Advanced Propulsion System
GEM 423E

Week 2: The Screw Propeller Geometry

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- Propeller Basics
- Propeller Geometry
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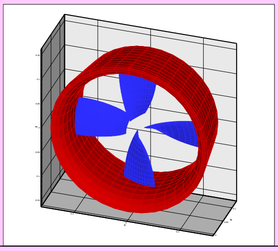
Propeller Basics

Propeller Basics – Blade Design

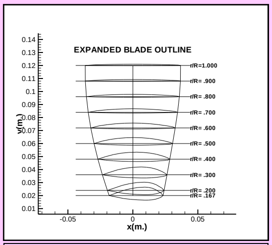
- The main objectives within the constraints is to obtain as high a TPE (total propulsion efficiency) as possible and to suppress the cavitation to an acceptable level.
- However, for a fixed propeller diameter the only part-efficiencies being influenced by the blade design are the open water efficiency and the relative rotative efficiency.
- It is a common belief among propeller designers that the two design objectives are in contradiction to each other and consequently must be balanced to get a compromised design.
- But today some design features are available which can be applied to reduce the cavitation without sacrificing the efficiency.
- To build up a propeller blade, the complicated 3-dimensional form is usually reduced into 2-dimensional elements which are then adjusted during the design process.

Propeller Basics – Blade Design

- To build up a propeller blade, the complicated 3-dimensional form is usually reduced into 2-dimensional elements which are then adjusted during the design process.



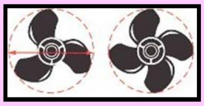
3D Representation of Ka 4.55 – P/D = 1 propeller with 19a Duct



2D Representation – Ka 4.55

Propeller Basics - Diameter

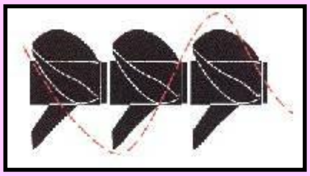
- Diameter is two times the distance from the center of the hub to the tip of the blade.
- It also can be looked at as the distance across the circle that the propeller would make when rotating.



- It is the first number listed when describing a propeller.

Propeller Basics - Pitch

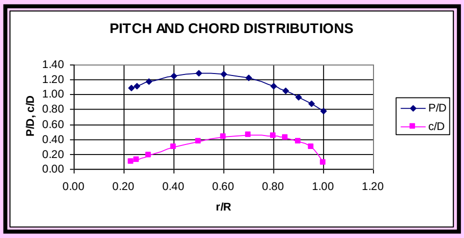
- Pitch is defined as the theoretical forward movement of a propeller during one revolution -assuming there is no "slippage" between the propeller blade and the water.
- For most boats, there is slippage and therefore the distance advanced is less than the design pitch.
- The amount of slippage varies from boat to boat.
- Pitch is the second number listed in the propeller description.

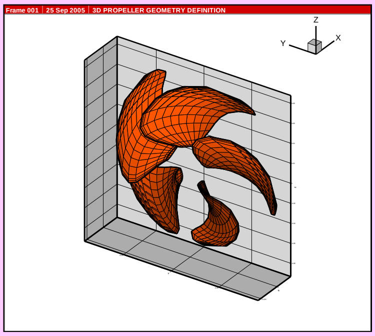


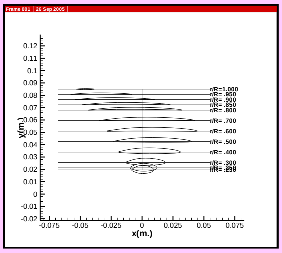
Propeller Basics – Pitch Distribution

- An important parameter in propeller design is the distribution of pitch as a function of radius which need not be constant as is the case with a screw or bolt thread as the propeller is moving its way through water.
- Using pitch reduction at both the hub and the tip can be advantageous in reducing the cavitation extension, although care must be taken not to apply excessive reductions which will result in a decrease in efficiency.

