به نام خدا

کارگاه آموزشی

طراحی پیشبرنده

ارائه کننده :

سهیل بزرگی

کارشناسی ارشد مهندسی دریا

سومین دوره مسابقات شناورهای هوشمند

The 3rd Autonomous Surface Vehicle Competition

دانشگاه صنعتی شریف

برگزار کننده :

دانشگاه صنعتی شریف

انجمن مهندسی دریا

سرفصل مطالب

- معرفی انواع پیشبرنده های دریایی و ویژگی های آن ها
- معرفی پارامترهای موثر در عملکرد پروانه های دریایی
- تعیین پارامترهای طراحی پروانه با توجه به نقطه طراحی

انواع پیشبرنده ها

- Propellers
  - Fixed Pitch
  - Controllable (Reversible) Pitch
  - CRP
  - Super Cavitating
  - Ducted
  - Vertical Axis
- Jet
  - Water jet
  - Pump jet
- Podded Propulsion

پروانه های با گام ثابت (FPP)

مزایا

- **راندمان بالا تا سرعت های مختلف بر حسب نوع**
- **هزینه کم**

معایب

- **قابلیت کارکرد در شرایط عملیاتی محدود**

پروانه های با گام متغیر (CPP)

مزایا

- **تراست رو به عقب بدون نیاز به جعبه دنده**
- **محدوده عملکرد وسیع**
- **سازگاری بهتر با موتور در سرعت های مختلف**
- **افزایش مانور پذیری شناور**

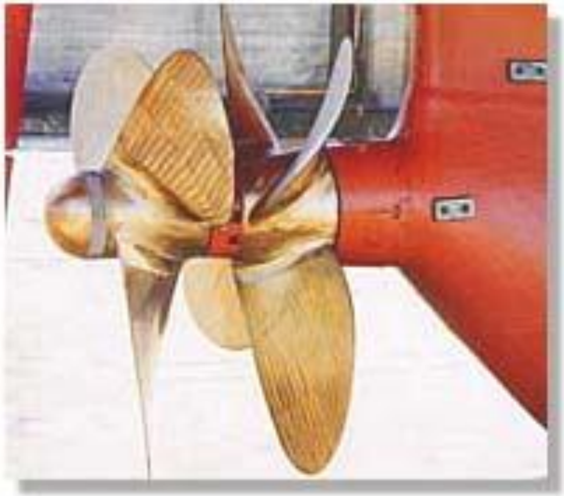
معایب

راندمان کمتر نسبت به F.P.P

پیچیدگی ساختار

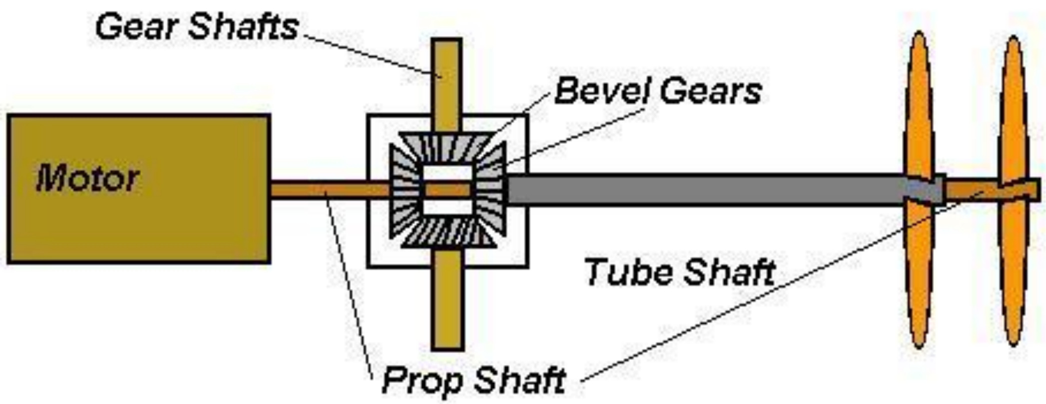
هزینه بالا

پروانه های معکوس گرد Contra-Rotating Propellers



+ تعادل در گشتاور
+ راندمان بالا
+ ارتعاشات و نویز کم

– پیچیدگی و هزینه بالا



پروانه های نیمه مغروق

- راندمان رانش بالا در سرعتهای بالا
- کاهش درگ ملحقات
- امکان استفاده از پروانه های بزرگتر
- کاهش خوردگی سایشی سطح پره ناشی از کاویتاسیون

