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Propeller Geometry:

Terms and Definitions

Master Document

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Purpose

This document provides standard definitions for marine screw propeller geometry terminology and associated characteristic descriptions. This standardization is an attempt to clearly define the complex nature of propeller geometry and thus foster efficient, knowledgeable communication.

Section I of this document presents pure, general definitions of terms associated with propeller geometry. The approach is to move from the obvious physical features of a propeller to a more detailed level that describes properties just as important, but perhaps somewhat more difficult to see. Section II describes various conventions for defining geometric properties. The presentation is objective and makes no recommendations as to which methods are most accurate or appropriate. The aim is to uncover the different interpretations of common terms and establish a clear understanding of the importance of standardization in propeller geometry terminology.

Table of Symbols

C	Chord length
D	Diameter
h	Drop height
LE	Leading edge
P	Pitch
R	Radius
TE	Trailing edge
α	Geometric pitch angle
α_h	Geometric pitch angle near the hub
α_t	Geometric pitch angle near the tip
r_h	Radius near the hub
r_t	Radius near the tip
β	Swept Angle
PCA	Propeller Center Axis
BCA	Blade Center Axis
PCL	Propeller Centerline
BCL	Blade Centerline

1.1 Propeller Geometry: General Features

Reference Figure 1.1 for the following terms.

No.	*TERM*	*DEFINITION*
1.	Diameter	The diameter of the imaginary circle scribed by the blade tips as the propeller rotates.
2.	Radius	The distance from the axis of rotation to the blade tip. The radius multiplied by two is equal to the diameter.
3.	Blade Face	Pressure Side, Pitch Side. Aft side of the blade (surface facing the stern).
4.	Blade Back	Suction Side. Forward side of the blade (surface facing the bow).
5.	Leading Edge	The edge of the propeller blade adjacent to the forward end of the hub. When viewing the propeller from astern, this edge is furthest away. The leading edge leads into the flow when providing forward thrust.
6.	Trailing Edge	The edge of the propeller adjacent to the aft end of the hub. When viewing the propeller from astern, this edge is closest. The trailing edge retreats from the flow when providing forward thrust.
7.	Blade Number	Equal to the number of blades on the propeller.
8.	Blade Tip	Maximum reach of the blade from the center of the hub. Separates the leading and trailing edges.
9.	Hub	Solid cylinder located at the center of the propeller. Bored to accommodate the engine shaft. Hub shapes include cylindrical, conical, radius, & barreled.
10.	Blade Root	Fillet area. The region of transition from the blade surfaces and edges to the hub periphery. The area where the blade attaches to the hub.
11.	Rotation (Right hand shown here)	When viewed from the stern (facing forward): Right-hand propellers rotate clockwise to provide forward thrust. Left-hand propellers rotate counter-clockwise to provide forward thrust.

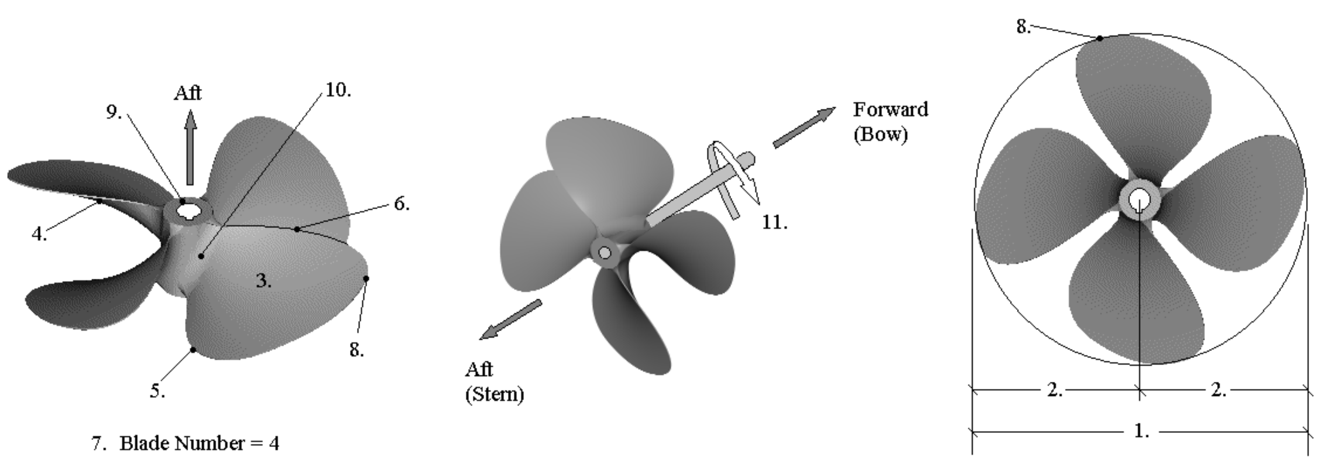

Figure 1.1

1.2 Propeller Geometry: Pitch

Reference Figures 1.2A, 1.2B, and 1.2C for the following terms.

No.	***TERM***	***DEFINITION***
1.	Pitch	The linear distance that a propeller would move in one revolution with no slippage.
2.	Cylindrical Section	A cross section of a blade cut by a circular cylinder whose centerline is the propeller axis of rotation.
3.	Pitch Reference Line	Reference line used to establish the geometric pitch angle for the section. This line may pass through the leading and trailing edges of the section and may be equivalent to the chord line. See Item No. 4 of Section 1.5.
4.	Geometric Pitch Angle, α	The angle between the pitch reference line and a line perpendicular to the propeller axis of rotation.
5.*	Controllable Pitch Propeller	The propeller blades mount separately on the hub, each on an axis of rotation, allowing a change of pitch in the blades and thus the propeller.
6.*	Fixed Pitch Propeller	The propeller blades are permanently mounted and do not allow a change in the propeller pitch.
7.*	Constant Pitch Propeller	The propeller blades have the same value of pitch from root to tip and from leading edge to trailing edge.
8.*	Variable Pitch Propeller	The propeller blades have sections designed with varying values of local face pitch on the pitch side or blade face. See Section 2.2.
9.	Circumference	A geometric property of a circle, defined as the linear distance equal to 2 x π x Radius. The length of the perimeter of the circle.
10.	Helical Line or Helix	The corkscrew shaped line traced by a fixed point on an object undergoing both rotational and linear motion.