Propeller Basics – Pitch Distribution



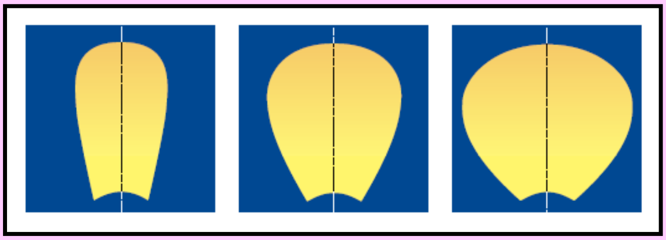




Propeller Basics – Blade Area

- The blade area should be kept as small as possible in order to reduce the friction losses when turning in the water
- Not to suppress the cavitation extension a certain area is needed.
- A measure of the blade area is the so-called “blade area ratio” (Ae/Ao) which is the ratio of all the blades compared to the area of the circle circumscribed by the propeller diameter.

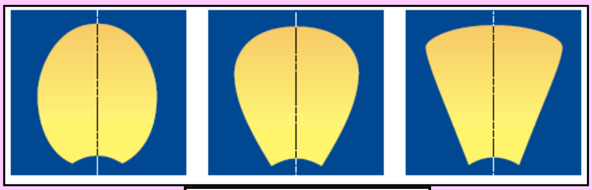
Propeller Basics – Blade Area



Different blade area ratios:
Left: Ae/Ao=0.40
Center: Ae/Ao=0.55
Right: Ae/Ao=0.70

Propeller Basics – Blade Shape

- The blade shape can be varied to even out the cavitation along radius and in the case of a nozzle propeller, it is advantageous to have wide-chord length at the tip (Kaplan shape).



Different blade shapes.
Max chord location varied from center of blade to tip of blade.

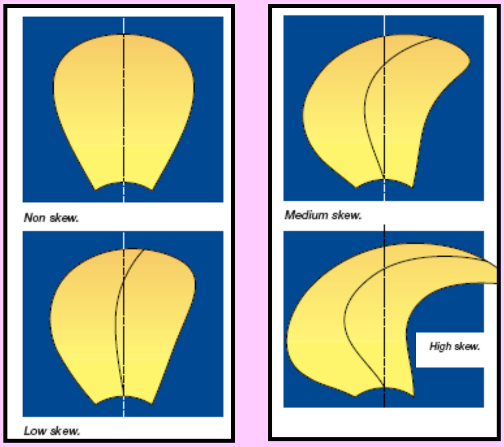
Propeller Basics – Skew

- A powerful tool to suppress propeller induced noise and vibration is the application of skew.
- For modern CP propellers, the skew distribution is of the balanced type, which means that the blade chords at the inner radii are skewed (moved) forward, while at the outer radii the chords are skewed aft.
- By applying this type of skew it is possible to control the forces (spindle torque) needed for pitch settings.
- In most cases the blades will be balanced in such a way that the forces in the design pitch setting will be zero.

Propeller Basics – Skew

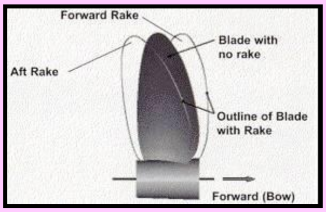
- Skew has the advantage of reducing the pressure impulses emitted from propeller to the hull surface to as much as one third of an unskewed design without sacrificing the efficiency, which will remain unchanged.

Propeller Basics – Skew



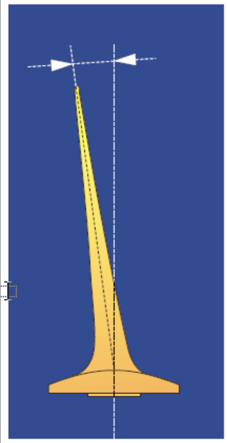
Propeller Basics - Rake

- Rake is the degree that the blades slant forward or backwards in relation to the hub.
- Rake can affect the flow of water through the propeller, and as implications with respect to boat performance.
- Aft Rake helps to trim the bow of the boat upwards, which often results in less wetted surface area and therefore higher top end speed.
- Aft rake propellers also typically "bite" better on ventilating type applications.
- Forward, or negative rake, helps hold the bow of the boat down.
- This is more common in workboat type applications.
- F Blade with no rake Aft Rake Outline of Blade with Rake -F=d (Bow)



