Three-dimensional representation of a propeller blade surface

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Such propellers are designed at Everllence (former MAN) and built by mounting the blades onto the propeller hub. There are different propellers available of both, the shown conventional type or the so called Kappel-type. The latter are commonly known as tip-rake propellers, where the propeller tips are inclined towards the ship. This problem set is concerned with the conventional type. Should, however, the study group finish this problem set, can similar problems for the Kappel type be discussed.

In order to better utilize the possibility of novel optimization algorithms, it would be useful to have a three-dimensional parametric representation of the propeller blade surface. Given a set of two-dimensional profile curves, a parametric equation for an associated three-dimensional surface (B-Spline surface, Bezier surface or equivalent) is to be generated. The procedure should be bi-directional, meaning that not only can the user create the final blade shape from a set of parameters. The user should also have the option to extract airfoil sections from the final geometry.

In particular, two geometric features should be included in the blade parametrization: the anti-singing-edge, and the hub fillet.

Propeller design fundamentals:

A propeller contains several blades composed together on a hub, see figure 1. The blades have a suction side (SS) facing the direction of travel and a pressure side (PS) facing aft. Cylindrical sections of the blade reveal hydrofoils defined at different radii. The shape of the blade is defined using radial distributions that specify for example thickness, camber and chord-length of the airfoils. Additional radial distributions describe the installation angle of the airfoils (pitch) and position of the airfoil, relative to the generator line (skew and rake).

Figure 2 illustrates the propeller contour, together with a number of radial positions at which the profile sections may be defined. Figure 3 illustrates two such profile section air foils. Profile sections are described by a number of parameters for their mean line and thickness. An example of the mean line and the thickness distribution are given in [1954_Abbott_book_Theory Of WingSections_chapter6.pdf, Formula 6.2 and 6.6, see attached].

In the current practice for propeller design, the two-dimensional sections are defined at various radial locations (Figure 2). A smooth interpolation of the sections is found in 3D software to obtain the eventual blade surface. Locations and directions of the profiles in space are illustrated in Figures 4 and 5. On controllable pitch propellers (CPP), each blade is attached to a blade foot, that is connected by bolts to the hub via holes in the blade foot. That is important for the fillet design.

An exemplary blade geometry including the holes through the fillet (described below) is illustrated in 3D in the attached bladeExample-3D.pdf (open with Adobe Acrobat and enable 3D view).

Propeller singing & Anti-singing-edge

Propeller singing describes the acoustic phenomenon that occurs when the vortex shedding frequency from the blade trailing edge resonates with the local natural frequency of the propeller blade, causing intense harmonic tonal noise.

The anti-singing-edge (ASE) is a geometrical detail near the trailing edge of the blade, mitigating the resonant vibrations indirectly by avoiding vortex shedding. It can be described as a straight cut, which is subsequently milled off one side of the section, see Figures 6 and 7. The ASE is mostly applied on one side of the profile (suction side or pressure side), but it can also change sides at a certain local radius r, tapering out on either side towards the radial location of side change. The global propeller radius (half diameter) is denominated by R. The propeller singing and the ASE are described in [Carlton, “Marine Propellers”, 1997, chapter 21.7], see attached 1994_carlton_book_Marine_Propellers_p456f.pdf

Currently, the ASE is milled off, after the propeller has undergone numeric shape optimization. It is desirable to include the ASE in the propeller parametrizations, such that future shape optimization studies regard the ASE as an integral part of the propeller.

The start and the end of the ASE are faired out into the remaining geometry, where no ASE is foreseen, see fig. 9 and 10. The ASE is not included in the attached bladeExample-3D.pdf.

Hub Fillet:

Another detail is the blade fillet connecting hub and blade, which is needed for strength reasons. It is described by a not constant radius geometry around the blade section profile at the hub position. It is described by the parameter R_I in Figure 4. It connects the blade geometry in radial direction with the hub geometry in tangential direction.

In CPP the fillet translates into a circle at the hub. That is a requirement for this problem, because most propellers at Everllence are CPP.

The fillet contour starts either at the aft ending connection point of the blade foot and blade or at the trailing edge (TE). The former is the case at the example (bladeExample-3D.pdf). The geometry at this point depends on the possible hub foot radius and the needed chord length at the hub.

The fillet runs from this point along the SS to the Leading edge (LE). At the LE it runs back along the PS to the TE, completing the contour.

Problems:

Blade parametrization

(1) Is it possible to describe the camber of a foil as a reversible transformation? I.e. start with a symmetric foil (Phi(x)=0). Now introduce a mean line, for example the line in equation (6.4) in [Abbott] and transform all points accordingly.