* denotes terms that do not have a graphic representation to aid in definition

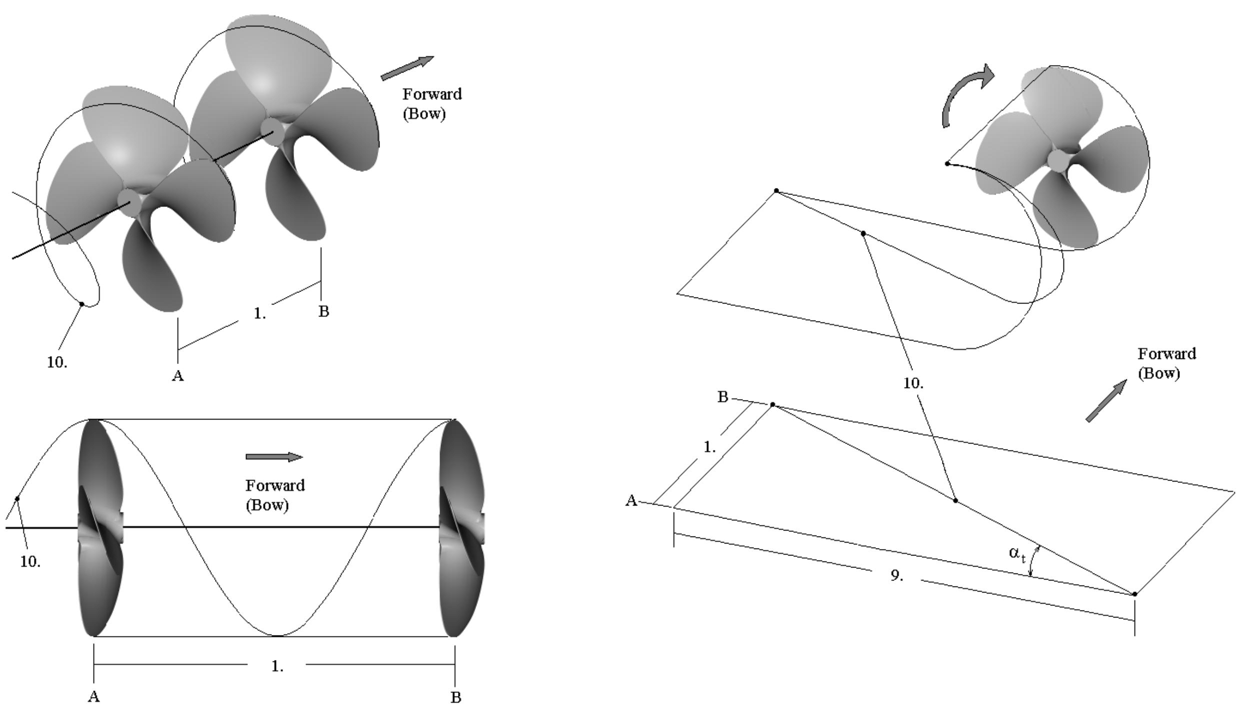

Figure 1.2A

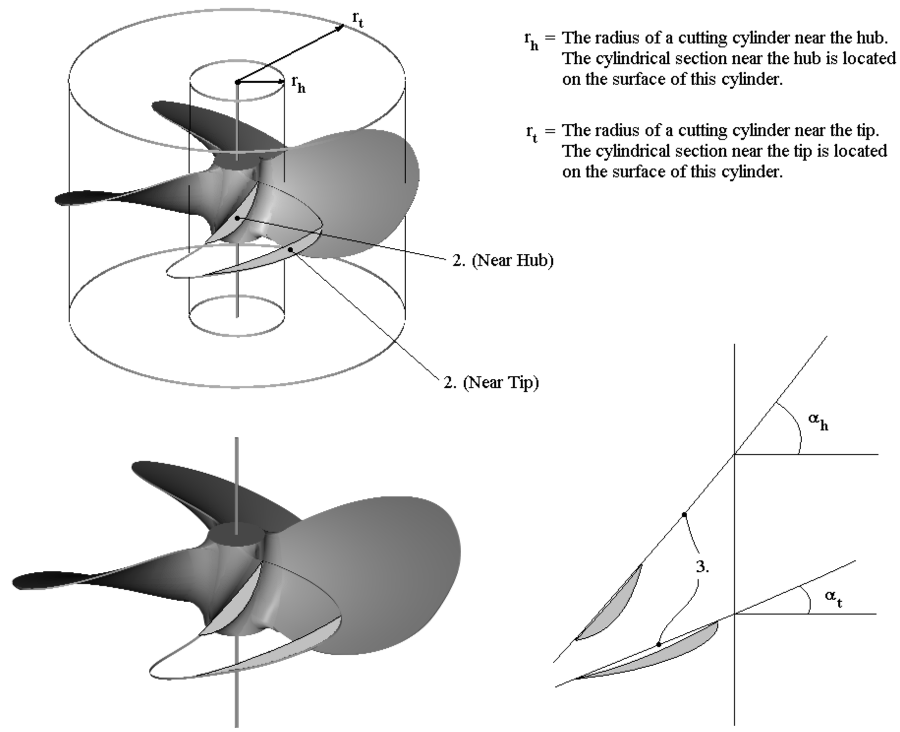

Figure 1.2B

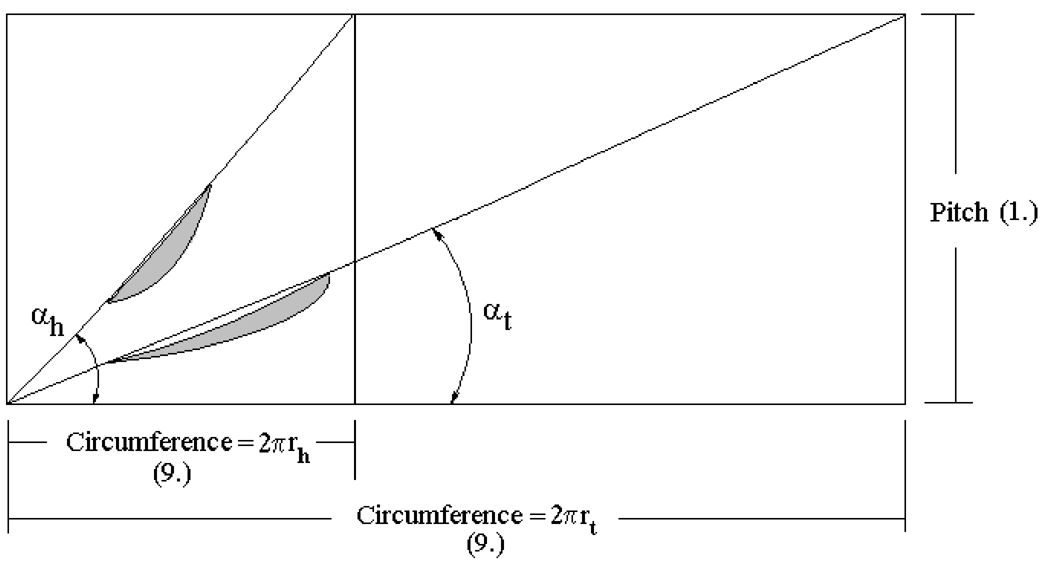

Figure 1.2C

Geometric Relationship between Pitch and Pitch Angle: $\tan(\alpha) = \dfrac{Pitch}{Circumference} = \dfrac{P}{2\pi r}$

1.3 Propeller Geometry: Skew, Rake, and Cup

Reference Figures 1.3A and 1.3B for the following terms.

