DESIGN OF PROPELLER BLOCKS
By
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This article describes creating a propeller block model in SolidWorks. If you have other CAD software - basic ideas should apply, but realization of some details might be different. Sizing of a block is covered in Part 1. Study of helical, non-helical, and cambered surfaces is discussed in Part 2. Generating solid blocks is shown in Part 3.

1: Sizing of a propeller block

First, we need to determine the planform dimensions of a required block. For example, let's create a block for 460x600 propeller with 180mm long and 60mm wide blade. If we need extra 10mm around the blade perimeter, than required block should be 200x80, see Fig. 1. Notice that 40mm and 240mm dimensions are gray. It means that they are driven - defined by propeller radius and blade length. While the blade itself is located between radii R50 and R230, the block will be from R40 to R240.
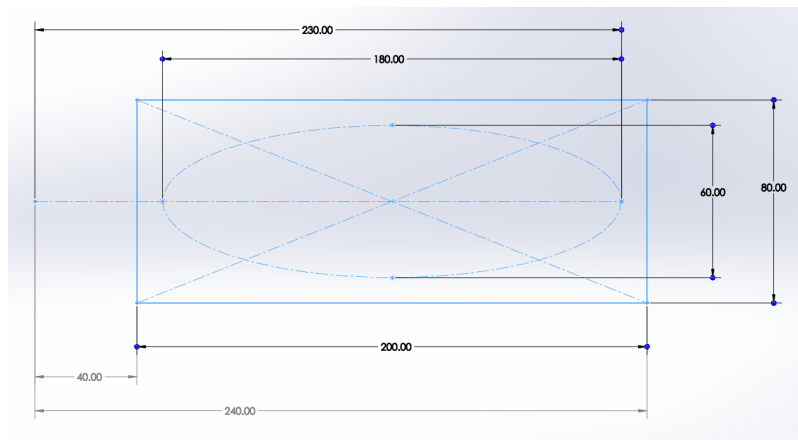

Figure 1: Blade planform.

2: Helical and non-helical surfaces

2.1: Helical surface (Helicoid)
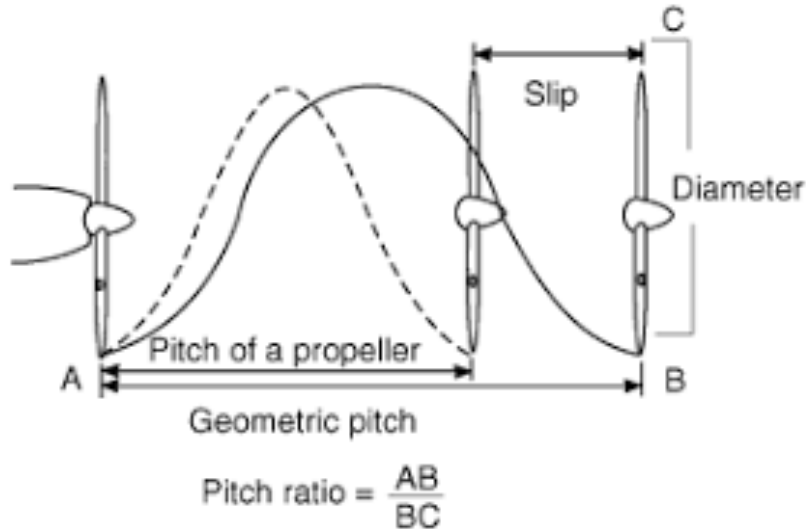Pitch is a distance that a propeller would travel in solid media in one turn, see Fig. 2.

Figure 2: Definition of geometric pitch.
[http://www.pilotfriend.com/training/flight_training/fxd_wing/props.htm]

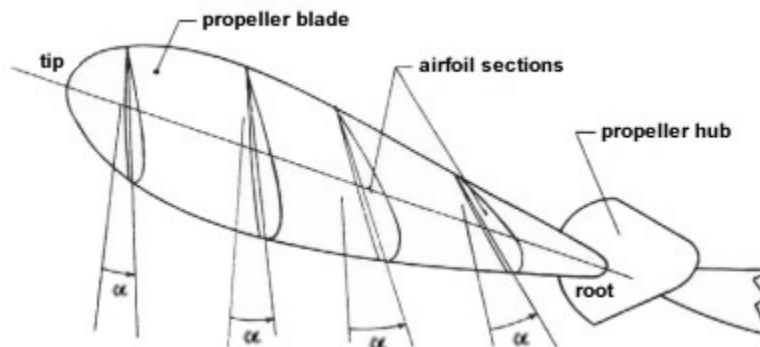To have a constant pitch along the blade, installation angle should gradually decrease, see Fig. 3.

Figure 3: Installation angle along the blade.
[http://www.pilotfriend.com/training/flight_training/fxd_wing/props.htm]

For a given pitch H, installation angle at radius R can be found as

$$\alpha = atan\left(\frac{H}{2\pi R}\right) \qquad\qquad (1)$$

Equation (1) is used by modelers to create solid propeller blocks. Instructions for a classical hand-carved block have been published many times through the years, see examples in Figs. 4 and 5.

FOR FREQUENTLY USED 2:1 PITCH-DIAMETER RATIO PROPELLERS:

DIAMETER"	RADIUS"	HEIGHT"	WIDTH"	PITCH"
15	7 1/2	1 1/2	2 23/64	30
16	8	1 1/2	2 23/64	32
17	8 1/2	2.75	4.3	34 *
18	9	2.75	4.3	36 *
19	9 1/2	2.75	4.3	38 *
20	10	2.75	4.3	40 *

1.75:1 PITCH - DIAMETER RATIO

15	7 1/2	1 1/2	2 45/64	26 1/4
16	8	1 1/2	2 45/64	28
17	8 1/2	1 1/2	2 45/64	29 3/4
18	9	1 1/2	2 45/64	31 1/2
19	9 1/2	1 1/2	2 45/64	33 1/4
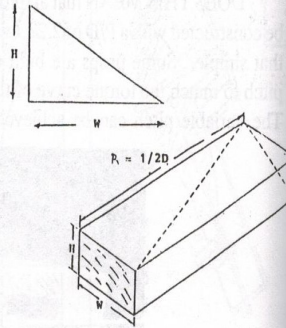
On a correctly carved pitch block, a straight line can be projected on the helical surface from the midpoint at the hub to the midpoint at the tip. During carving, check for straightness by laying a straight edge on the helical surface between these two midpoints. **A circular airfoil** or under camber can be molded into the blades, about 5%, by the lamination procedure described later for making E.Z.B. prop blades, or by carving it into the prop block form.