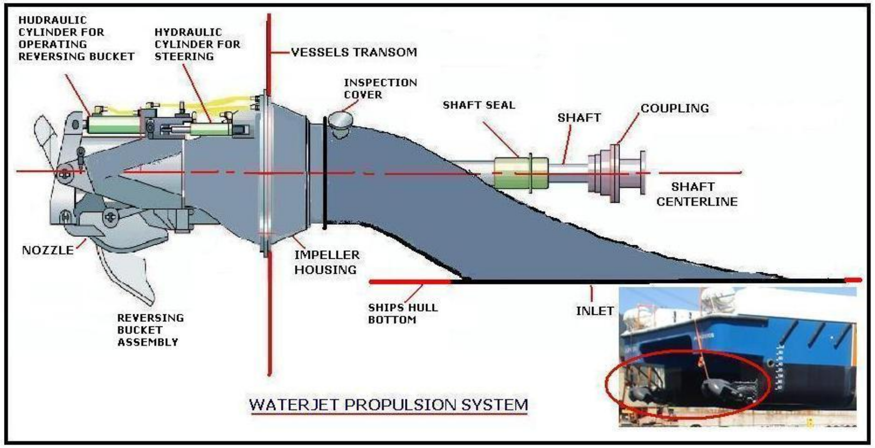
- افزایش ارتعاشات
- پیچیدگی وهزینه بالا
- در معرض بارگذاری نوسانی شدید

واتر جت (جت آب)

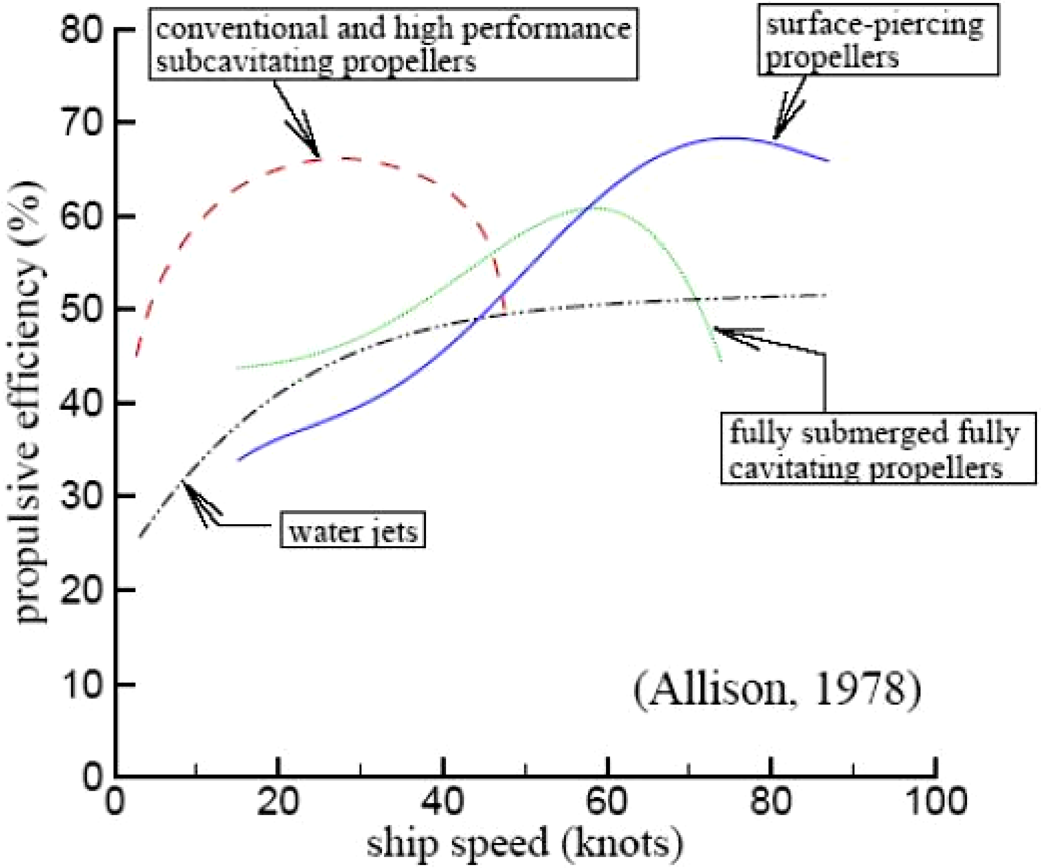
- مزایا:
- راندمان بالا در سرعت های بالا
- قابلیت عملکرد در آب کم عمق
- مانورپذیری بالا