No.	TERM	DEFINITION
1.*	Rake	The fore or aft slant of a blade with respect to a line perpendicular to the propeller axis of rotation.
1a.	Aft Rake	Positive Rake. Blade slant towards aft end of hub.
1b.	Forward Rake	Negative Rake. Blade slant towards forward end of hub.
2.	Track	The absolute difference of the actual individual blade rake distributions to the other blade rake distributions. Always a positive value and represents the spread between individual blade rake distributions
3.*	Skew	The transverse sweeping of a blade such that viewing the blades from fore or aft shows an asymmetrical shape.
3a.	Aft Skew	Positive Skew. Blade sweep in direction opposite of rotation.
3b.	Forward Skew	Negative Skew. Blade sweep in same direction as rotation.
4.	Cup	Small radius of curvature located on the trailing edge of blade.

* denotes terms that do not have a graphic representation to aid in definition

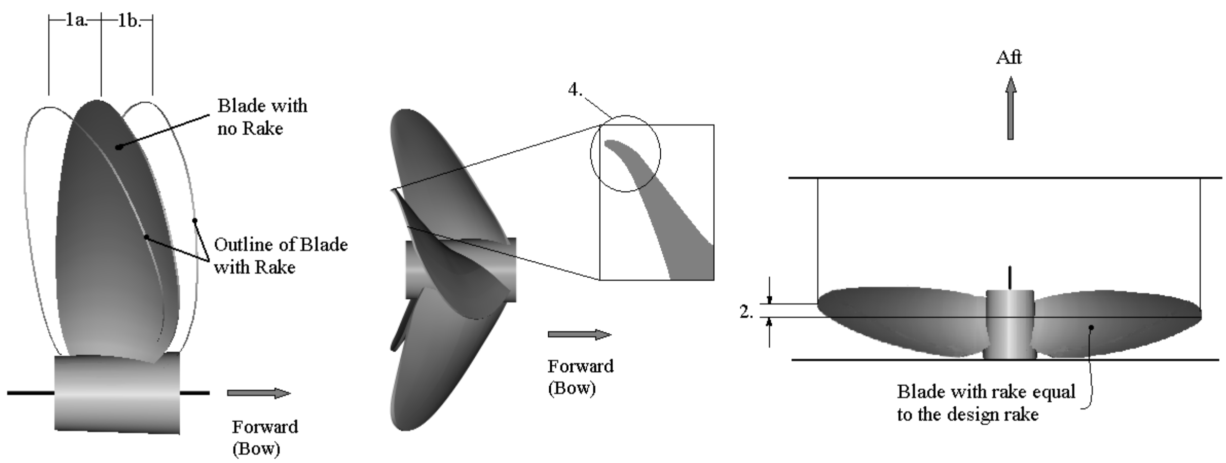

Figure 1.3A

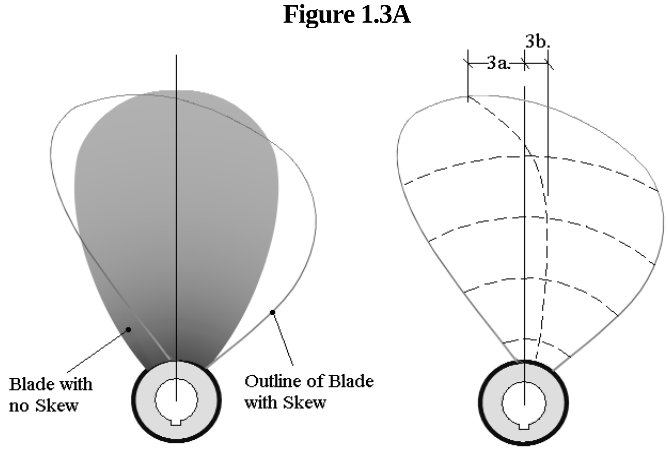

Figure 1.3B

1.4 Propeller Geometry: Blade Outlines and Areas

Reference Figures 1.4A and 1.4B for the following terms.

No.	***TERM***	***DEFINITION***
1.	Projected Outline	The outline of the silhouette created on a screen just forward of the propeller, by a light directly behind the propeller, shining directly forward.
2.*	Projected Area	The area enclosed by the projected outline.
3.	Developed Outline	An attempt to show the shape of the 2D body that would be attained by flattening a blade having zero thickness into a planar figure.
4.*	Developed Area	The area enclosed by the developed outline.
5.	Expanded Outline	This is the outline created when the pitch reference lines of blade cylindrical sections are expanded (drawn as straight lines, not as a helix) and swung parallel to one another.
6.*	Expanded Area	The area enclosed by the expanded outline.
7.	Disc Area	The area of the circle scribed by the blade tips. $Disc\ Area \equiv \left(\pi \times D^2/4\right)$, *where D is Diameter*
8.*	Projected Area Ratio (PAR)	Projected Area expressed as a percentage of total disc area. $PAR \equiv \left(Projected\ \ Area/Disc\ \ Area\right)$
9.*	Developed Area Ratio (DAR)	Developed Area expressed as a percentage of total disc area. $DAR \equiv \left(Developed\ \ Area/Disc\ \ Area\right)$
10.*	Expanded Area Ratio (EAR)	Expanded Area expressed as a percentage of total disc area. $EAR \equiv \left(Expanded\ \ Area/Disc\ \ Area\right)$
11.*	Blade Mean Width	The width of a rectangle with area equal to the expanded area of a single blade and with length equal to the distance from root to tip.
12.*	Mean Width Ratio (MWR)	$MWR \equiv \left(Blade\ Mean\ Width/Diameter\right)$