Figure 4: Design of a propeller block.

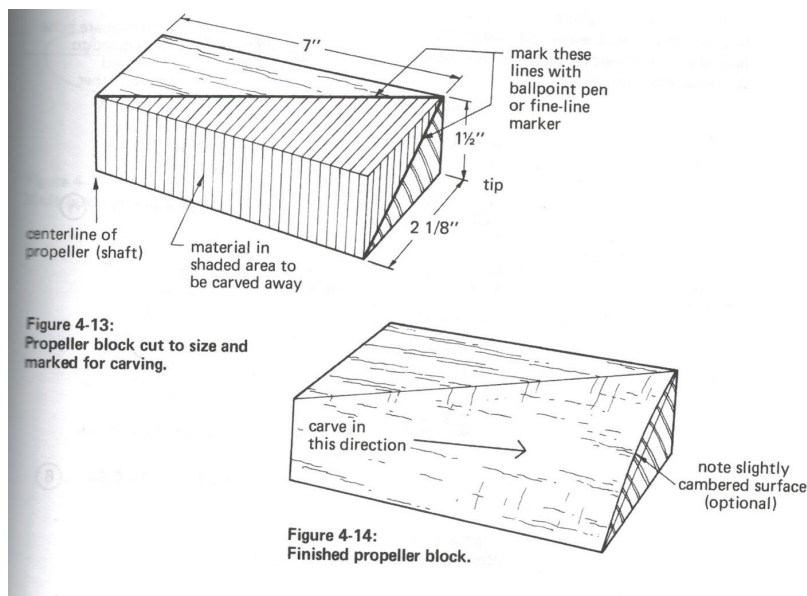Adopted from "Indoor flying models" by Lew Gitlow.

Figure 5: Hand-carved block.
Adopted from "Building and flying of indoor model airplanes" by Ron Williams.

Despite being standard way to cut a propeller block, method shown in Figs. 4 and 5 has several fundamental flaws.

First, true helicoid is a ruled surface. It is formed by simultaneous rotation and transition of a line along and around axis. This means that helicoid is flat only along axis and along ruling line, but never in a chordwise direction, see Fig. 6.
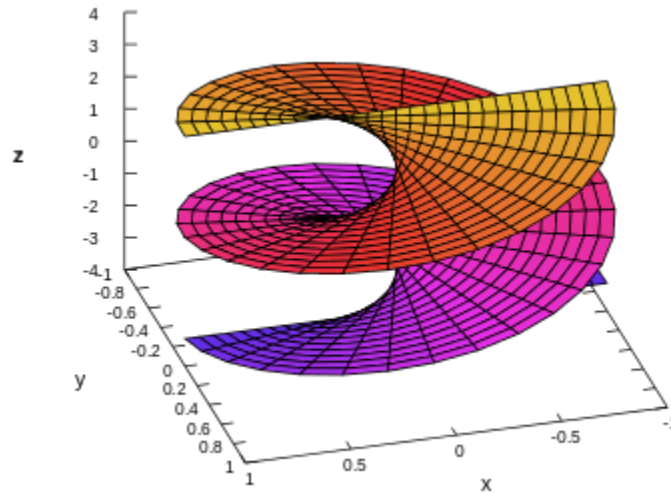
Figure 6: Helicoid.
https://en.wikipedia.org/wiki/Helicoid

If block is cut to provide straight lines along chords - at best it can only be tangent to the true helicoid. In general case it would have close, still not completely correct surface.

Second, rectangular shape of a block introduces another distortion. If desired angle at the end of a block if measured on a flat face, then actual installation angles will be higher, see Fig. 7. This error propagates along the block and reaches a maximum at the end. The wider the block, the larger the error. This deviation can be fixed if desired angle at the tip is measured not on the flat end of a block, but on rounded face, see Fig. 8.
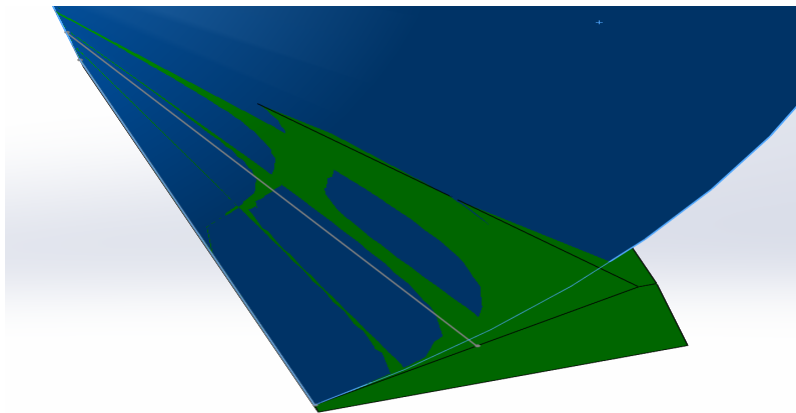
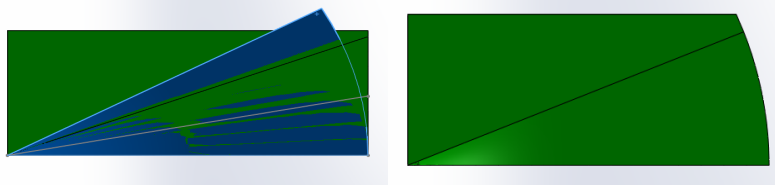Figure 7: Deviation of a block surface from true helicoid.

Figure 8: Cutting the block end for proper angle.

