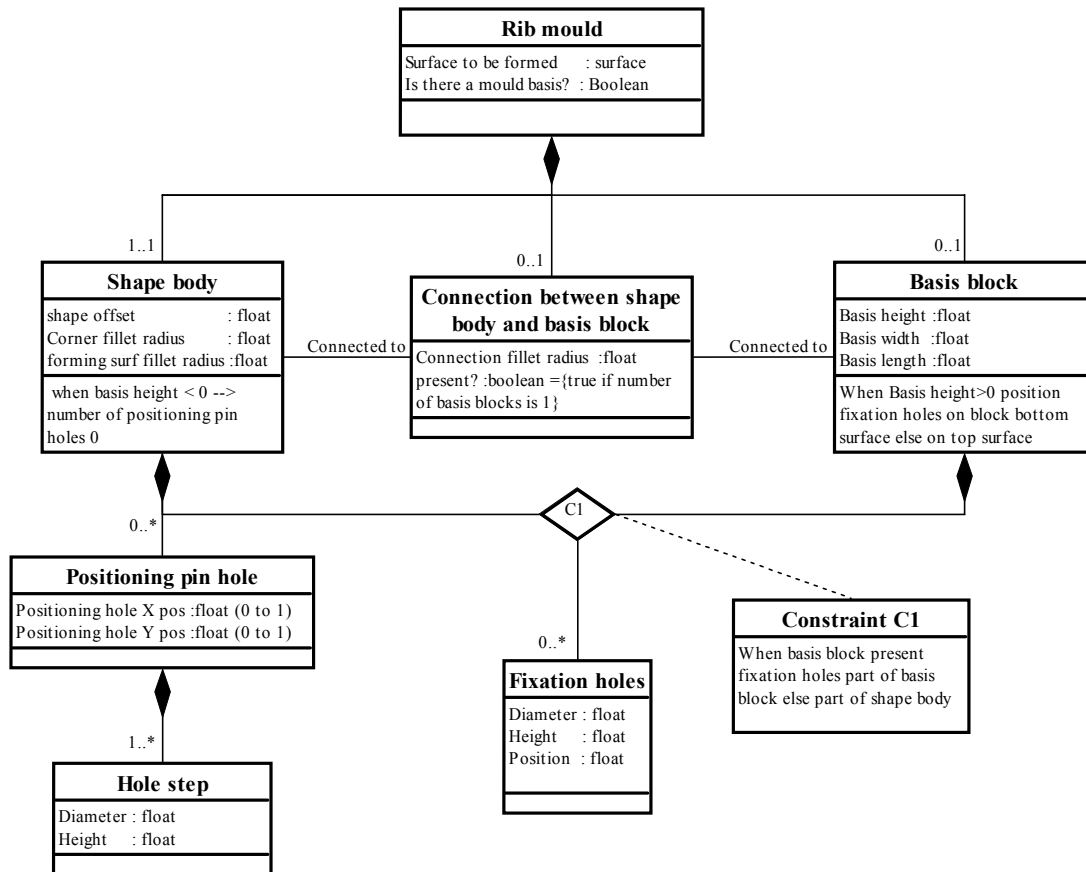


Figure 4 Rib mould MML structural view

4. PACKAGING THE KNOWLEDGE INTO THE RIB MOULD ICAD MODULE

The formal model must now be packaged; this will be done using ICAD KBE software. With the ICAD software all information and methods of the formal model can be packaged into a rib mould tool that will enable designers to create rubber-forming moulds for thermoplastic composite ribs. The rib mould model will be modeled using surfaces; when using surfaces, features can be used to model negative or positive moulds. The surfaces generated by the tool will form the outside shape of the mould.

From the movable model, discussed earlier, the rib mould tool uses the surfaces that represent the ribs in this model. The rib mould that is created by the tool will be based on this surface. The rib tool also needs other inputs; these inputs are stored in a text file, a piece of which can be seen in Figure 5.