* denotes terms that do not have a graphic representation to aid in definition

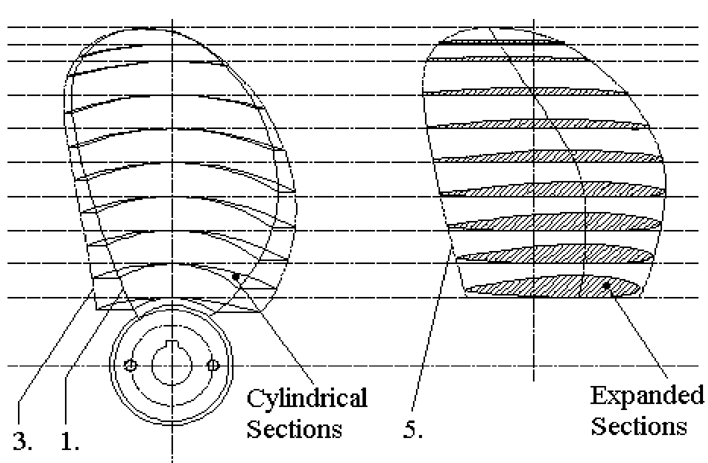

Figure 1.4A

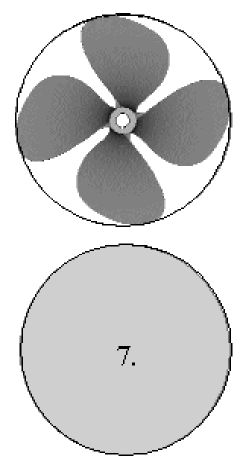

Figure 1.4B

1.5 Propeller Geometry: Blade Sections

Reference Figures 1.5A and 1.5B for the following terms.

No.	***TERM***	***DEFINITION***
1.	Airfoil	Section shape resembling traditional airplane wing section, with maximum thickness located approximately 1/3 to1/2 chord length aft of LE.
2.	Ogival	Section shape with flat blade face and symmetrically shaped blade back.
3.	Supercavitating	Section shape with sharp LE and max. thickness near TE, often with high camber.
4.	Chord Line	A helical line that connects LE to TE at a given radial location. In an expanded view, the chord line becomes a straight line and can be referred to as the nose-to-tail line.
5.	Chord Length	The length of the chord line.
6.	Mean Line	Camber Line. A reference line located halfway between the upper and lower surfaces, bisecting the section thickness.
7.	Thickness	The distance between upper and lower surfaces at a particular station measured perpendicular to the chord line.
8.	Maximum Thickness	The maximum distance between upper and lower surfaces measured perpendicular to the chord line.
9.*	Blade Thickness Fraction (BTF)	The maximum blade thickness as extended to the axis of rotation, divided by the propeller diameter.
10.*	Camber Value	The distance between the mean line and chord line at a particular station measured perpendicular to the chord line.
11.	Maximum Camber	The maximum distance between the mean line and the chord line measured perpendicular to the chord line.
12.	Offset	The distance measured perpendicular to the chord line from the chord line to the blade surface.
13.	Station	Reference location along the chord length of the section, usually used to locate pairs of thickness offsets.
14.	Leading Edge Radius	Radius defining the shape of the section LE.
15.*	Trailing Edge Radius	Radius defining the shape of the section TE.
16.	Symmetric Foil	Blade shape is symmetric about chord line.
17.	Non-Symmetric Foil	Blade shape is not symmetric about chord line.

* denotes terms that do not have a graphic representation to aid in definition

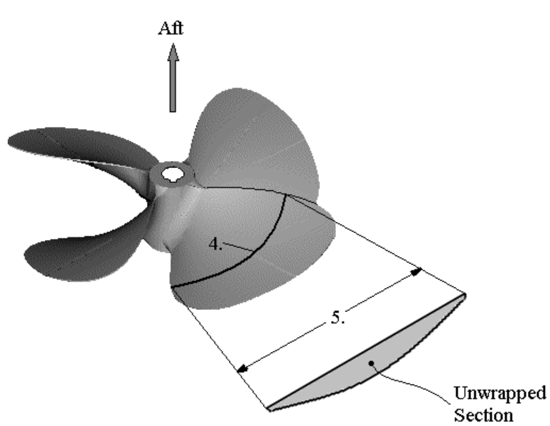

Figure 1.5A

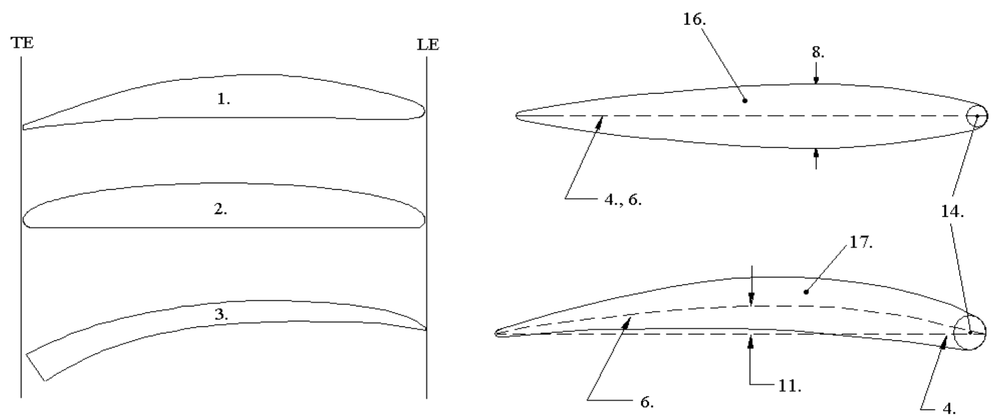

Figure 1.5B

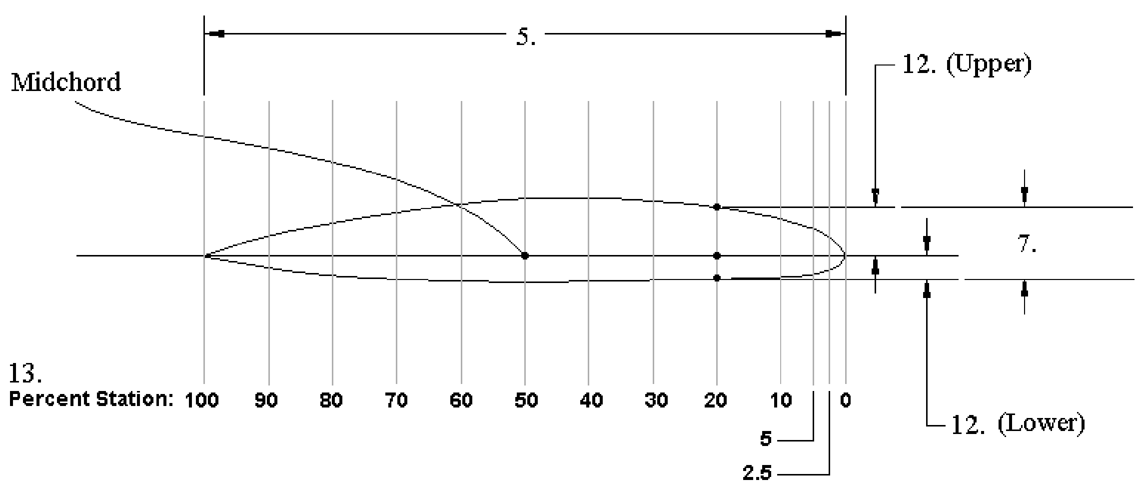

Figure 1.5C

1.6 Propeller Geometry: Hub and Blade Edge Details

Reference Figures 1.6A and 1.6B for the following terms.