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Finally, another distortion is introduced by using bottom edge of a block as a reference to define angle at the end. Reminder, this bottom edge would be a ruler, line forming the helix. Thus, built from this line would be a tangent to the true helicoid. If tangent line in on the bottom of a block, then the whole surface, including blade axis line, will be off from true helicoid. This distortion can be fixed by defining the end angle around blade axis, i.e. in the middle of end face.

2.2: Helical lofted surface

CAD software allows complete control over propeller block geometry: all the deviations can be removed, non-helical twist can be used, custom varied camber can be added. All these features would allow to retire old technology and to build proper shaped propeller blocks instead.

Loft is a smooth surface formed by a set of cross sections. Guide curves and tangency controls can be applied to achieve desired smoothness and proper transition between consecutive sections.

It might appear that this definition would require only two sections to form a proper propeller surface. First, use the root section, then use the tip one. CAD software, however, if not used properly, can produce incorrect surface.

Let's build a lofted surface in SolidWorks and find how many elements are really needed to define it. Fig. 9 shows required elements - two planes at R40 and R240 that carry sketches with chord lines. Each chord line is symmetrical with respect to a propeller axis. Angle between each line and horizontal plane is calculated with equation [1] for 460x600 propeller example. Note that model also has a 3D sketch with blade axis line.
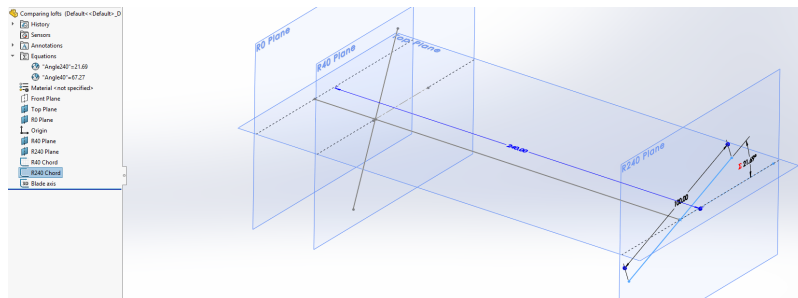

Figure 9: Defining loft surface with two cross-sections.

Once all the auxiliary geometry is defined, lofted surface can be created with "Surface-Loft" command. Here blade axis is used as a guide - meaning that surface is forced to follow this line, see Fig. 10.
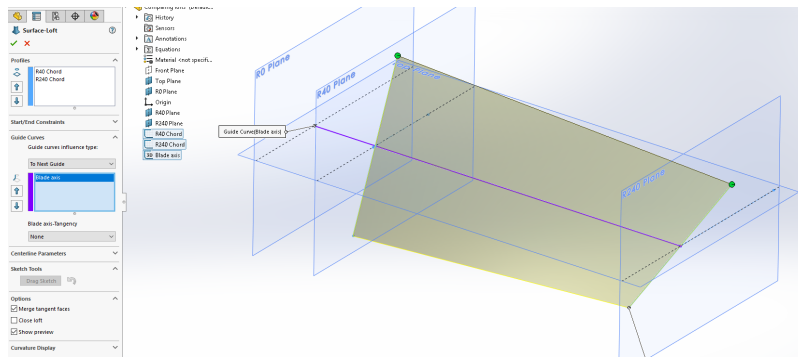
Figure 10: Two-sections loft.

Using blade axis as a guide is quite important here. It guarantees that propeller block will have straight line along the spar.

Here is an example of a surface produced without guide curve and for asymmetrical chord at R40. Blade axis is not straight in this case, see Fig. 11.
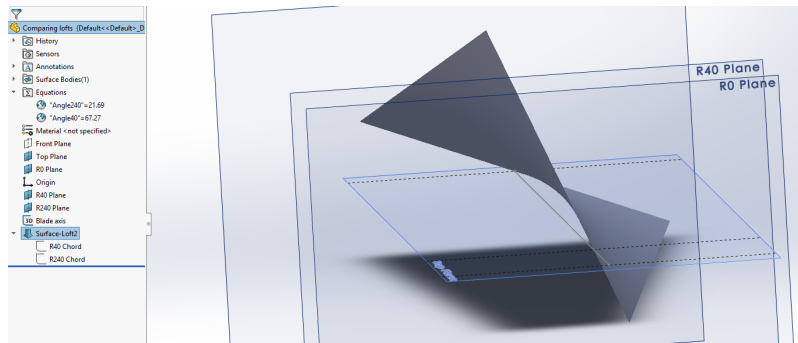

Figure 11: Loft surface without center guide.

Now let's see if generated surface is a true helicoid. First let's add another section in the middle of a blade. For H=600 at R=140 installation angle is $\alpha = 34.29$. Fig. 12 shows that loft surface built only with two sections is not following surface of a helicoid.
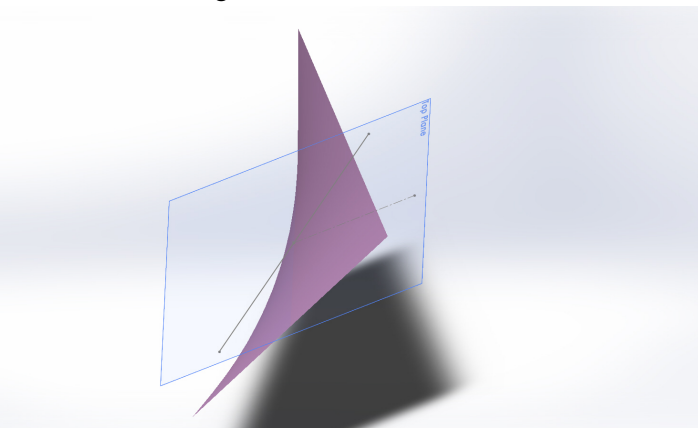
Figure 12: Deviation of two-section loft from required angle distribution.