Propeller Basics - Rake

- Aft rake alse helps to reduce the noise and vibration level in the aft ship by increasing the distance between the propeller tip and hull surface.
- A way of increasing the distance is to rake (incline) the blade towards aft.
- As with skew the efficiency remains unchanged. However, the blade is exposed to higher stresses originating from an increase in the centrifugal forces which must be counteracted by an increase in blade thickness.

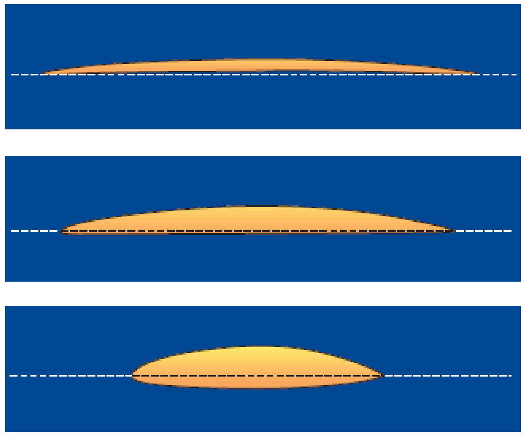


Aft raked propeller.

Propeller Basics – Profile Section

- For each radius, the blade is built-up of 2-dimensional airfoil sections.
- The airfoil used in propellers is mostly from the NACA family series which have proven successful in having
- both low drag and good cavitation characteristics.
- A NACA profile is characterised by a basic thickness and a camber distribution which can be changed independently of each other.
- This facilitates the design of profiles with specific properties at each radius.

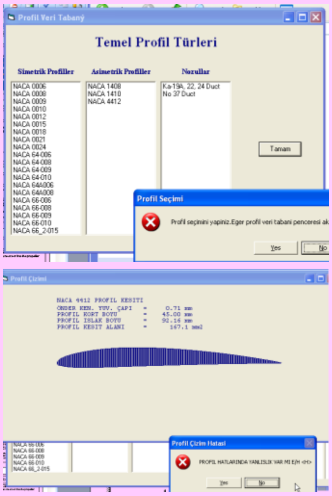
Propeller Basics – Profile Section



Typical profile sections at different propeller radii.

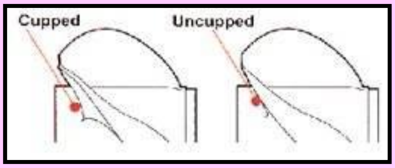
Propeller Basics – Profile Section

- NACAP - Naca Section Geometry Generation Program
  - http://www.gidb.itu.edu.tr/staff/takinaci/bilg_prog_index.html
- It includes 20 symetric, 3 asymmetric and 2 Ducts (19A, No:37) sections.
- Output to Autocad is available.



Propeller Basics - Cupping

- Many of today's propellers incorporate a cup at the trailing edge of the propeller blade.
- This curved lip on the propeller allows it to get a better bite on the water.
- This results in reduced ventilation, slipping, and allows for a better hole shot in many cases.
- A cupped propeller also works very well where the motor can be trimmed so that the propeller is near the surface of the water.
- The cup will typically result in higher top end speed on one of these applications



Propeller basics - Ventilation

- Ventilation is a situation where surface air or exhaust gasses are drawn into the propeller blades.
- When this situation occurs, boat speed is lost and engine RPM climbs rapidly.
- This can result from excessively tight cornering, a motor that is mounted very high on the transom, or by over-trimming the engine.