No.	*TERM*	*DEFINITION*
1.	Aft End Diameter (AED)	The outer diameter of the aft end of the hub.
2.	Forward End Diameter (FED)	The outer diameter of the forward end of the hub.
3.	Hub Length	The length of the hub measured along the propeller axis of rotation.
4.	Keyway	A slender rectangular slot broached into the interior of the hub used to secure the propeller to the shaft.
5.	Bore	The hole bored through the center of the hub that can be either straight (cylindrical) or tapered (conic).
6.	Relief Bore	A section of the hub bore which is at a larger diameter than the remaining bore to aid in correct fit between hub and shaft.
7.	Edge Thickness	The thickness of the propeller blade edge.
8.	Flat Edge	Edge shape with square corners on both the pressure and suction sides of the blade.
9.	Rounded Edge	Edge detail rounding the corners of both pressure and suction sides of the blade.
10.	Chiseled Edge	Edge detail featuring a chamfered region located on the suction side of the blade.

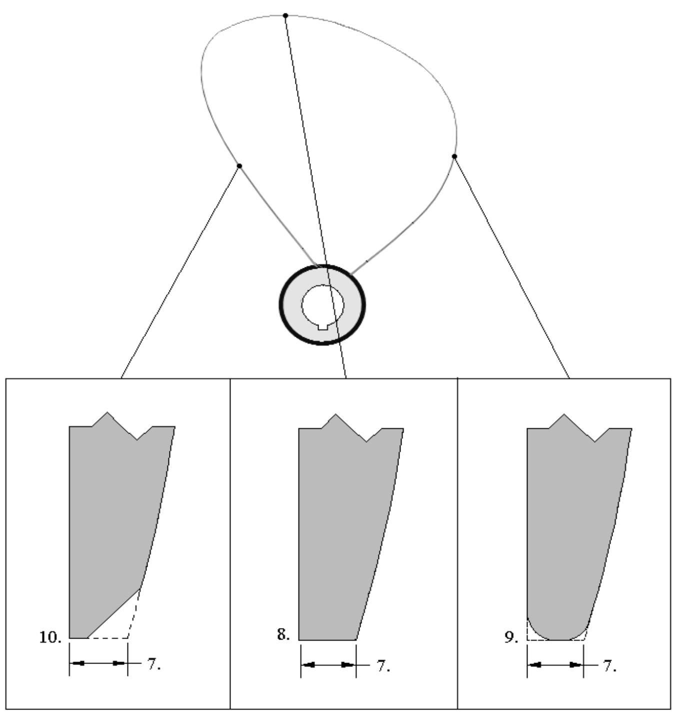

Figure 1.6A

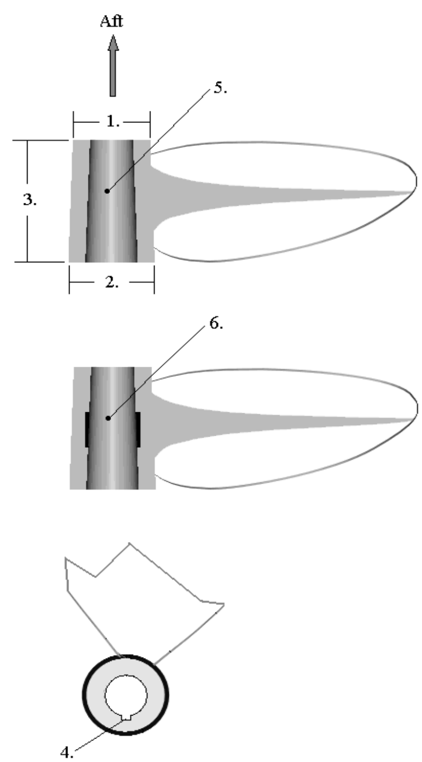

Figure 1.6B

2.1 Coordinate Systems

Three types of coordinate systems describe the region in which the propeller operates. Specifically, we wish to define the location in space of points on the surface or in the interior of a propeller blade, and the surrounding area. These coordinate systems are Cartesian coordinates, cylindrical coordinates, and expanded view coordinates.

Locations in 3D (true) space require three values to define the position completely. Perhaps the most popular means for doing this is with the use of Cartesian coordinates (x,y,z). In this coordinate system, the X, Y, and Z axes are perpendicular to each other, and the origin (x=0, y=0, z=0) is at the point where the X, Y, and Z axes intersect. A point P in space is located by giving a value for the offset distance from the X, Y, and Z axes respectively.

Common convention is that the x-axis is coincident with the propeller shaft axis, which is also coincident with the propeller centerline by definition. As shown in Figure 2.1A below, the positive X-direction is pointing forward, toward the bow of the vessel. In some cases, a convention showing positive X pointing downstream or aft simplifies analysis of the downstream wake, for example.

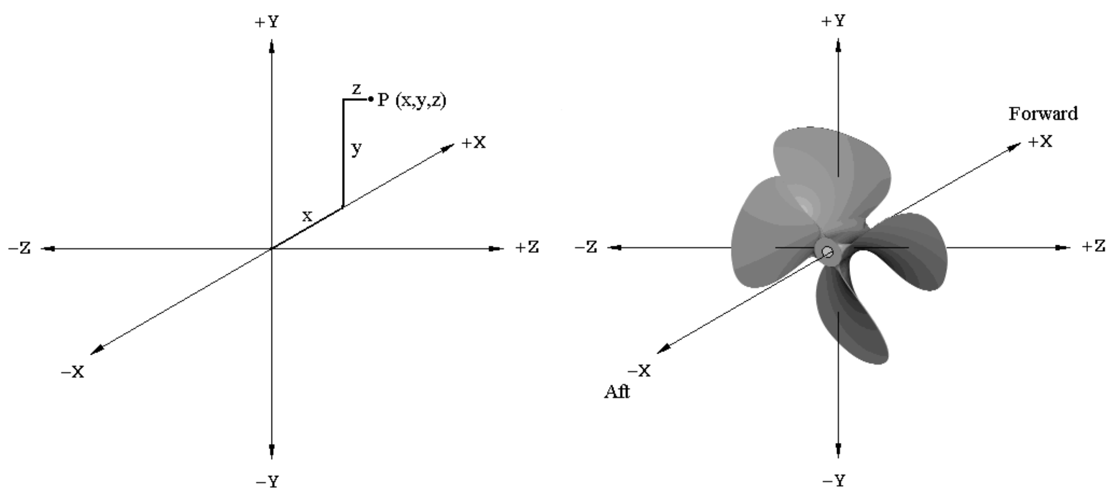

Figure 2.1A Cartesian coordinate system

The cylindrical coordinate system (x, r, θ) has the same X and Y axes as the Cartesian system, but a point P is located in the Y-Z plane using a combination of the radial distance (r) from the X-axis to the point, and the angle (θ) between r and the Y-axis. The sign of r is always positive; θ is positive when rotated clockwise from the Y-axis, negative when rotated counter-clockwise from the Y-axis. Cylindrical coordinates are very useful in computation and derivation.