In Fig. 13 two-section loft is overlapped with true 460x600 helicoid. Center line, root, and tip sections are forced to have follow helicoid, but middle region of a lofted surface deviates from required twist.
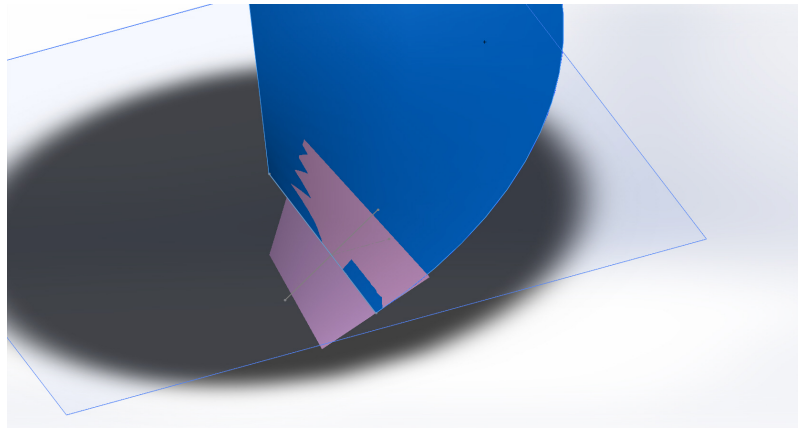
Figure 13: Two-section loft and true helicoid.

Let's now add the R140 section into the loft definition, see Fig. 14. Adding third section brought lofted surface closer to helicoid.
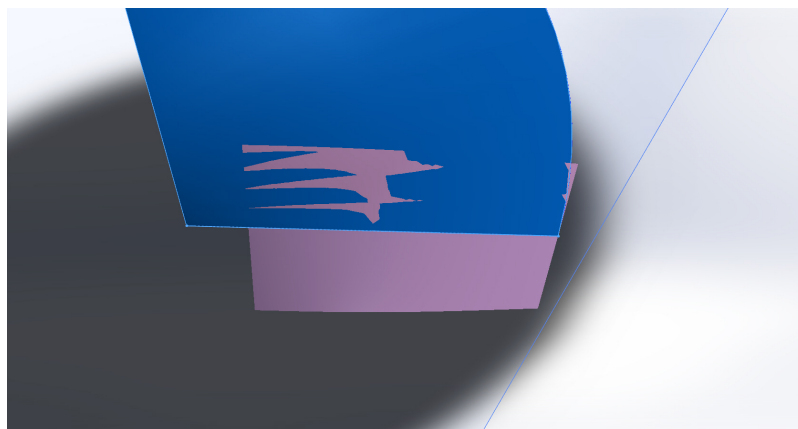

Figure 14: Three section loft and true helicoid.

Adding fourth section would improve loft even further, see Fig. 15. Note that loft is formed with straight sections (chord lines). At the same time section view of a helicoid is a sinusoid. Thus, any loft formed with straight sections will always be only a tangent to the true helicoid, see Fig. 16.
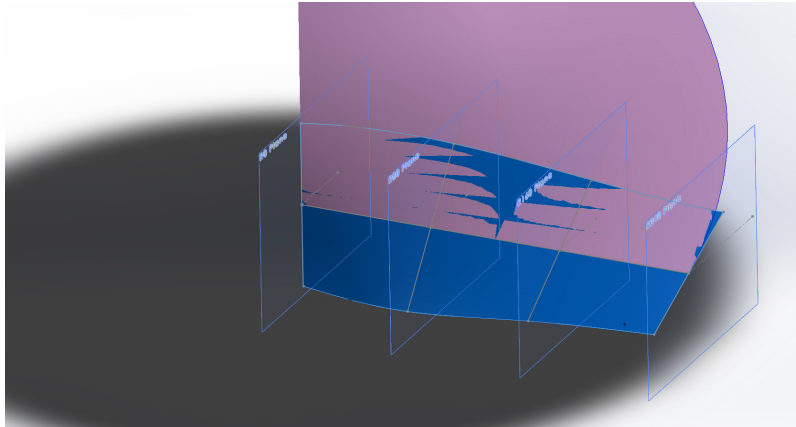
Figure 15: Four-section loft and true helicoid.

Figure 16: Cross section of a helicoid.

2.3: Non-helical lofted surface

Using lofted surfaces instead of helicoids might seem as overcomplication. It becomes justified when block with non-helical pitch is needed. Perfect example here would be the propeller designed by Ivan Treger, see Fig. 17.
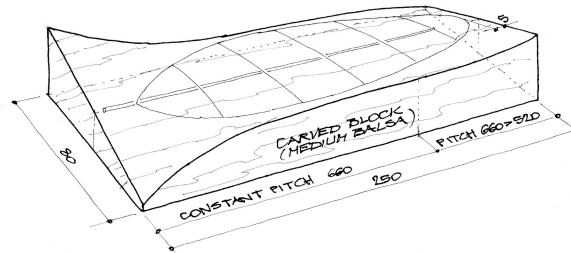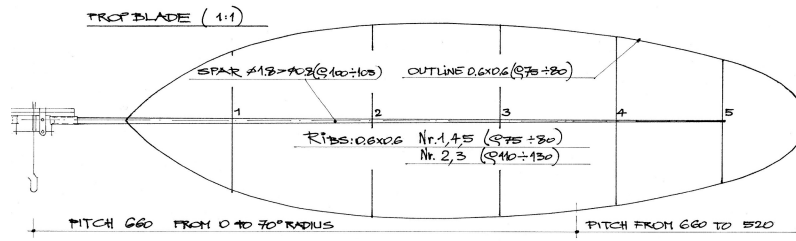
Figure 17: Ivan Treger's F1D propeller.
[https://thef1dblog.files.wordpress.com/2012/08/treger-2010-plan-img008.jpg]

Proper modelling of this block would require at least four cross section for constant pitch portion of a blade and another four for the tip portion with varied pitch. Fig. 18 shows an example of a block with eleven forming cross sections.
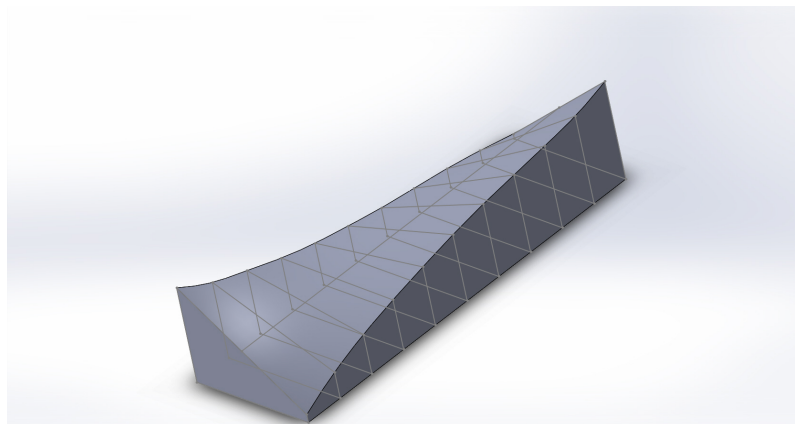
Figure 18: Propeller block example with varied pitch.