The rib mould tool is based on the MML structural view as can be seen in Figure 4. Therefore it consists of 3 basic elements and 2 elements that can be added to the basic elements. The 3 basic elements are:

- Shape body
- Basis block
- Shape-basis connection fillet

The 2 elements that can be added are:

- Fixation pin
- Positioning pin

These elements and their positions can also be seen in Figure 6.

```

:optional-inputs
(
  ;;general inputs:
  :trunc-nr          1
  :rib-nr           5
  :offset-distance  2.4
  :extrude-distance 40
  :top-fillet-radius 2
  :basis-fillet-radius 3
  :side-fillet-radius 4
  :invert-extrude-direction? 'nil
  :basis?           'nil
  ;;inputs used for basis box:
  :basis-height     100
  :basis-length     400
  :basis-width      70
  ;;pin inputs:
  :pin-offset-vert-list (list 0.0 0.0 0.05 -0.05)
  :pin-offset-hor-list  (list 0.4 0.0 -0.4 -0.4 )
  :pin-radius           (list 3 4 5 )
  :pin-other-radius-height (list 30 10 )
)

```

Figure 5 Part of rib mould input file

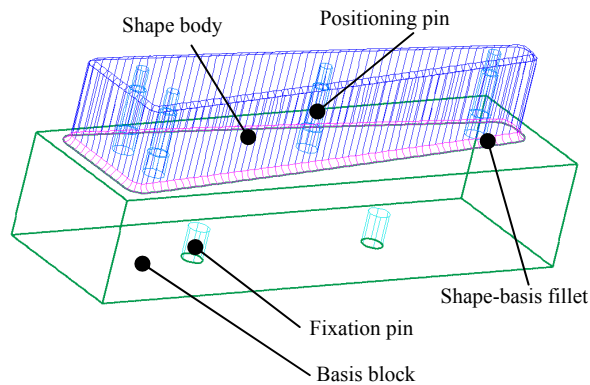


Figure 6 Rib mould features

Shape body

The shape body is the part of the rib mould that determines the shape of the rib that is going to be produced by the mould. It consists of several surfaces. The first of which is the top surface, which determines the shape of the rib. This surface is created by using the rib surface from the movable model and offsetting it. The user determines how large this offset should be. The offset depth is dependent on the material thickness of the rib that has to be produced, whether the mould is negative or positive and the material thickness of other production elements between the rib and the outer mould surface of the movable. Finally holes are made in the surface to accommodate the positioning pins. The diameters of these holes are dependent on the diameters of the positioning pins.

The top surface is connected to another surface that determines the height of the rib mould. The connection is done via a fillet. This is necessary because the rubber counter mould would otherwise tear in at the corners. The radius of this fillet has to be determined by the user via the input file. The minimum radius is dependent on the properties of the rubber.

The surface that determines the depth of the shape body is an extrusion of the top surface without the fillet. The extrude direction is perpendicular to the top surface; this means the flanges of the rib that is pressed are also going to be perpendicular to the top surface. The dept of the surface is determined by a user input. This depth determines the maximum length of the flanges that can be pressed.

The final surface of the shape body is the optional lower surface. This surface only exists when there is no basis block and closes the shape body when needed. Its shape is determined by the end contour of the extruded depth surface. Holes to accommodate the fixation and positioning pins are added to this surface when necessary.

Basis block

The basis block is a rectangular block that is sometimes needed for fixation of the rib mould in the rubber press. It consists of 6 surfaces that form a rectangular box. The dimensions of this box are determined by inputs provided by the user. For the length and width this can be done in 2 ways, first by just inputting an absolute value for the width or length of the basis block, second by inputting a width or length that should be added to the width or length of the shape body. The rib mould module checks if the absolute length and width make it fit to the shape body. When this is not the case the added lengths are used. Finally holes are added to make sure the basis block fits to the shape-basis connection fillet and can accommodate the fixation pins.

The basis block can also be used to define a negative mould; this is done by specifying a negative height. Positions of fixation pins will be adjusted automatically and positioning pins will also be removed from the shape body automatically.

Shape-basis connection fillet

The shape body and basis block have to be connected via a fillet. This is especially necessary when a negative mould is created. In case of a negative mould the fillet “guides” the rubber into the cavity in which the product is formed and prevents tearing of the rubber.