معایب:

- هزینه بالا
- مشکلات تعمیر و نگهداری



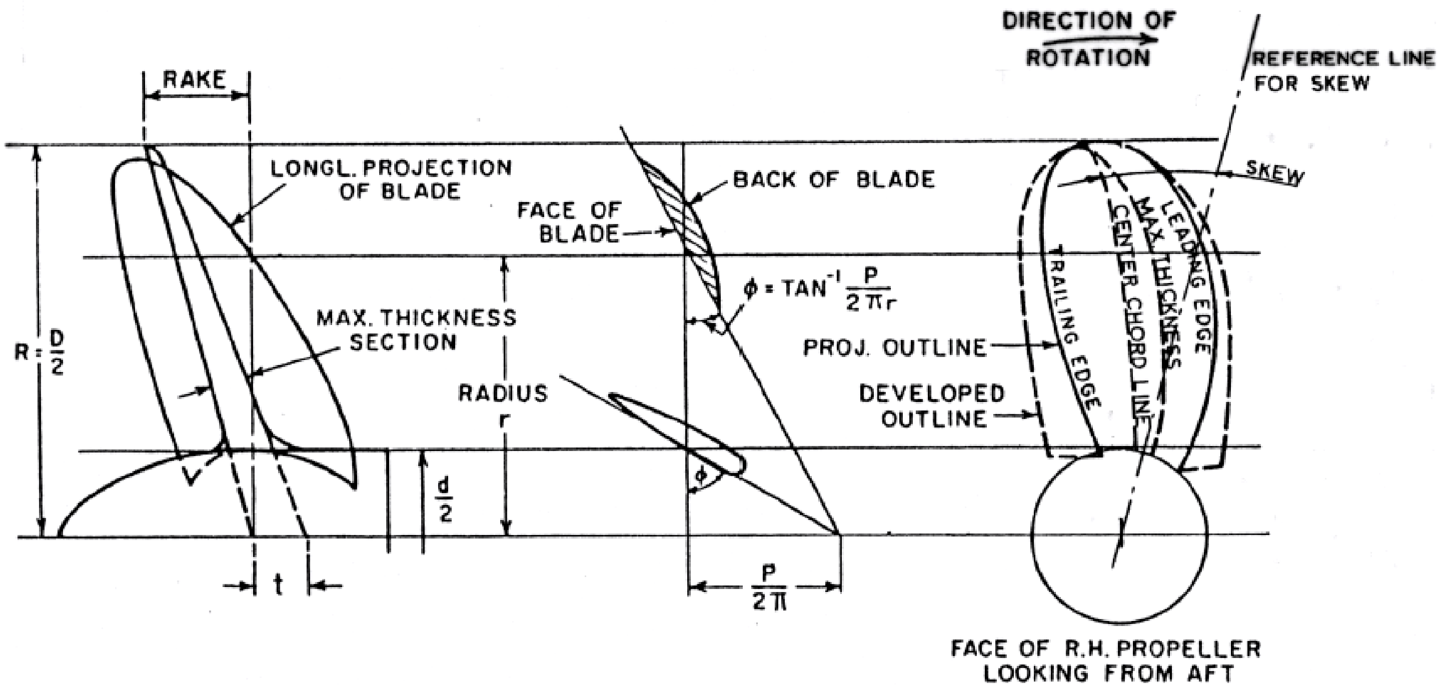
مقایسه انواع پیشبرنده ها



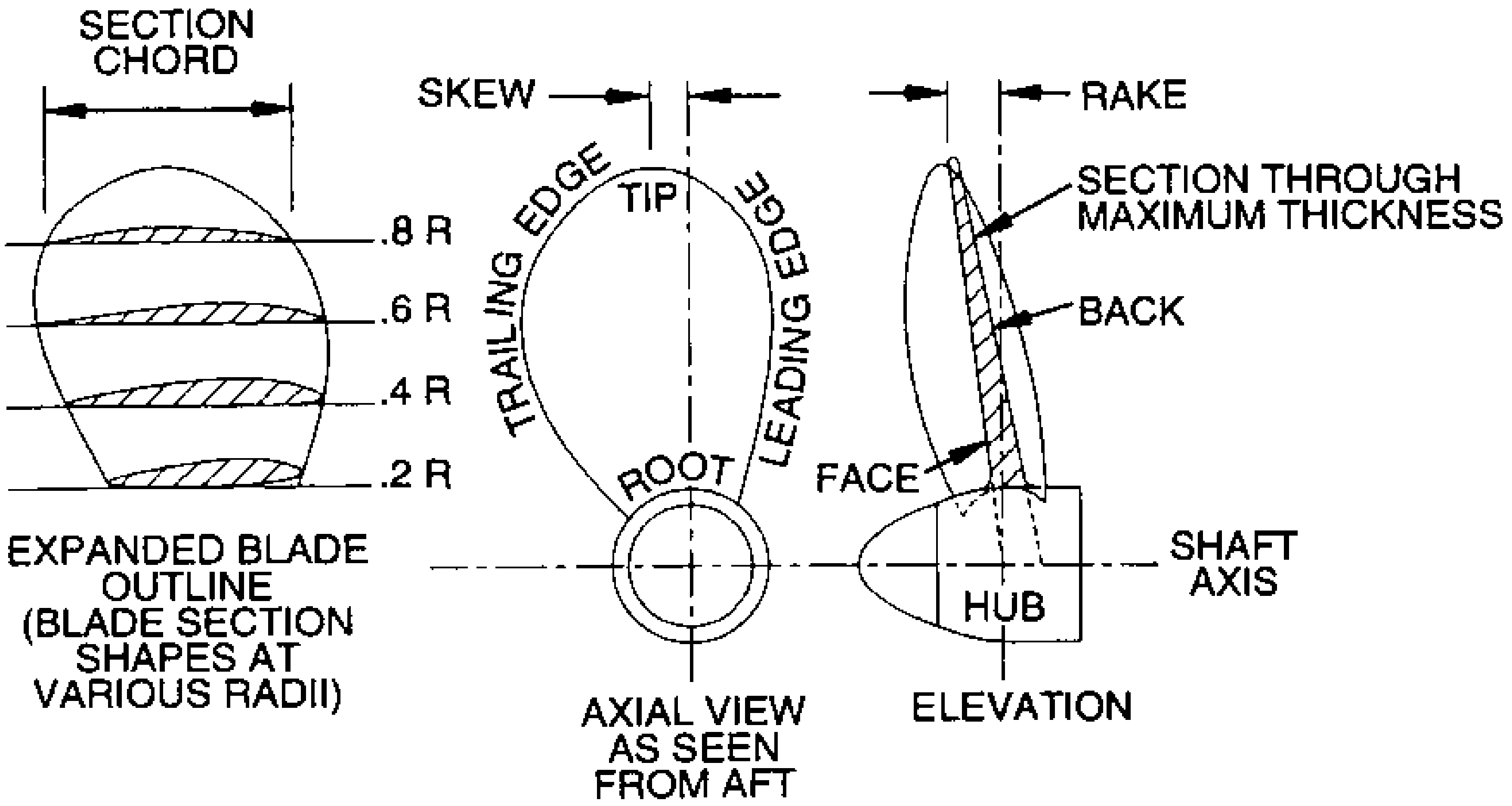
مشخصات پروانه

- Blade
  - Tip
  - Root
  - Leading Edge
  - Trailing Edge
  - Pitch Angle
  - Angle of Attack