2.4: Lofted and cambered surfaces

Lofted surface with desired pitch distribution can be easily modified to have camber. Camber is added in each cross section, see Fig. 15. Note that in this example camber is defined as section of an arc with chord and sagitta. Loft forming sections can be airfoils as well. In any case, all of the sections in the loft must have one fixed point. A guide line will go through these fixed point to ensure that block is flat were blade spar will be placed, see Fig. 19.
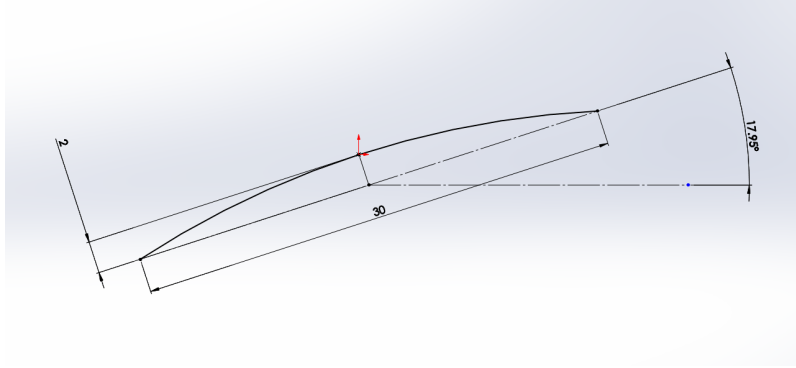
Figure 19: Forming section of a cambered surface.
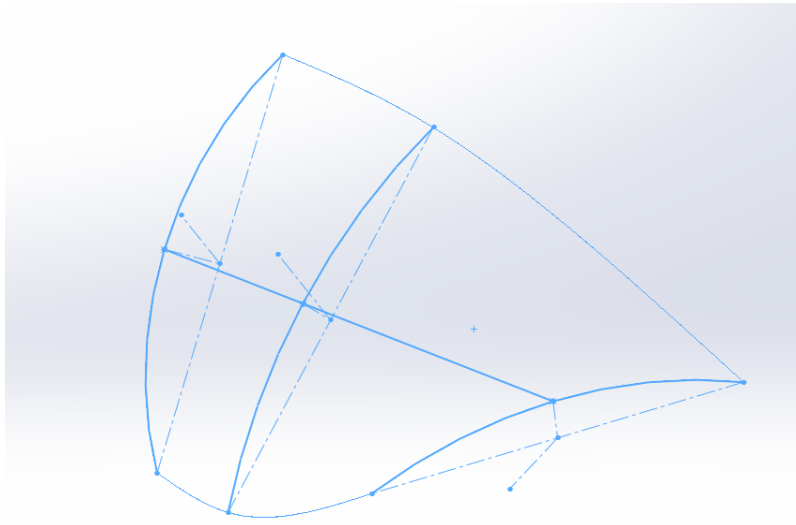
Figure 20: Elements of a cambered loft.

Block for a flaring propeller would require slight modification in each section, see Fig. 21. Here there is still one fixed point on the arc in each cross section. Arc can slide along this fixed point to define offset of a section with respect to blade axis. To show another way to define arc airfoil, radius of curvature is used instead of sagitta.
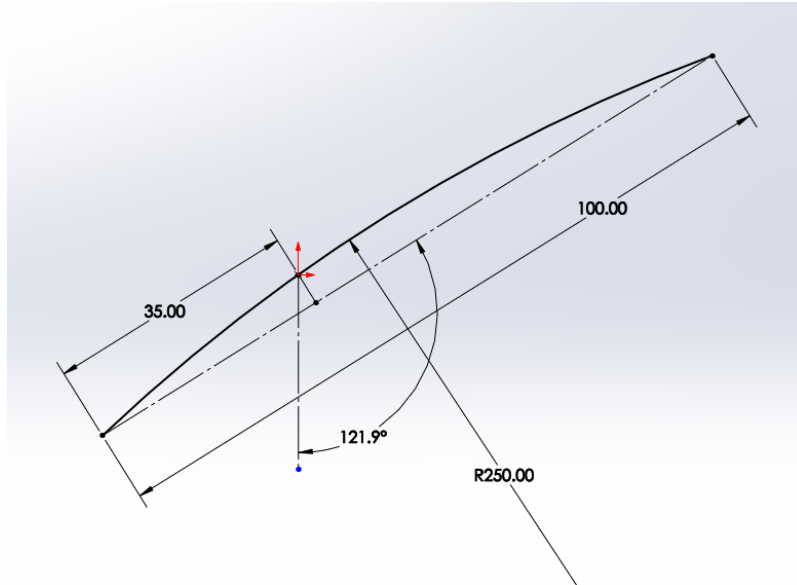
Figure 21: Elements of a cambered loft.

