Propellers:
Nomenclature & Materials
What are we going to learn in this lesson?

• Identify the parts and characteristics of a propeller

• Describe typical propeller materials and manufacturing methods
Reading Assignment:

• HBTW, pp. 50-56.
Propeller Terminology
Hub

- Center part of propeller that connects the propeller to the shaft.
Diameter

• Diameter of circle with center of circle at center of *hub* and perimeter of circle passing through all the blade tips.

• Usually measured in inches, typically to the nearest inch (on inboard propellers).
Pitch

• Pitch is the theoretical linear distance the propeller travels in one revolution.

• Usually measured in inches.

• Propeller pitch is usually specified to the nearest inch, but sometimes to the nearest half inch on some planing powerboat propellers.
Number of Blades

- Boat propellers typically have 2, 3, 4 or 5 blades depending on the application.

- More blades:
  - Less vibration
  - Absorb more power
  - Create more drag

Michigan Wheel Propellers
Rotation
(all when viewed from astern)

- Right-hand, clockwise
- Left-hand, counter-clockwise
- Foot (or hand) test for prop rotation.
- Propellers turn outboard on conventional twin screw installations.
- **Exception!** Many high performance (60+ mph) have inboard turning propellers.
Propeller Markings

- Diameter, pitch and rotation are typically stamped on propeller hubs, in that order.
- "18 x 16" RH" means:
  - 18" diameter
  - 16" pitch
  - right-hand rotation

from Michigan Wheel
Blade Leading Edge and Trailing Edge

• The **leading edge** is the vertical edge of blade that first encounters water when propeller is turning.

• The **trailing edge** is the vertical edge of blade opposite the leading edge.
Blade Tip and Root

- The blade **tip** is the outermost portion of the blade.
- The blade **tip** separates the leading and trailing edges.
- The blade **root** is where the blade attaches to the hub.
Blade Width

• The width of the blade, usually measured at the "seven tenths" radius.

• The seven tenths radius is a distance measured from the hub centerline out 70% toward the tip of the blade.
Blade Face

• The blade face is the blade surface that faces aft (relative to the boat).

• When the propeller is turning, a positive pressure is developed on the blade face.
Blade Back

• The blade back is the blade surface that faces forward (relative to the boat).

• When the propeller is turning, a negative pressure is developed on the blade back.
Blade Area Ratios (BARs)

- **Blade Area Ratios (BARs)** compare the blade area (of either the face or the back) of a propeller to the area of a circle with a diameter equal to the diameter of the propeller (the **Disc Area**).

- We are most concerned about blade area when analyzing the power absorption ability of a propeller and the likelihood of cavitation.

- Highly loaded propellers (propellers transmitting high horsepower relative to the speed of the boat) require a lot of blade (surface) area.
Comparison of Blade Areas

Increasing Blade Area

Michigan Wheel Propellers
Three commonly used BARs

• Projected Area Ratio (PAR)

• Disc Area Ratio (DAR)

• Expanded Area Ratio (EAR)
Projected Area Ratio (PAR)

• The PAR is the projected area of the outline of the propeller divided by the disc area. Sort of like making shadow silhouettes on the wall.

• It is the smallest of the three area ratios and the least useful from a technical standpoint.
Disc Area Ratio (DAR)

- The DAR is similar to the PAR, but the blades are rotated to "0" pitch. The projected area of the rotated blades is divided by the disc area.

- DAR = Rotated Total Blade Area / Area of a Circle (with diameter same as propeller)

- DAR is larger than PAR.
Expanded Area Ratio (EAR)

- The EAR is similar to the DAR, but the blades are not only rotated, they are also "unwrapped" from the hub. This accounts for any curvature in the propeller blades, which is typically minimal.

- EAR is slightly larger than, but very close to, DAR.

- We will use the two (EAR and DAR) interchangeably for our work.
Typical DAR/EAR ratios

- Typical DAR/EAR ratios vary from 0.5 to 0.92 depending on application.

- 2-blade sailboat propellers might have a DAR/EAR of 0.4 or less. The sailor is more worried about drag under sail than optimum performance under power.