The shape-basis connection fillet is a fillet that runs from the extruded surface of the shape body to the top surface of the basis block. The only input that is needed is the fillet radius. The minimum radius is dependent on the mould geometry and the type of rubber that is used. The user therefore determines the fillet radius via the input file.

Fixation pin

The fixation pin is needed to fixate the mould to the rubber press. In the model it consists of a cylindrical cutout. The distance between the fixation pins is fixed; its position is after all determined by the fixation supports of the rubber press. Therefore the inputs determining the position of the fixation pin in the basis block or shape body are absolute values. The base point for the positioning of the fixation pins is the middle point of the rib mould. From this point the fixation pins are positioned based on inputs provided by the user via the input file. The user also determines radius and height of the fixation pin via the input file. The fixation pin is positioned in the basis block or shape body, depending on whether or not the basis block is present.

Positioning pin

The positioning pins are cavities in the mould that provide room for pins that position the blank on top of the mould. The base point for the positioning of these pins is again the mid point of the rib. Because the position of the pins in the mould is not influenced by external factors, the positioning inputs are relative to the shape body length. In this way the same relative distribution of positioning pins can be achieved even when the size of the mould has changed. The user provides the positioning values via the input file.

The positioning pins can have different complex geometries. However within one mould the geometry of the pins is the same. The geometry usually represents several cylindrical parts with different diameters. The pin runs from the bottom to top of the shape body. In the model the holes are represented by several cylindrical parts, the number of which depends on the input in the input file. For all the cylindrical parts the radius has to be provided through the input file. Another input that is needed is the position of the height steps, meaning when one cylindrical part ends and another one starts. This position is also provided via the input file.

The five different elements are combined to form the rib mould. In ICAD they are represented graphically, as can be seen in Figure 6, and also in a text form. In this text form the tree build up of the model, which is the result of the object-oriented nature of ICAD, can be seen. An example of this tree is shown in Figure 7. This tree is useful in identifying the relations between the different parts and also shows the multiple instantiation, and thus reuse, of several parts, such as the positioning and fixation pins.

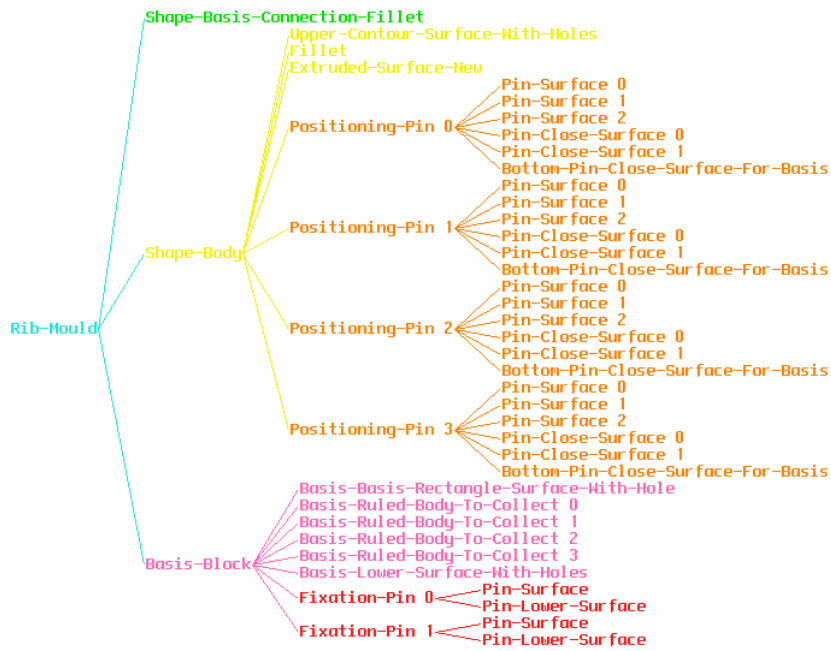


Figure 7 ICAD product tree of the rib mould

5. RESULTING RIB MOULDS

With the ICAD rib tool several rib moulds for the thermoplastic GA rudder project where designed. The rib tool generated the designs and little post processing work was needed to create technical drawings of the design that could be used by the workshop to manufacture the moulds. The family of rib moulds created for the Eaglet rudder project can be seen in Figure 8.