Predicting the Inception of Ventilation

- The inception of ventilation correlates to thrust loading. Greater thrust means more suction side (vacuum), which in turn, means a greater likelihood of ventilation.
- In the referenced publication, the prediction of the inception of ventilation relied on the relationship between pitch, RPM and advance velocity as a measure of thrust loading. The implementation of the method herein converts the relationship so that a limiting .critical. speed of advance, $V_{A\text{-}CRIT}$, is used as the indicator of ventilation. Non-ventilating performance is maintained when $V_A > V_{A\text{-}CRIT}$.

Predicting the Inception of Ventilation

VARIABLES

D = diameter [ft; m]
G = gravitational constant [32.2 ft/s^2; 9.81 m/s^2]
H = hub immersion below WL [ft; m]
n = shaft speed [revs/s]
P = pitch [ft; m]
R = radius [ft; m]
V = ship speed [ft/s; m/s]
w = wake fraction

RANGE OF APPLICABILITY

The prediction method is suitable for the following ranges of parameters.

H/R = 1.0 to 1.5
K = 0.05 to 0.44

FORMULA

K = tip speed parameter

$$K = \frac{G}{n^2 D}$$

V_A = speed of advance [ft/s; m/s]

$$V_A = V(1-w)$$

$V_{A\text{-}CRIT}$ = critical speed of advance [ft/s; m/s]

$$V_{A-CRIT} = Pn\left[1 - \frac{0.416\,H/R - 0.004}{0.854 + 0.34e^{(-6.1K)}}\right]$$

Predicting the Inception of Ventilation

EXAMPLE

This example checks if ventilation is predicted to occur if the propeller tip should reach the surface during a particular operating condition.

D = 2.50 ft
G = 32.2 ft/s2
H = 1.25 ft
n = 13.0 revs/s (shaft speed)
P = 2.50 ft
R = 1.25 ft
V = 20.3 ft/s (12 kts)
w = 0.06

H/R = 1.0
K = 0.076
V_A = 19.1 ft/s
$V_{A\text{-}CRIT}$ = 20.0 ft/s

Conclusion: V_A is less than $V_{A\text{-}CRIT}$, so ventilation is predicted to occur.

VentPre.Exe : Ventilation inception prediction programme

http://www.hydrocompinc.com/knowledge/library.htm

Propeller basics - Cavitation

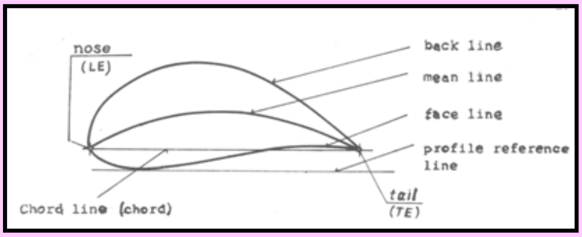
- Cavitation, (which is often confused with ventilation), is a phenomena of water vaporizing or "boiling" due to the extreme reduction of pressure on the back of the propeller blade.
- Many propellers partially cavitate during normal operation, but excessive cavitation can result in physical damage to the propeller's blade surface due to the collapse of microscopic bubbles on the blade.
- There may be numerous causes of cavitation such as incorrect matching of propeller style to application, incorrect pitch, physical damage to the blade edges, etc...
- Be advised disturbances in the water flow forward of the 4 propeller can result in blade damage which appears to be blade cavitation, but is actually due to non-favorable water flow into the propeller.
- *http://www.boat-props.com*

Propeller Geometry

- Different procedures of screw blade geometry description can be used.
- A procedure that will be used in this week is related to the successive steps in blade designing.
- The fundamental elements in constructing the blade is the blade profile.
- Blade profile:
  - The intersections of the blade with the cylindrical surface
  - Expanded together with this surface

- In the design of screw propeller
  - Expanded blade sections are described first.