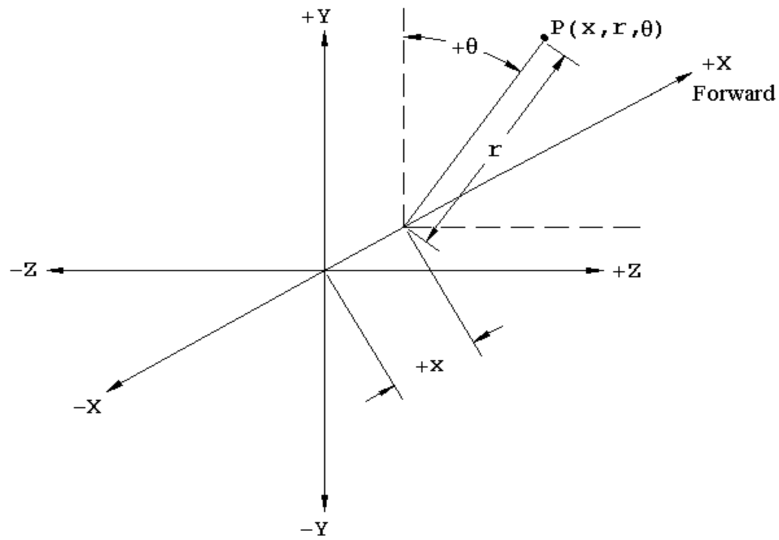

Figure2.1B Cylindrical Coordinate System

Expanded view coordinates (x, z') essentially take the Y direction out of the system. Imagine a cylinder with radius equal to the radius of the propeller, and aligned with the propeller axis of rotation. If the cylinder is then sliced longitudinally and unrolled, a plane (2D) surface results. This plane is an "expanded" view with the X-axis remaining the same as in Cartesian and cylindrical coordinates. The new axis created in the expanded view can be labeled Z'. Figure 2.1C depicts the derivation of the expanded coordinate system.

The expanded coordinate system can be referred to as the X-Z' plane.
The following characteristics of points and lines in the X-Z' plane should be noted:

1. An expanded view is not a true space view.
2. All points in the X-Z' plane are at the same radius (since the expanded view is an unwrapped cylinder).
3. A curve that is a helix in true space is a straight line in the X-Z' plane. Conversely, any straight line in the X-Z' plane is a helix in true space, with the exception of the axes.

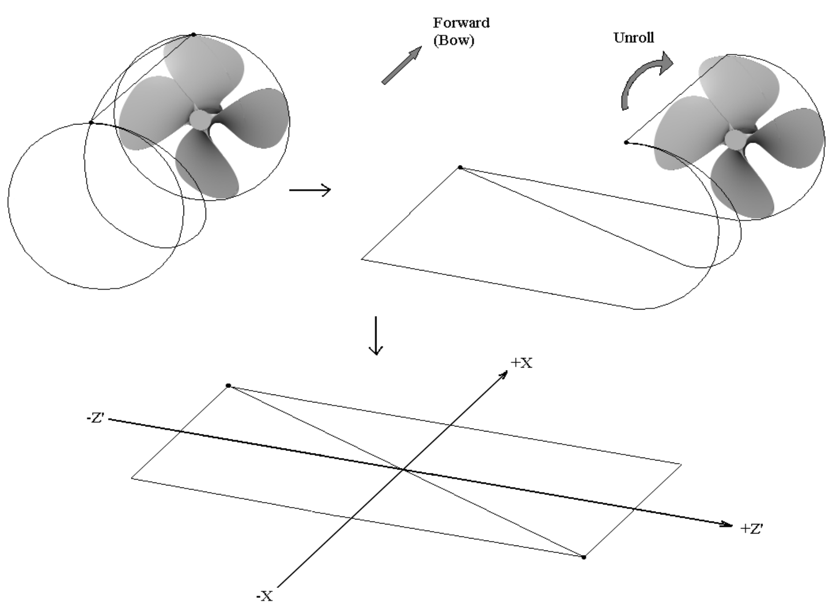

Figure 2.1C Expanded Coordinate System

A branch of the United States Navy called Naval Sea Systems Command (NAVSEA) is responsible for the manufacture and support of the country's fleet of ships. This task has motivated their development of many marine construction related standards and recommended practices. NAVSEA has presented a convention defining reference lines to aid in the definition of propeller geometry. These lines in combination with a general hub representation form a simplified model of a propeller to demonstrate geometry characteristics.

Propeller Centerline (PCL)
A straight reference line passing through the hub center or axis of propeller rotation.

Propeller Center Axis (PCA)
A straight reference line for each blade that is perpendicular to the PCL and locates the blades on the hub.

Blade Center Axis (BCA)
Linear (straight) or non-linear (curved) reference line that indicates propeller rake. When the rake is linear, the BCA is linear. When the rake is non-linear, the BCA is non-linear.

Blade Centerline (BCL)
Linear or non-linear reference line that intersects each cylindrical section at the center of each chord and indicates propeller skew.