3: Propeller block

Once block dimensions are defined and propeller surface is generated, a solid extrusion (boss) can be produced. This boss can be either extruded up to the blade surface or extruded past the surface and then cut by it, see Fig. 22.
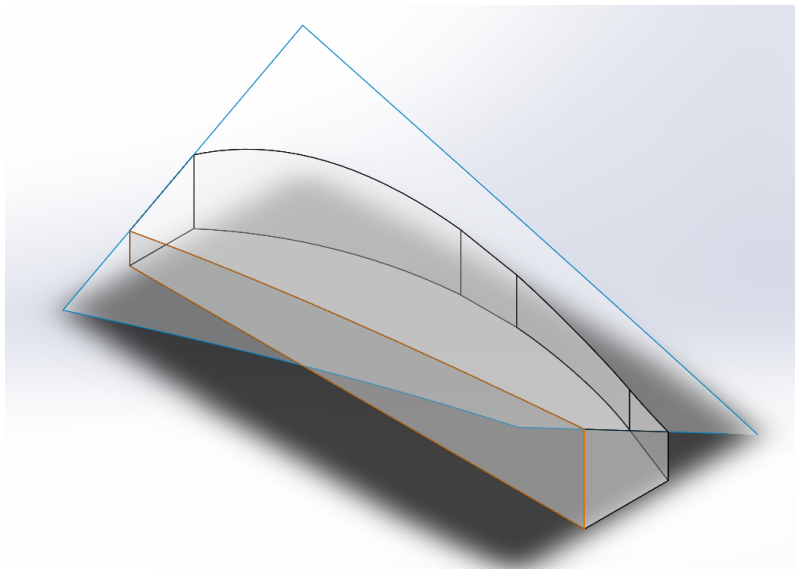
Figure 22: Block extruded up to blade surface.

Modern CAD software allow parametric modelling. Let's use this feature and create a template that can be used for many different blocks.
We start with generating of array of parallel planes along the blade axis. Each plane is defined by variable "RadiusX", see Fig. 23.
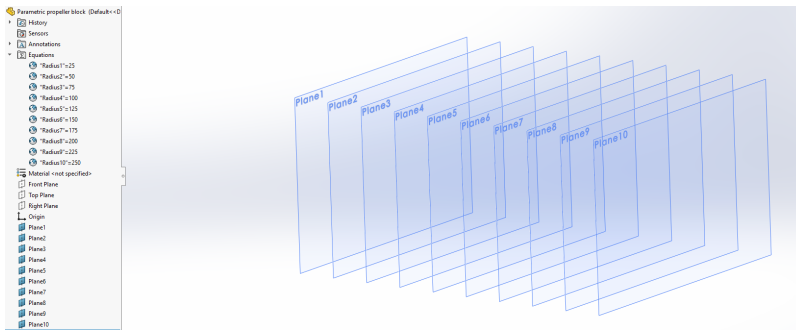
Figure 23: Array of planes.

A cross section sketch is inserted in each plane, see Fig. 24. Here each section is defined as an arc with "Angle" and "Sagitta" as parameters. For no-camber blocks all of the sagittas should be set to a very small, but non-zero value.
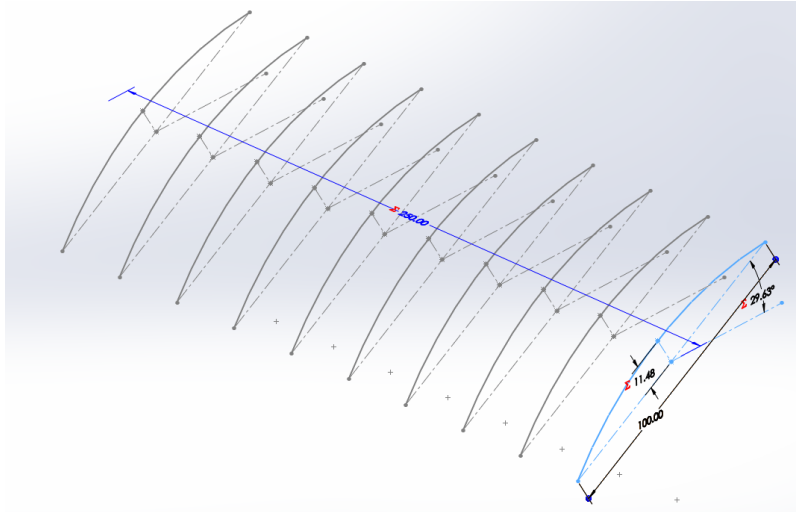
Figure 24: Parametric cross-sections.

Then, blade axis is added as line between origin and fixed point of the last section, see Fig. 25. This would allow it to adjust automatically when template is being modified to a custom block.
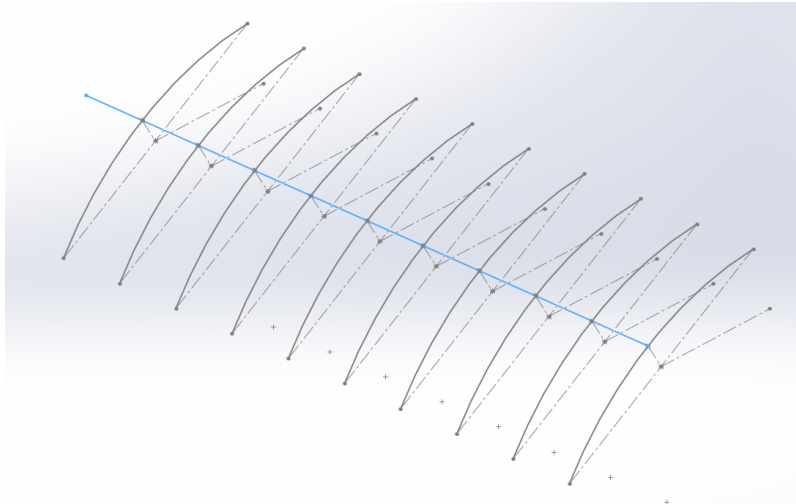
Figure 25: Blade axis sketch.

The next step is to generate a lofted surface of the future propeller block, see Fig. 26. This surface is not a solid body yet, rather just a boundary. Note that blade axis is used as a guide curve. At least two profiles are required for a loft, see Chapter 2.2.
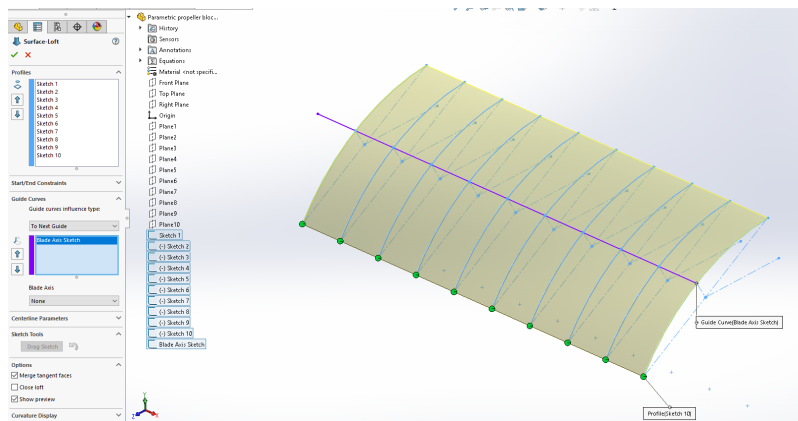
Figure 26: Generating loft.