- The typical 3-blade powerboat propeller might have a DAR/EAR of around 0.60.

- A typical planning boat will have a 4-blade propeller with a DAR/EAR between 0.70 and 0.92.

- A DAR/EAR greater than 1.0 is possible if the blades overlap each other (similar to a submarine propeller).
Comparison of Blade Areas

Increasing Blade Area

Michigan Wheel Propellers
**Rake**

- Rake is the angle of the blade to the perpendicular (to the shaft) in profile.
- Most inboard propellers have zero rake.
- Most outboard and sterndrive propellers have positive rake (blade tip aft of blade root).
- Increasing rake effectively increases diameter, and helps propellers operating in a cavitating environment.
Sweep

- **Sweep** is the angle of the blade to the perpendicular (to the shaft) in plan view.

- Most inboard propellers have zero sweep (unlike outboard and sterndrive propellers).

- Blade sweep is usually used to reduce propeller noise or to help shed weeds.
Cupping

• **Cupping** is a subtle curling of the trailing edge or tip of the propeller blades.

• Cupping can improve performance and reduce cavitation.

• Cupping is used to “fine tune” a propeller after all the basic parameters, especially pitch, have been determined.
Where to cup?

- Cupping along the blade **trailing edge** effectively **increases pitch**.

- Cupping along the blade **tip** effectively **increases rake** (and therefore **diameter**).
Propeller Types

• Fixed Blade
  – Power
  – Sail

• Folding
  – Simple
  – Geared

• Feathering

• Controllable (or Variable) Pitch
Fixed Blade Propellers

• Power
  – 2-, 3-, 4-, and 5-blade propellers
  – Blade area

• Sail
  – 2- and 3-blade
  – Narrow blades
  – Low drag
Folding Propellers

- **Sailboats**
- Typically 2-blade, some 3- and even 4-blade
- **Simple Folding**
  - inexpensive
  - “floppy blade syndrome”
- **Geared Folding**
- Very low drag when folded
  - Mark propeller shaft coupling
- Reduced performance backing down
Feathering Propellers

- Sailboats
- 2- or 3-blade
- **Good performance ahead and astern**
- Low drag when feathered
- **Expensive**
Controllable (or Variable) Pitch Propellers

- Rare on small to moderate size yachts
- More likely on tugs, ferries and commercial vessels
- Maximize available shp (minimize “gap” between engine and prop HP curves)
- Increases control in twin screw application
- Very expensive and complex
- Large hub diameter/drag
(Not so good) Vibrations

• Folding, feathering and controllable (variable) pitch propellers all increase the likelihood of shaft vibration.

• Propeller is heavier and center of gravity moves aft.

• Always check unsupported shaft length calculation when switching to, or allowing for, one of these propellers.
Propeller Materials

and

Manufacturing Methods
Propellers are typically made from:

- Bronze
- Aluminum
- Stainless Steel
Bronze Propellers

- Many inboard propellers and almost all sailboat propellers are made from manganese bronze.

- High performance inboard propellers are made from NiBrAl (Nickel-Bronze-Aluminum)

- NiBrAl is stronger than manganese bronze which allows for thinner propeller blades (and less cavitation) and helps to prevent damage from cavitation.

- NiBrAl is also more expensive than manganese bronze.
Aluminum and Stainless Steel Propellers

- Outboard and sterndrive propellers are usually made from die cast aluminum or investment cast stainless steel.
Propeller Manufacturing Methods
Sand Casting

- Bronze propellers are typically sand cast
- Sand casting is cost effective for low volume applications.

Advantages/Disadvantages:
- Initial pattern and mold cost is low
- Each part requires significant post-finishing
- The “mold” can not be reused
Sand Casting Process

One half of the pattern

Flask placed over the first pattern

One half the mould (cope)

Other half of the pattern

Flask placed over the second pattern

Other half the mould (drag)

Assembled molds

Casting through the gating system

The solidified casting

Wikipedia
Green Sand Casting

Diagram of a Green Sand Mold Section:
- Cope Flask
- Set Core
- Casting
- Sprue
- Gate
- Runner
- Green Sand
- Parting Line
- Core Print
- Drag Flask

Pouring Basin
- Flask Pin and Bushing
- Draft
Sand Casting Process

- A pattern is made. The pattern is oversize to account for the shrinkage of the material.