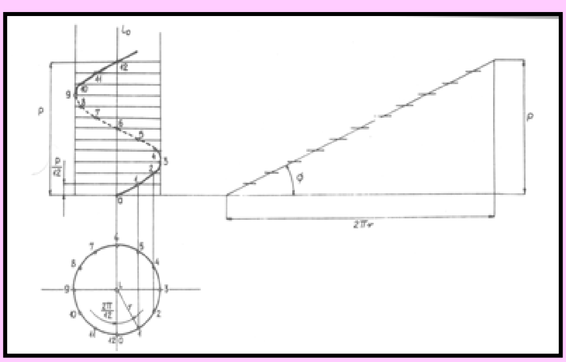
Blade section profile



- Then, the following geometrical parameters of the profile are to be determined;
  - Profile chord distribution $c(r)$;
  - Mean line or camber distribution $\frac{f_M}{c}(r)$;
  - Profile maximum thickness distribution $\frac{t}{c}(r)$;
  - Pitch ratio distribution $\frac{P}{D}(r)$;
  - Pitch angle distribution $\Phi(r) = arc\tan\frac{P}{2\pi r}$

The helix and the helicoid

- Let us have two parallel straight lines "l_0" and "l" forming a plane.
- The plane is rotating about the axis "l_0" with constant angular velocity "ω".
- The trajectory of a point "M" moving with constant velocity "V_1", along the line "l", which is a helical line on a cylindrical surface .
- There is an angle, Φ, between this line and the expanded circle $2\pi r$.

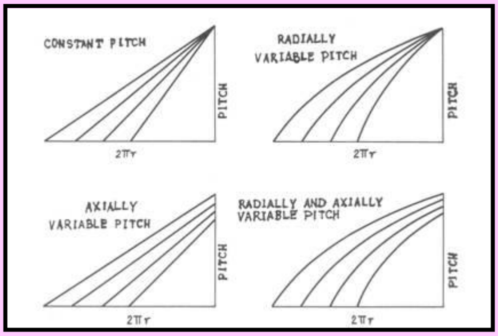


$$\tan\phi = \frac{P}{2\pi r} = \frac{P}{2\pi \frac{r}{R} R} = \frac{\frac{P}{D}}{\pi\chi}$$

P/D – the pitch ratio

$\chi = r/R$ – the nondimensional radius

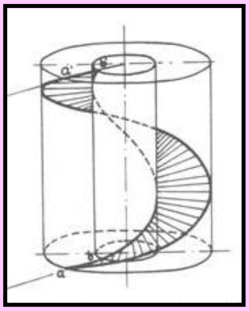
- In case when the angular velocity (*ω=constant)* is constant but the point "*M*" velocity along the line "*l*" is variable, ($V_1 \neq$ constant). The axially variable pitch is determined.



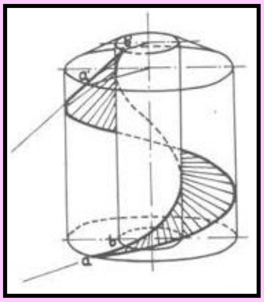
- A definition is to be introduced in relation with the helical line: the right or left handed screw line.

"A right handed helix occurs when the plane rotates clocwise and the point "*M*" is moving away from the observer looking along the axis of rotation"

"The surface, being the locus of helices with different cylindrical surface radii, is defined as the helicoid."



The helicod with radially constant pitch



The helicod with radially variable pitch

The Parent Blade

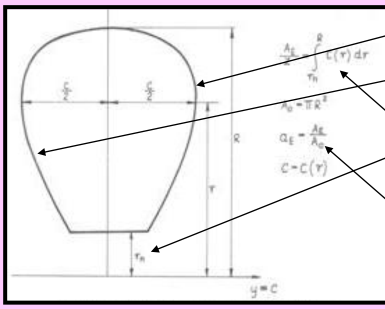
- Let us assume that in the prop design procedure the blade profiles were fixed:

$$c = f_c(r), \quad \frac{f_M}{c} = f_M(r), \quad \frac{t}{c} = f_t(r)$$

- And the pitch radial distribution determined

$$\frac{P}{D} = f_p(r)$$

- The parent blade can be built on the basis of these data.
- First the expanded blade outline of the parent blade is formed.
- On the plane *Orc* the function $\frac{c}{2} = \pm f(r)$ is plotted