(2) Parametrize a 3D foil, by making the fundamental parameters depend on the z-coordinate: The position of max. amplitude p(z), the max. amplitude of mean line m(z), the radius of the leading edge LER(r), the thickness at the trailing edge TE(z) and the chord length c(z).

(3) Now parametrize a 3D foil through with skew, rake and pitch: Consider using a local Frenet-Serret frame following a generator line (instead of the z-axis in (2)).

(4) Towards Bi-directional processing: Flatten the propeller. The 3D propeller will then be cut into cylinder sections that need to be developed to 2D cross sections. Given the profile section at some radial position (e.g. in Fig. 4), find coefficients for parametric representation.

Anti singing edge

(5) Include the parametric ASE in the 2D parametric profile section foil geometry. The geometry of the ASE is defined by the three parameters: alpha_ASE, t_TE, l_F, see Fig. 7. Note that the profile mean line is defined piece-wisely. The straight cut could be another curve piece behind a specific chord length q (The parameter x and/or x/c is used by prop. designers for a certain chordwise position). The profile is therefore not symmetric about the mean line from this position on towards TE.

(6) Construct the flat (no skew angle, pitch or rake) 3D propeller with ASE in radial direction. The ASE varies along the trailing edge, see Figure 6. Starting without ASE at the hub, the geometry tapers towards the full ASE at a radius of abt. r/R=0.45. The ASE is mostly applied on one side of the profile (SS or PS), but it can also change sides at a certain radius, tapering out on either side towards the radial location of side change.

Hub fillet

(7) Smooth fillet transition: Let RH (better rH) be the radius of the cylindrical hub. The blade geometry should reshape into the cylinder as r -->RH. See Fig. 4: The parameter R_I defines the radius of the asymptotic circle section. The steepness of the transition could be modelled asymptotically through circles, ellipses, parabolas or hyperbolas. Other forms than circles might make even more sense from strength point of view.

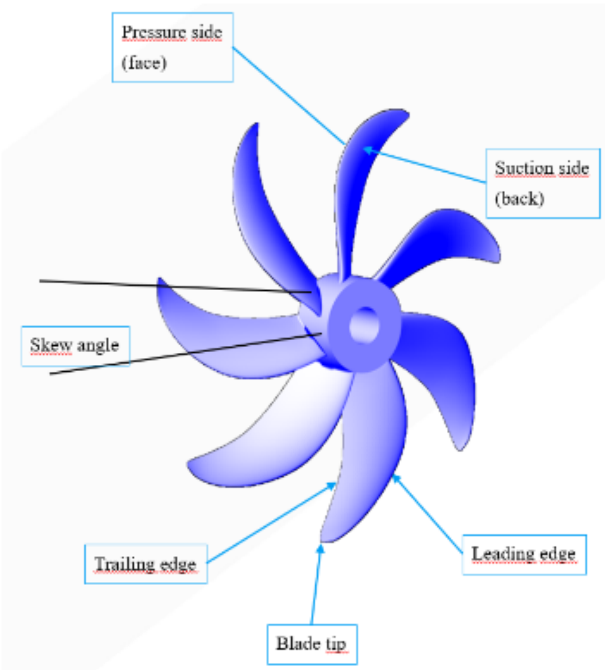

Figure 1: Global parameters (source: 190603_VL_SDyn_SS19_Propulsion_MGre)

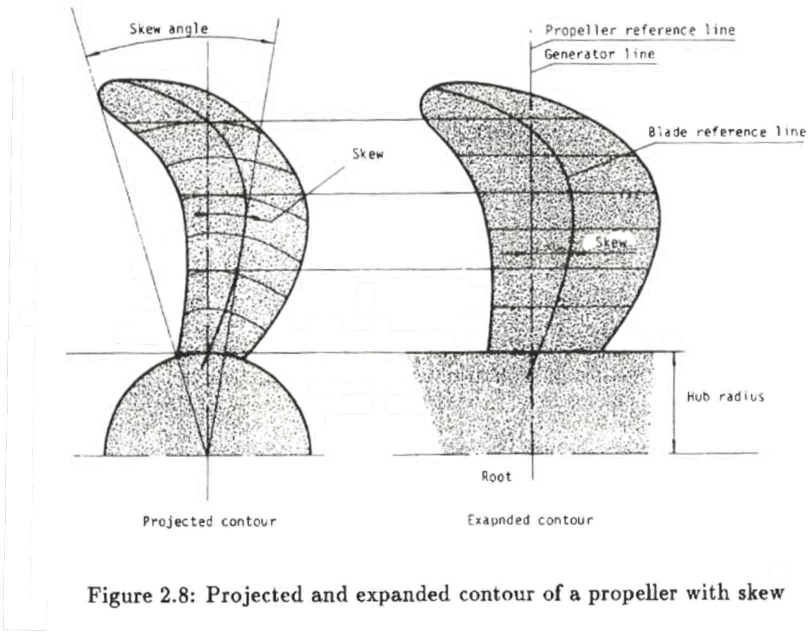

Figure 2: Propeller contour (source: Kuiper, 1992)