- The pattern is placed in a flask
  - The flask is essentially a two-part wooden box.
  - The lower half of the flask is called the drag.
  - The upper part of the flask is called the cope.
  - The flask splits at the parting line.

- Cores are used to control the thickness of the raw casting (for example where the hub is to be bored out for the shaft).
Sand Casting Process (cont'd.)

- Gates, sprue(s) and riser(s)

  - The pattern includes a system of gates, sprue(s) and riser(s) to distribute the molten metal.
  - Gates are distribution channels or pipes
  - A sprue is a funnel shaped opening into which the molten metal is poured
  - A riser is a column above the part (sometimes combined with the sprue) to provide a reservoir of molten metal on the part for shrinkage and static pressure for flow.
  - Sand is poured into the drag and then the cope around the pattern
  - Molten bronze is poured into the cavity in the sand left by the pattern
    - Typical melting points:
      - NiBrAl: 1190-1215 deg F
      - Manganese bronze: 1590-1630 deg F
  - The rough casting is allowed to cool and then removed from the sand mold (which is destroyed) for subsequent machining and finishing
Die Casting

• Die casting is typically used to make aluminum propellers
• Die casting is good for high volume parts

• Advantages/Disadvantages:
  – Cast parts require little post-finishing
  – The initial mold cost is significant
Die Casting Process

Process Schematic

- Metal
- Parting line
- Sprue
- Riser
- Casting
- Clamps
- Permanent mould
Die Casting Process

- A precision, split mold is machined.
  - Typical mold material is carbon steel
  - Sometime molds are made from cast iron
- The molten metal is poured into the precision mold
- The mold is opened after the part cools, the part removed and the mold is reused.
- Melting Points
  - Aluminum melts at 865-1240 deg F (depending on the alloy)
  - Cast iron melts at 2150-2360 deg F
  - Carbon steel melts at 2600-2800 deg F
Investment Casting

• Investment casting is typically used to make stainless steel propellers
• Investment casting is also referred to as the “lost wax” or “lost foam” process.
• Investment casting is good for high volume parts
• **Advantages/Disadvantages:**
  – Cast parts require little post-finishing
  – Investment casting can be used with high melting point materials (stainless steel melts at 2750 deg F)
  – The initial cost of making patterns and molds is significant
  – “Molds” can not be reused.
Investment Casting Process

Die Construction (15 to 25 weeks)
Wax Injection (2 to 5 min/part)
Wax assembly (1 to 4 hr/assembly)
Slurry coating and stuccoing (3 days)

Dewaxing (1 to 2 hr)
Casting (Equilax, 10 min; DS and single crystal, 2-6 hr)
Shell removal (15 min/part)
Cut off (15 min/part)
Finishing (30 min/part)
Inspection (45 to 90 min/part)

FoundaryMag.com
Investment Casting Process

Pattern Tree  Shell-Making  Investment Casting  Casting

Runner
Sprue
Wax gating system
Wax patterns
Ceramic shell
Flask
Ceramic slurry
Molten metal
Ladle
Hollow ceramic shell
Finished casting

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Investment Casting Process

• A precision, split mold is machined (typically from carbon steel) for the purpose of making patterns.
• Wax or foam is poured in to the mold to make a pattern.
• The pattern (typically consisting of a tree holding several individual parts) is dipped in a ceramic slurry to build up the mold to make the final part(s)
• When the ceramic mold hardens it is heated to remove the wax patterns or a solvent is poured in to dissolve the foam patterns.
• Molten metal is poured into the hollow ceramic mold
• When the metal cools the ceramic molds are cracked open and the final parts removed.
Next Lesson:

More Propellers:
Slip, efficiency, cavitation, ventilation, sea trials