Now a plane can be added under the surface. This plane will carry a sketch with block planform on it, see Chapter 1. A planform sketch can actually be added above the surface as well - if negative block or a mold is needed, see Fig. 27.
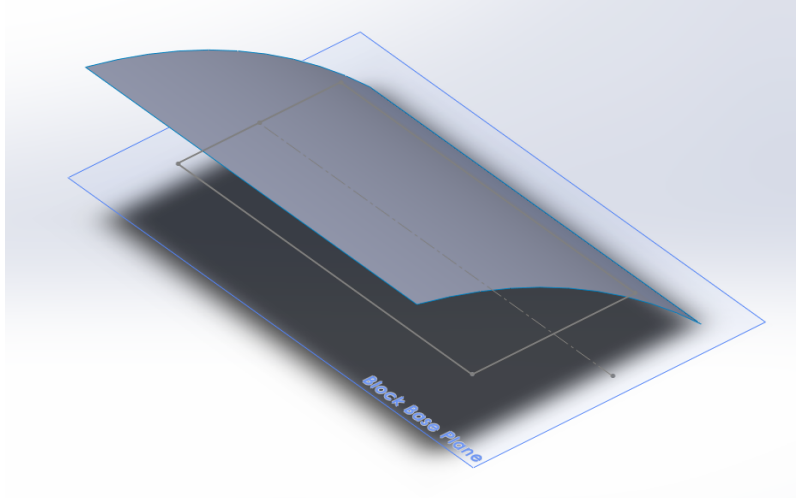
Figure 27: Planform sketch.

Finally, a solid propeller block can be extruded from planform sketch up to the lofted surface, see Figs. 28-29.
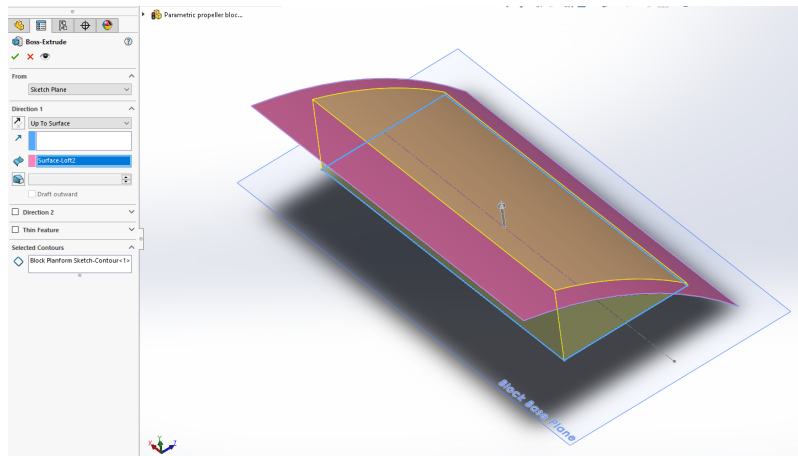
Figure 28: Forming solid propeller block.
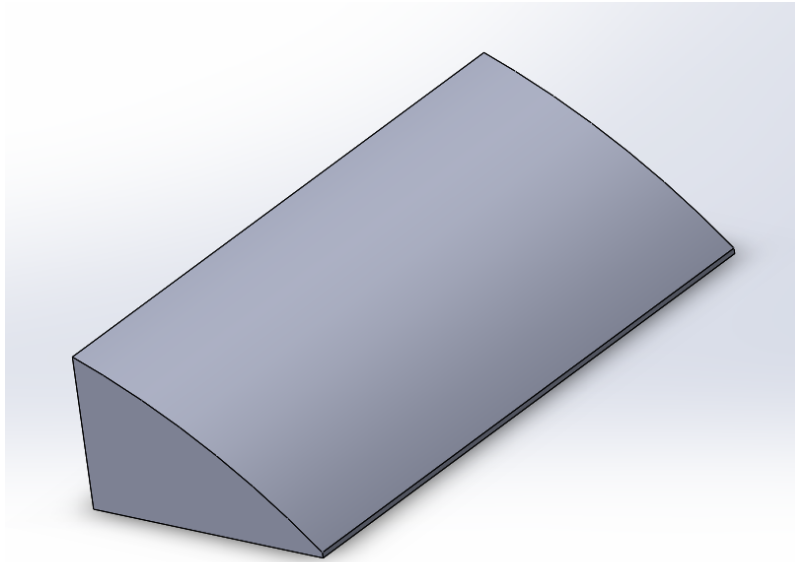
Figure 29: Solid propeller block (template).