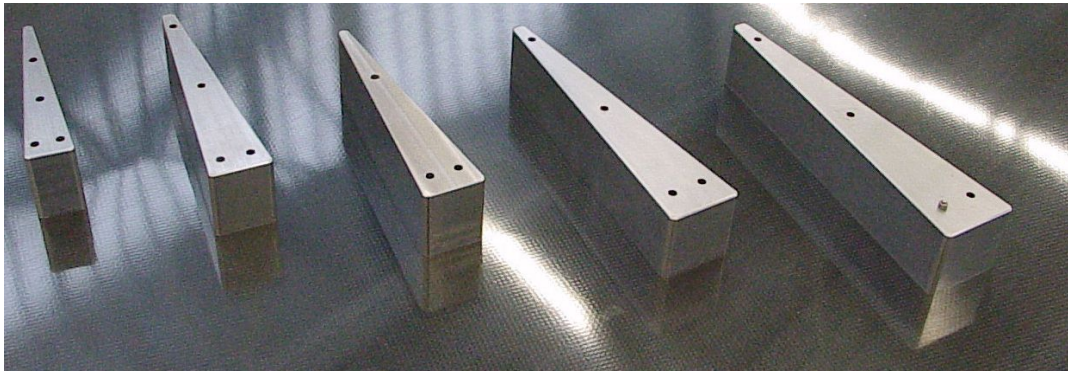


Figure 8 Mould family produced using rib mould tool

For future projects the rib tool can be used for different configuration rib moulds: positive moulds with or without a basis and negative moulds. Examples of all of these kinds of moulds can be seen in Figure 9.

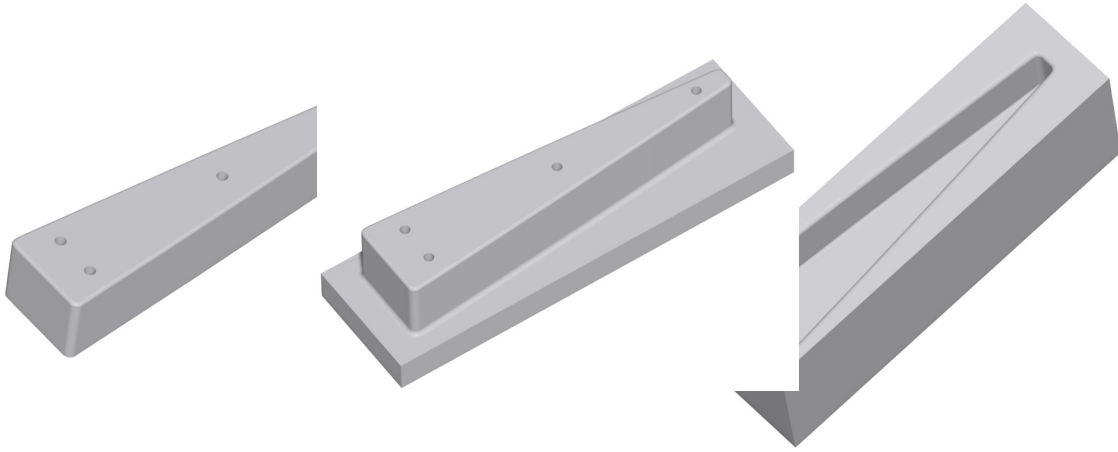


Figure 9 Examples of rib moulds created with the rib mould tool

6. CONCLUSIONS AND FUTURE WORK

A rib mould tool has been developed using ICAD KBE software. This tool can be used to quickly generate rib moulds that can be used in the thermoplastic rubber-forming process. Generation of a rib mould based on a surface from the movable model takes approximately 2 minutes, which is significantly faster than doing the work by hand.

The product knowledge about the rib mould has been stored in the rib tool, especially in the area of rib geometry, which is completely defined by the rib tool. In other areas user knowledge is still needed, for example in the area of placement of the fixation and positioning holes. However in future the model could be adjusted to contain even more knowledge:

- Placement of positioning holes based on material type and material thickness.
- Geometry of the positioning holes stored in a library.
- Position of the fixation pins for different presses stored in a library.

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