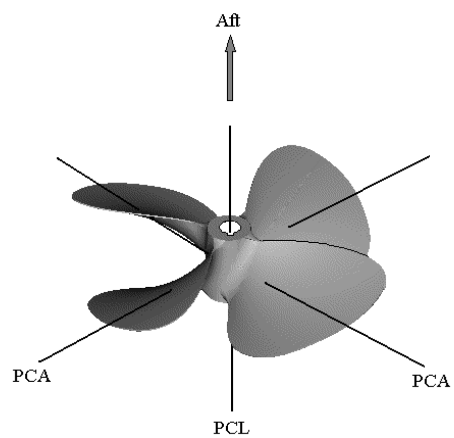

Figure 2.1D Propeller Centerline and Propeller Center Axes

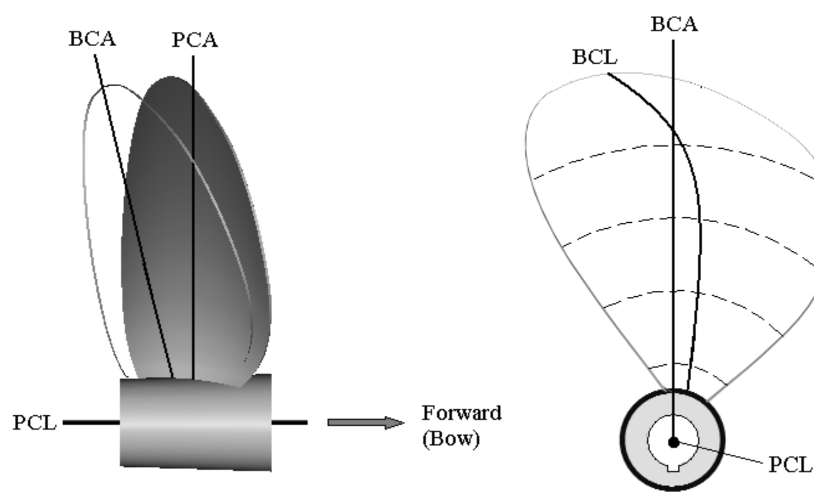

Figure 2.1E Blade Center Axis and Blade Centerline

2.2 Pitch

At this point a distinction is made between design section pitch and face pitch.

- Design section pitch is the pitch of the section as defined by the pitch reference line and is a constant, single value for the section. This is the pitch that the section (and the entire propeller if it is a constant pitch propeller) is designed to have. Since the pitch reference line does not necessarily lie on the blade surface, the design pitch can be difficult to measure on a finished propeller.
- Face pitch is the pitch of the propeller blade as measured from the physical blade surface rather than the pitch reference line.

On flat face sections, the pitch reference line often lies on the blade section surface, and thus the measured face pitch would correspond to a design section pitch value. Each local pitch reading along that section should be equal to the design section pitch since the pitch face is flat. In reality, the manufacturing process and accuracy of measurement equipment limits the accuracy to which a blade surface can be produced or measured. This means that even on a constant pitch propeller, local pitch readings will in general vary slightly along the chord of the sections as well as radially from hub to tip. Because of this, the measured pitch of a propeller may be best derived from a mean or average of the local pitch readings from all the blades. The aim in propeller manufacture is to ensure that the measured pitch will be equal to the design pitch within a specified tolerance.

In general, the pitch of a propeller is equal to the pitch of the propeller's blades.

- The average of the separate pitch values of the blades determines the propeller mean pitch value.
- The pitch of each blade is determined by averaging the pitch readings at various radial sections along the blade span.
- The pitch at each section can be found by the average of local pitch readings taken at various points along the section.
- Face pitch can be measured by finding the change in vertical distance ("drop") between a horizontal reference plane and the blade face as the blade rotates through a given angle, using a device called a pitchometer.
- Alternatively, the pitch of a propeller can be represented by the pitch at some radial location, for example at the 70 percent span location.

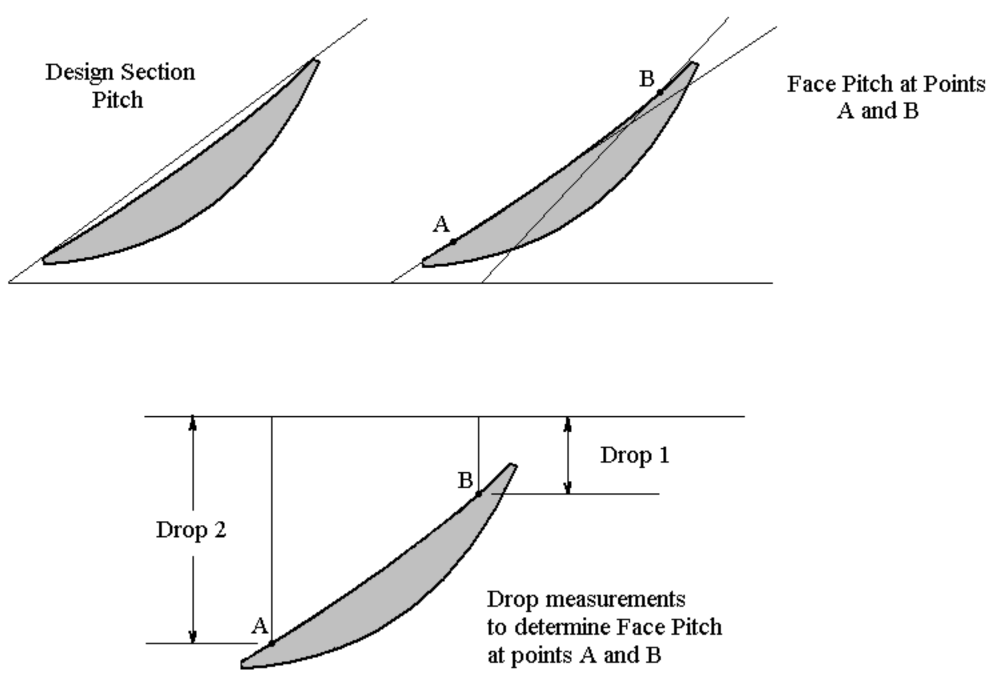

Figure 2.2A Design Section Pitch vs. Face Pitch

2.3 Skew, Rake, and Cup

Skew

In a propeller with skew, the blade shape is not radially symmetrical about a line perpendicular to the propeller axis of rotation. NAVSEA gives the following definition for skew:

- The displacement of the blade centerline from the blade center axis along the pitch reference line at each section.

Common methods for measuring skew include:

1. As offsets from blade centerline to blade center axis at each section.
2. As an angle from the center of the chord of each section to a reference line.
3. As the true length of the pitch helix between the midchord point on the pitch helix and the point of intersection of the pitch helix and the blade center axis.

Figure 2.3A below is a simplified diagram showing the relationship among NAVSEA reference lines and definition of skew and rake.