Leading edge - LE

Trailing edge - TE

$r_h = \text{hub radius}$

Expanded blade area

Expanded area ratio

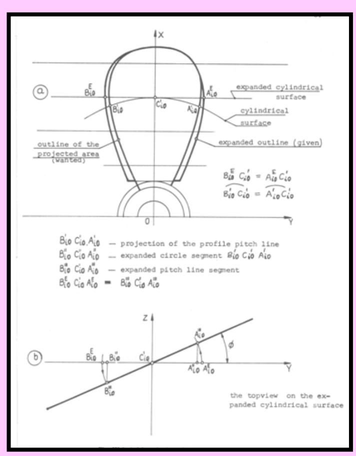
- Now the problem is to construct the projection of the parent blade on the plane perpendicular to the screw axis.

$B'_{i0}C'_{i0}A'_{i0}$ – projection of the profile pitch line

$B''_{i0}C''_{i0}A''_{i0}$ – expanded circle segment $B'_{i0}C'_{i0}A'_{i0}$

$B'''_{i0}C'_{i0}A'''_{i0}$ – expanded pitch line segment

$B^E_{i0}C'_{i0}A^E_{i0} \equiv B'''_{i0}C'_{i0}A'''_{i0}$



The real blade of the screw propeller

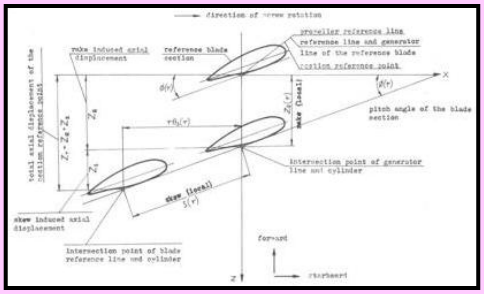
- The locus of the blade section reference points is defined as the *blade reference* line.
- The parent blade reference line = the *generator line* of the helicoid.
- The parent blade reference line = the *propeller reference* line.
- These three lines are *separeted* due to the deformation process of the parent blade

- First the generator line is *raked*, the blade reference line being deformed simultaneously.
- This deformation is the deformation of the helicoid, transforming it from the regular helicoid to the raked helicoid.
- After that the blade reference line is skewed, all points of raked position of this line are translated along pitch datum lines of the raked helicoid.

- The first stage of the deformation, raking the generator line, by translating each point of this line in axial direction can be described by the axial coordinate of these points

$$\boxed{Z_R(r) = r \tan \theta_R}$$

- Z(r) – axial translation of the generator line points
- θ_R(r) – angular measure of rake



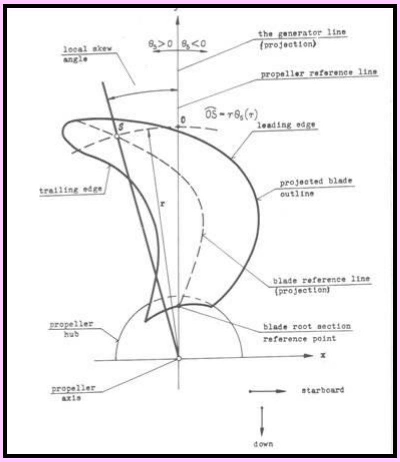
The second stage of deformation, skewing the blade reference line, based on translation of each point of this line along the pitch datum lines.

The second stage of deformation, skewing the blade reference line

The measure of the local translation along the helix is the helix segment *S*(*r*), with a given pitch angle *Φ*(*r*).