The template block shown in Fig. 29 can now be copied and modified to required specifications. First, all of the required parameters are calculated in a spreadsheet. Then, they are exported into the template, either manually, or through a linked file, see Fig. 30.
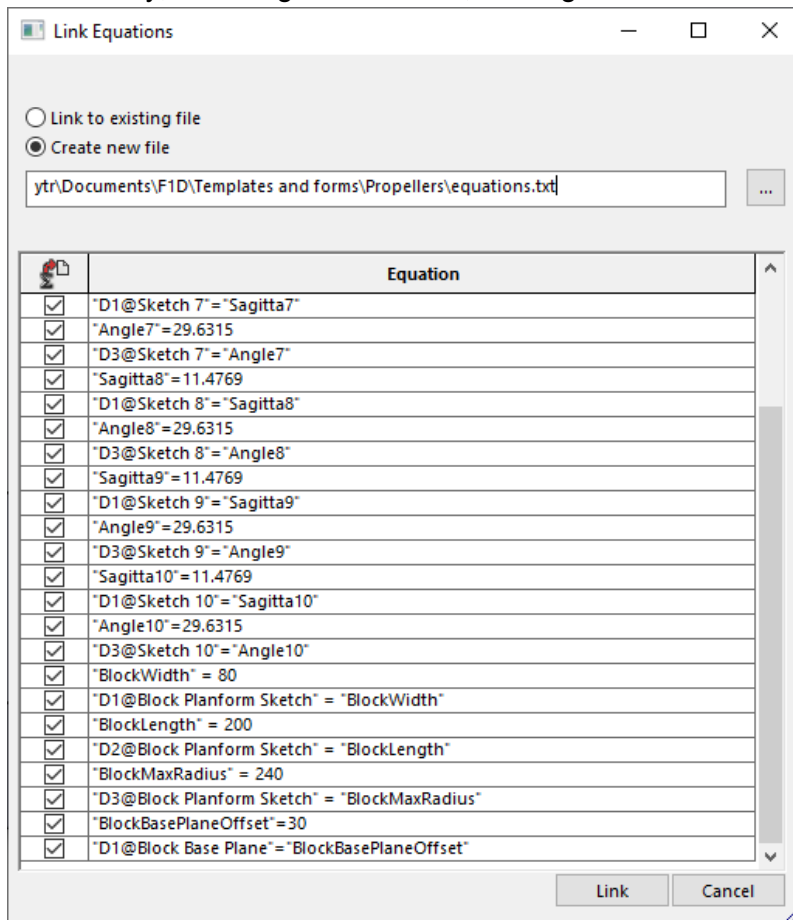
Figure 30: Equations for parametric block.

It often makes sense to minimize the volume of a propeller block. This can be done by derotating of the top surface so it will be parallel to a base in the middle of a blade. Fig. 31 shows an example of required calculations. Installation angle for each section is calculated for the desired pitch distribution. All of the sections are rotated then by an average between outer sections. Finally they are offset by 90 degrees. The latter step is needed for all the angles to be positive (SolidWorks will not accept negative dimensions) and would require vertical reference, see Fig. 32.
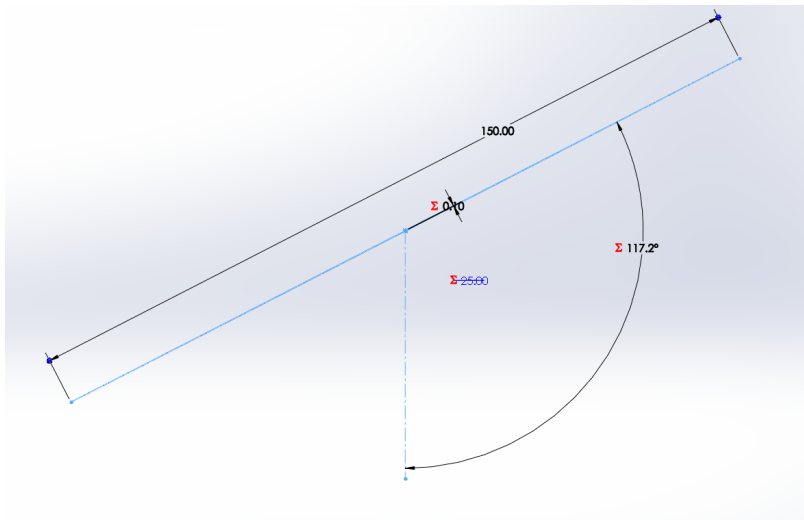
Figure 31: Calculation of section angles.

Figure 32: Defining always positive section angles.

Fig. 33 shows no-camber block template customized for 460x600, constant pitch F1D propeller with 200x60mm blades. A 3D-printed block based in this CAD model is shown in Fig. 34.
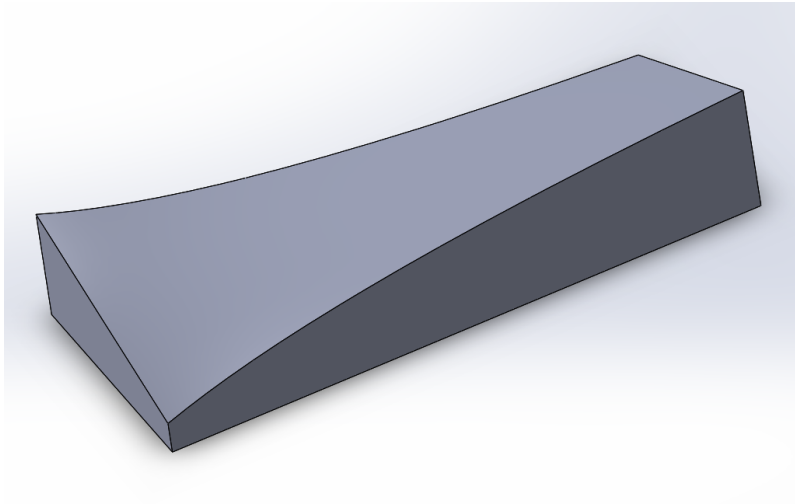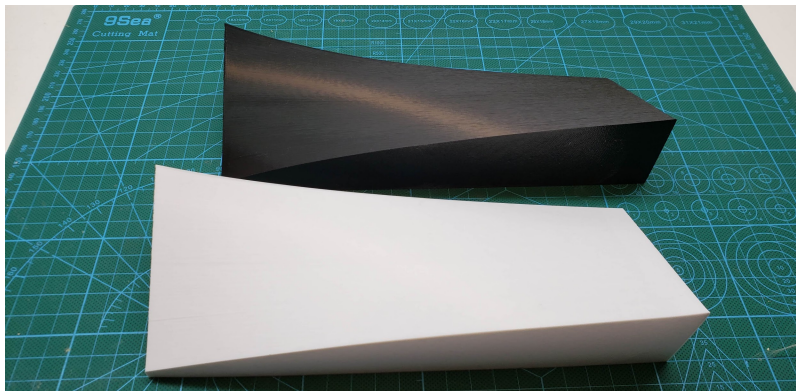
Figure 33: Block for 460x600 F1D propeller.

Figure 34: Examples of 3D-printed propeller blocks.

Acknowledgements