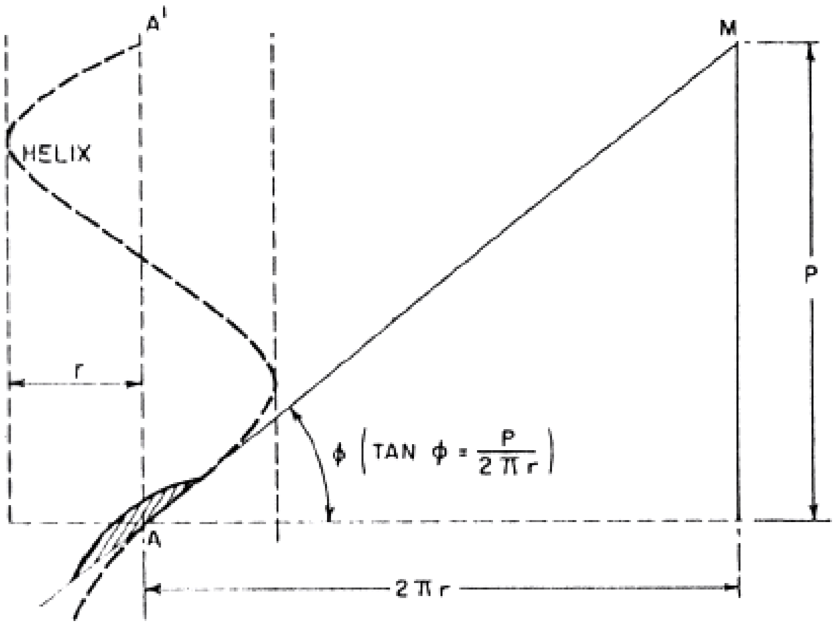
- Diameter
- Pitch
- Skew
- Rake
- Area
- Slip
- Thrust