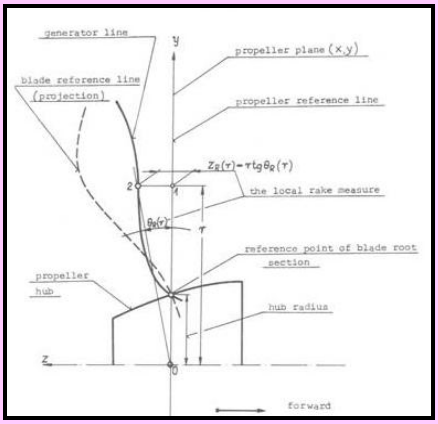
One can use the local angle $\theta_S(r)$ to determine the skew induced axial translation of the blade section reference points

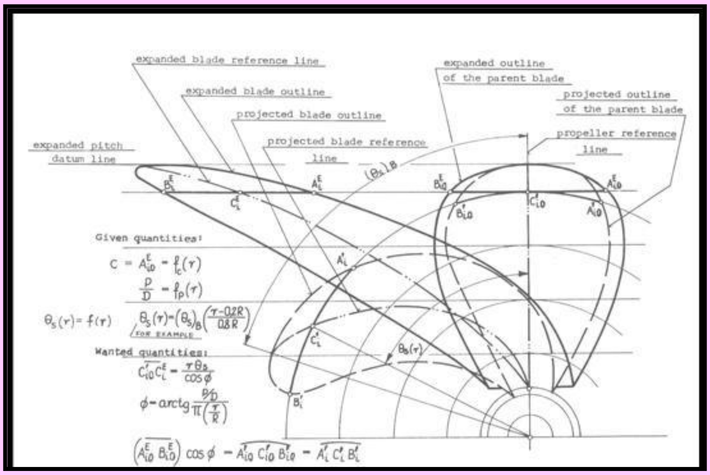
$$Z_S(r) = r\theta_S(r)\tan\theta(r)$$



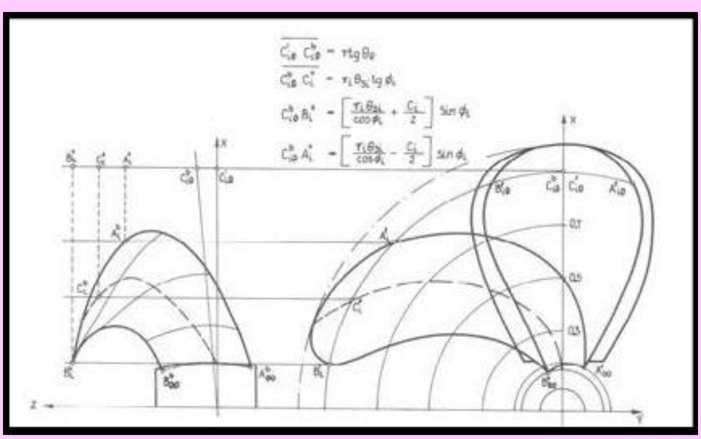
For design purposes the function

$$\theta_S = \theta_S(r)$$





- First the projected outline of the real blade is to be built. It is a mere formality.
- The curve $\theta_S(r)$ is built. This curve is the real blade reference line.

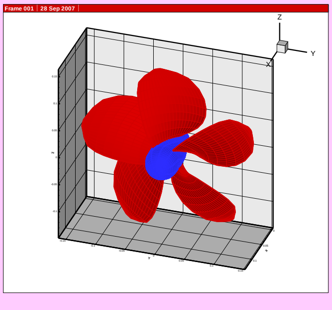


- Then the side view of the blade is to be built.

Propeller Series

Propeller Series – Wageningen B

- Blades : 2-7
  Pitch Ratio : 0.60~1.40 (Four bladed propeller has no constant pitch distribution)
  Area Ratio : 0.30~1.05
  Skew Angles : 0º>
  Section Type : Original
  Remark : Most widely used propeller series.
  Suitable for most application.