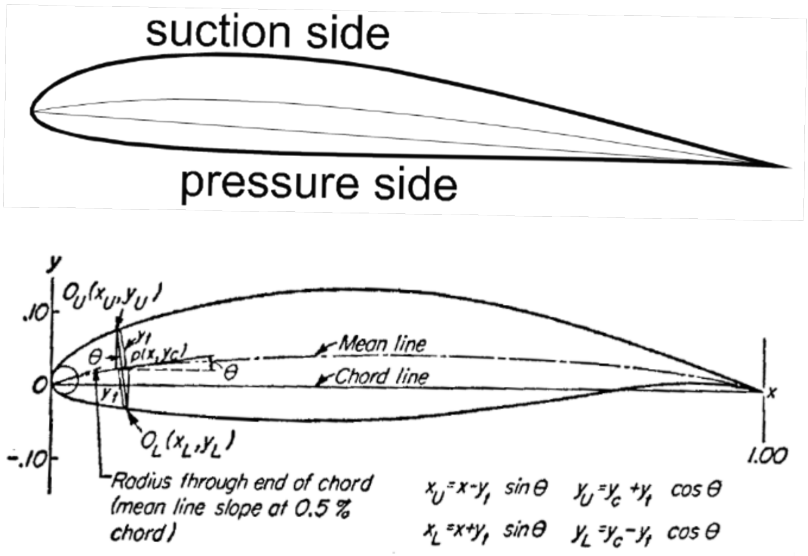

Figure 3: Profile section with mean line (top) and chord line (bottom) (source: Abbott_WingSections)

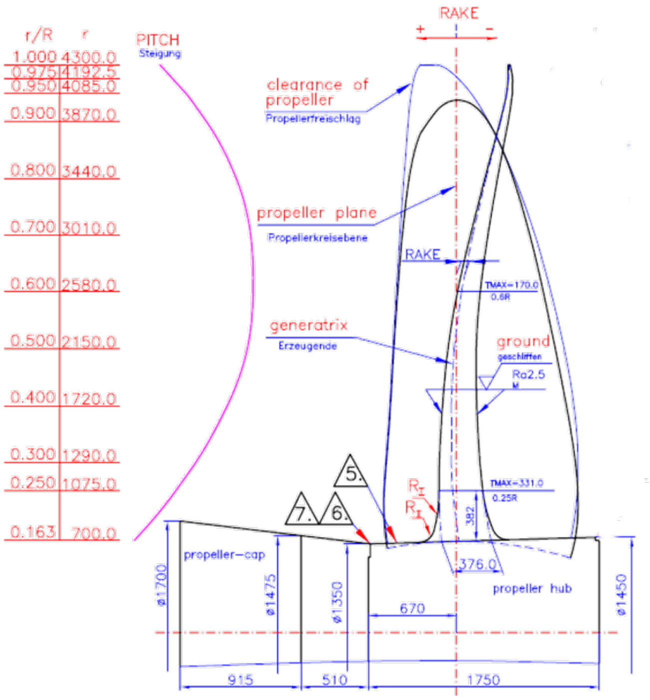

Figure 4: Propeller geometry, side view (source: 190603_VL_SDyn_SS19_Propulsion_MGre)