مشخصات هندسی پره

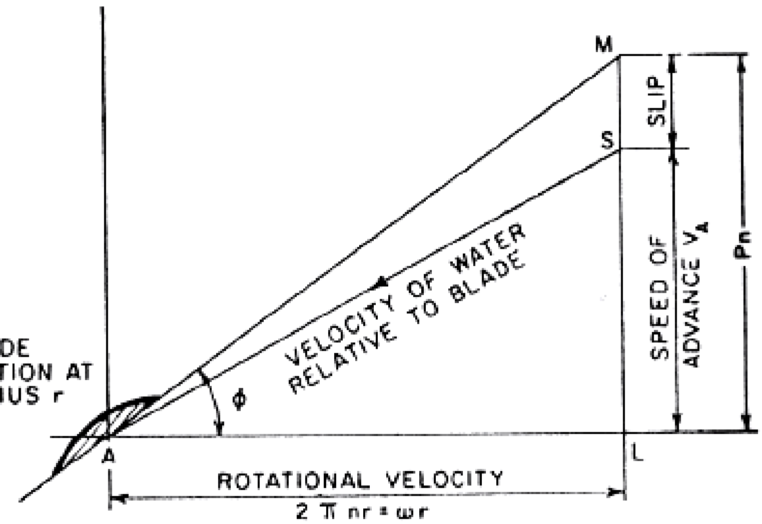


گام پروانه



Definition of pitch angle

ϕ = Pitch angle of screw propeller

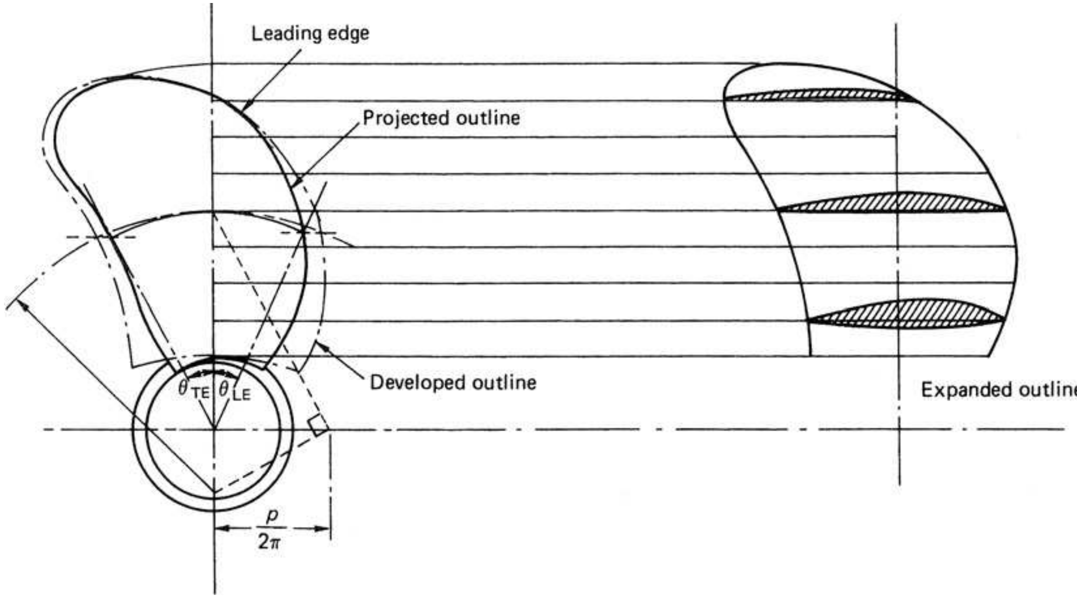


Definition of slip

$$\tan\phi = \frac{Pn}{2\pi nr} = \frac{P}{2\pi r}$$

$$\text{Real slip ratio } s_R = \frac{MS}{ML} = \frac{Pn - V_A}{Pn} = 1 - \frac{V_A}{Pn}$$

سطوح پروانه



$$\text{Disk area} = \text{area of tip circle} = \frac{\pi}{4}D^2 = A_O$$

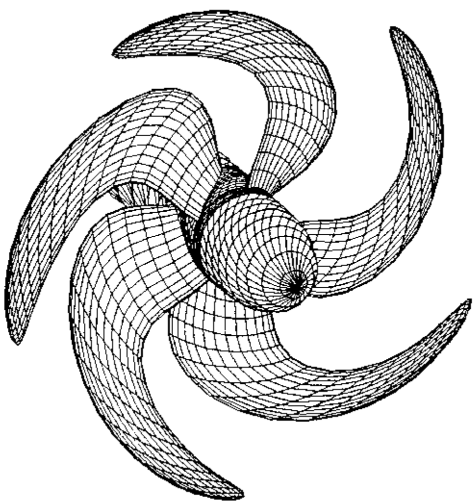
$$\text{Developed area of blades, outside hub} = A_D$$

$$\text{Developed area ratio} = DAR = \frac{A_D}{A_O}$$

$$\text{Projected area of blades (on transverse plane) outside hub} = A_P$$

$$\text{Projected area ratio} = PAR = \frac{A_P}{A_O}$$

اسکیو



The best practical option for reducing unsteady flow forces on the propeller, and thus reducing vibration is to skew the blades. The mid radius of a skewed propeller is in the same place as that of a conventional radial propeller, but the relationship between inner and outer radius is shifted, the tip hits it later and there follows a cancellation of forces. A skewed propeller can be “tuned” to a specific wake field in order to reduce the excitation at a given harmonic, and thus be very effective in reducing vibration.