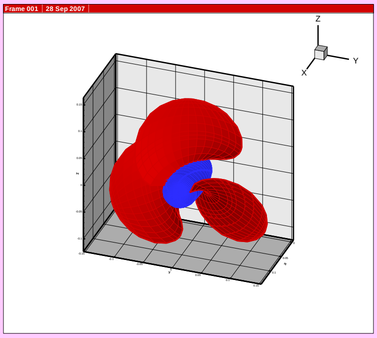


Propeller Series – Au Series

- Blades : 4-7
  Pitch Ratio : 0.50~1.20
  Area Ratio : 0.70~0.758
  Skew Angles : 0º>
  Section Type : AU type
  Remark : Complemantary series of Wageningen B Series

Propeller Series – Gawn Series

- Blades : 3
- Pitch Ratio : 0.40~2.00
- Area Ratio : 0.20~1.100
- Skew Angles : 0º>
- Section Type : Segmental
- Remark :

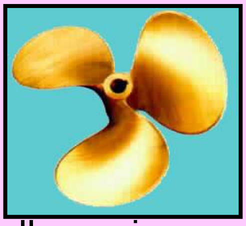


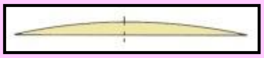
Propeller Series – Ma Series (Lindgren Series)

- Blades : 3, 5
- Pitch Ratio : 1.00~1.454
- Area Ratio : 0.75~1.20
- Skew Angles : 0º>
- Section Type : Circular

Propeller Series – KCA Series

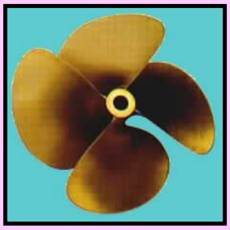
- Blades : 3,4,5
  Pitch Ratio : 0.60~2.00
  Area Ratio : 0.20~1.10
  Skew Angles : 0º>
  Section Type : Ogival
  Remark : Most widely use propeller series.
  Suitable for most application.

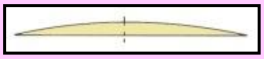




Propeller Series – Skew KCA Series

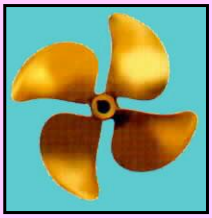
- Blades : 3,4,5
- Pitch Ratio : 0.60~2.00
- Area Ratio : 0.50~1.10
- Skew Angles : 25^{o} , 30^{o} , 35^{o}
- Section Type : Ogival
- Remark : Modified from standard KCA series for smooth application.
- Suitable for most application.

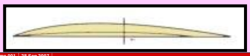


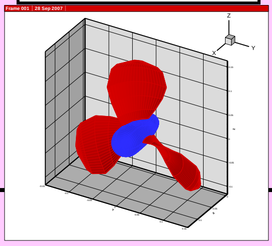


Propeller Series – NR Series

- Blades : 3, 4, 5
- Pitch Ratio : 1.00~2.00
- Area Ratio : 0.50~1.00
- Skew Angles : 25^{o} , 30^{o}
- Section Type : Crescent
- Remark : Suitable for higher speed range in trans-cavitating application.

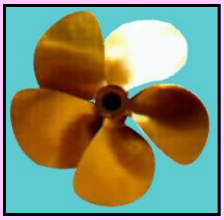


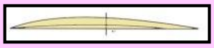




Propeller Series – NACA-Series

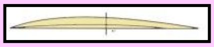
- Blades : 4,5,6,7
- Pitch Ratio : 0.80~1.60
- Area Ratio : 0.50~1.40
- Skew Angles : According to design
- Section Type : Airfoil
- Remark : Theoretical design propeller series.





Propeller Series – New Foil Series

- Blades : 3,4,5
- Pitch Ration : 0.80~1.60
- Area Ration : 0.50~1.40
- Skew Angles : According to design
- Section Type : New Foil
- Remark : Theoretical design propeller series.



Propeller Series – Ka Series

- Blades : 3, 4, 5
- Pitch Ratio : 0.60~1.60
- Area Ratio : 0.55~0.75
- Skew Angles : 0^0,Skew available
- Section Type : Airfoil
- Remark : Suitable for accelerating nozzle propellers and bow or stern thrusters.