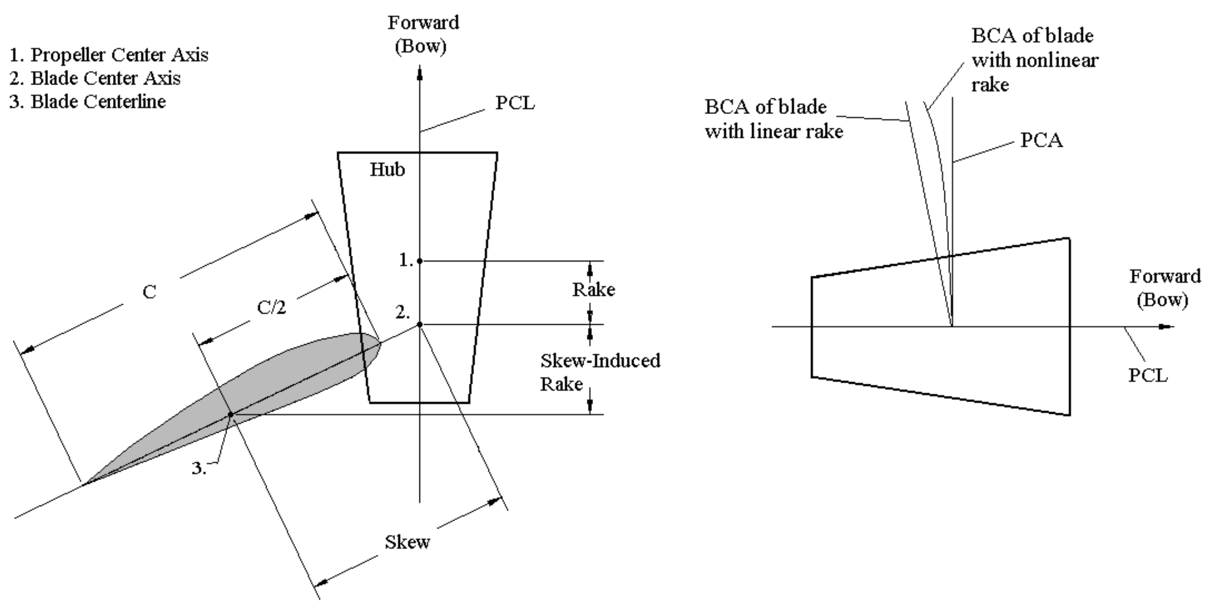

Figure 2.3A Reference Lines defining Skew and Rake

Rake

A propeller with rake has blades that slant fore or aft of a line perpendicular to the propeller axis of rotation. NAVSEA defines rake as:

- The axial displacement of the blade center axis from the propeller center axis at any radial position.

Common methods for measuring rake include:

1. As displacement at the tip from a line perpendicular to the propeller axis of rotation.
2. As an angle between the tip and a line perpendicular to the propeller axis of rotation.

The above two methods are effective for describing linear rake, since only two points are required to define a line. However, nonlinear rake implies that the axial displacement changes inconsistently as one moves radially outward and thus more than two points are required to define the rake of the blade. Perhaps it is more appropriate to describe nonlinear rake with the NAVSEA definition, for example with a table listing axial displacement versus radial location.

<u>Cup</u>

Propeller blades with cup have a small bend in the trailing edge of the blades. The amount and the location of the bend are the two main variables in cup geometry. The bend is always toward the aft of the boat, or toward the pressure face of the blades. The location of the cup can vary along the radius of the blade, but is commonly present on the outer radii. The cup can extend to and even past the blade tips. Figure 2.3B shows a typical cup location, from the 0.5 radius to the tip.

There exists no industry-wide standard on cup measurement and application. The amount of cup in a propeller blade is described using differing terminology. The adjectives light, medium, and heavy are commonly used but difficult to quantify. One method used to define cup assigns a number to represent offset of the trailing edge from the face of the blade. For example, a common value of 0.015 inches of offset per cup number would result in a “number 4” cup being an offset of 4 x 0.015 = 0.060 inches. An additional method for specifying cup would be to specify a cup length along with a radius of curvature for the cupped blade to follow. Figure 2.3B shows these two methods.

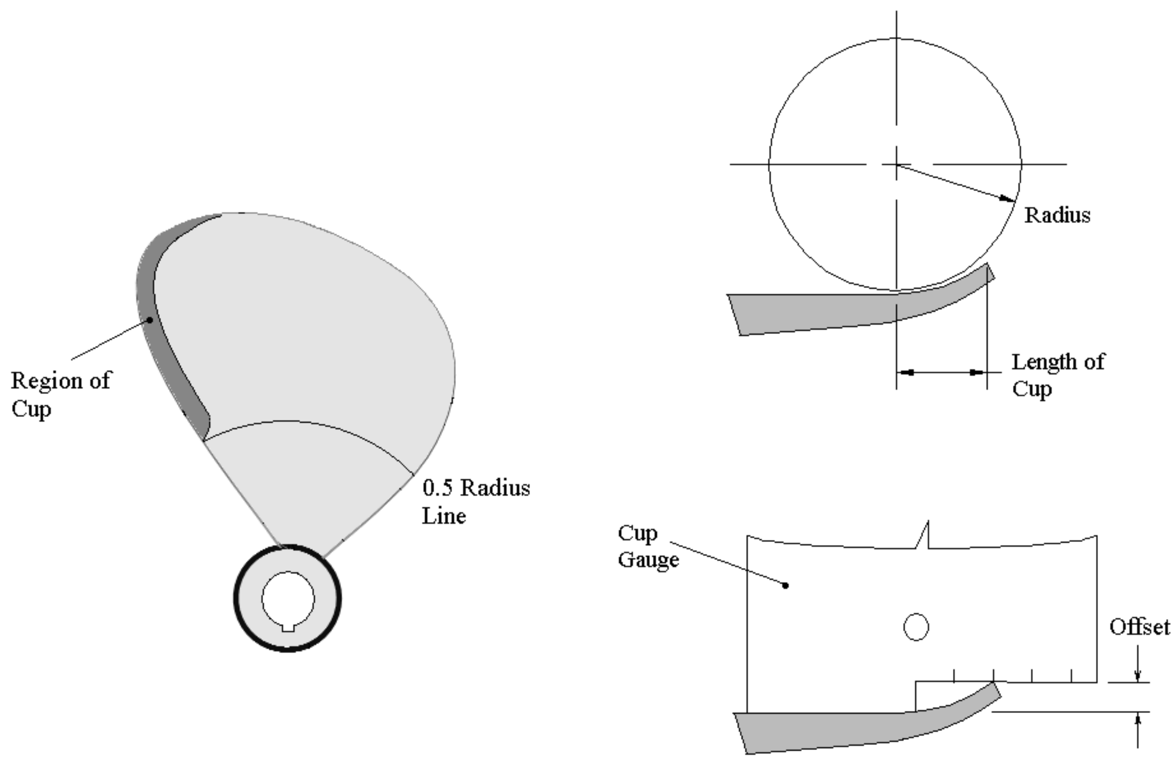

Figure 2.3B Location and Measurement of Blade Cup

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