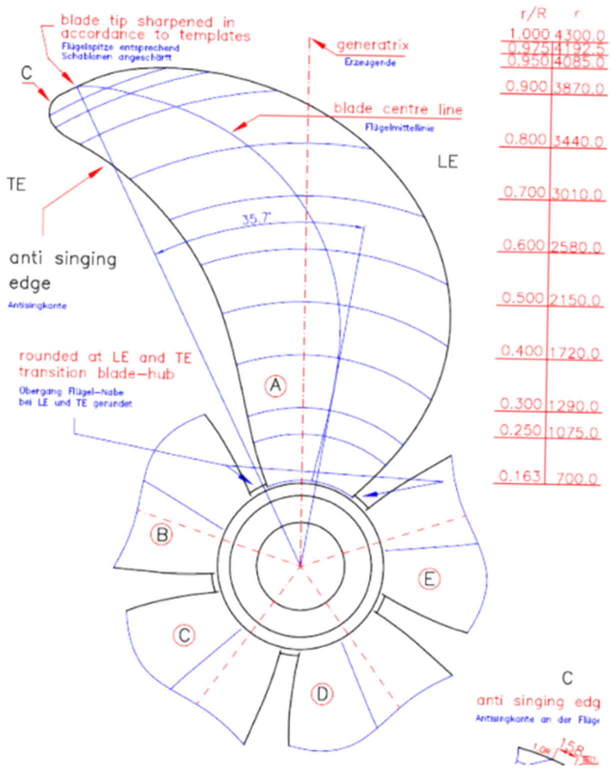

Figure 5: Propeller geometry, face view (source: 190603_VL_SDyn_SS19_Propulsion_MGre)

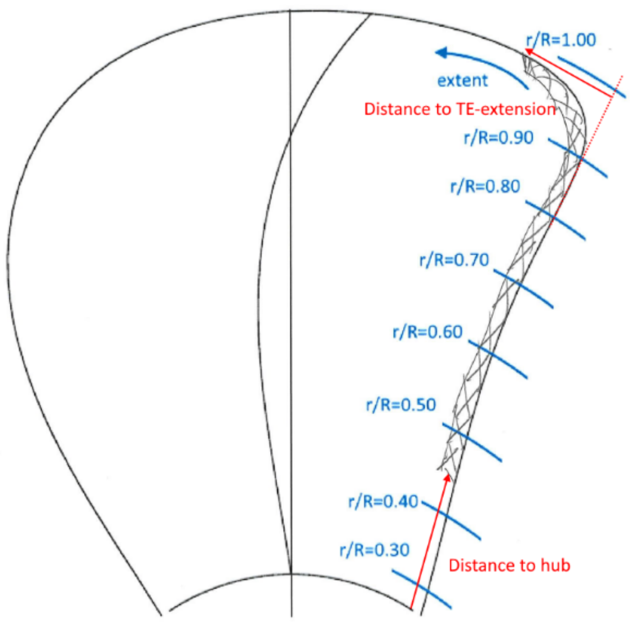

Figure 6: ASE, radial stations

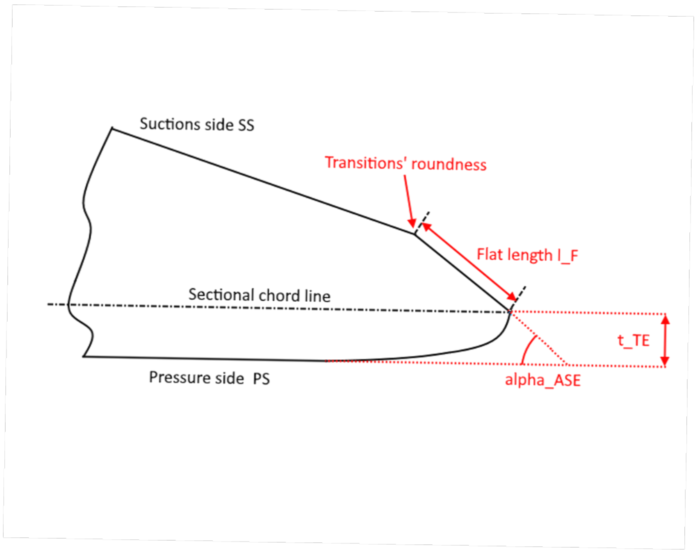

Figure 7: ASE parameters

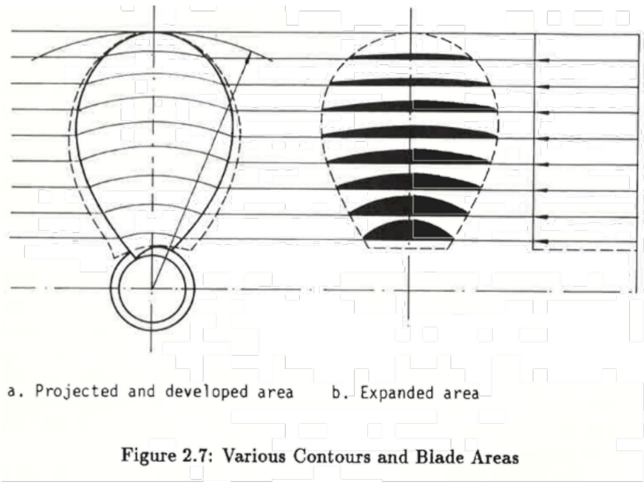

Figure 8: Blade area (source: Kuiper, 1992)