اصول تشابه

- Dimensional analysis:

$$T = f(\rho^a D^b V_A^c g^d n^e p^f \mu^g)$$

- Result is:

$$\frac{T}{\frac{1}{2}\rho D^2 V_A^2} = f\left(\frac{gD}{V_A^2}, \frac{nD}{V_A}, \frac{p}{\rho V_A^2}, \frac{\nu}{V_A D}\right)$$

قوانین مقیاس بندی در تست مدل

$$\frac{T}{\frac{1}{2}\rho D^2 V_A^2} = f\left(\frac{gD}{V_A^2}, \frac{nD}{V_A}, \frac{p}{\rho V_A^2}, \frac{\nu}{V_A D}\right)$$

- Introduce the scale ratio: $\frac{D_S}{D_M} = \lambda$
- Froude scaling results in: $\frac{V_{AS}}{V_{AM}} = \lambda^{1/2}$
- nD/V_A equality results in slip ratio equality.
- The third coefficient cannot be made equal unless we adjust the ambient pressure - cavitation tests.
- The fourth coefficient (Reynolds number) cannot be made equal. This is not as serious as for resistance.

قوانین مقیاس بندی در تست مدل

$$\frac{D_S}{D_M} = \lambda$$

$$\frac{V_{AS}}{V_{AM}} = \lambda^{1/2}$$

$$\frac{T_S}{T_M} = \frac{D_S^2 V_{AS}^2}{D_M^2 V_{AM}^2} = \lambda^3$$

$$\frac{n_S}{n_M} = \frac{D_M V_{AS}}{D_S V_{AM}} = \lambda^{-1/2}$$

$$n_M = n_S \lambda^{1/2}$$

$$\frac{P_{TS}}{P_{TM}} = \frac{T_S V_{AS}}{T_M V_{AM}} = \lambda^{3.5}$$

$$\frac{Q_S}{Q_M} = \frac{P_{TS}}{n_S} \cdot \frac{n_M}{P_{TM}} = \lambda^4$$

ضرایب پروانه

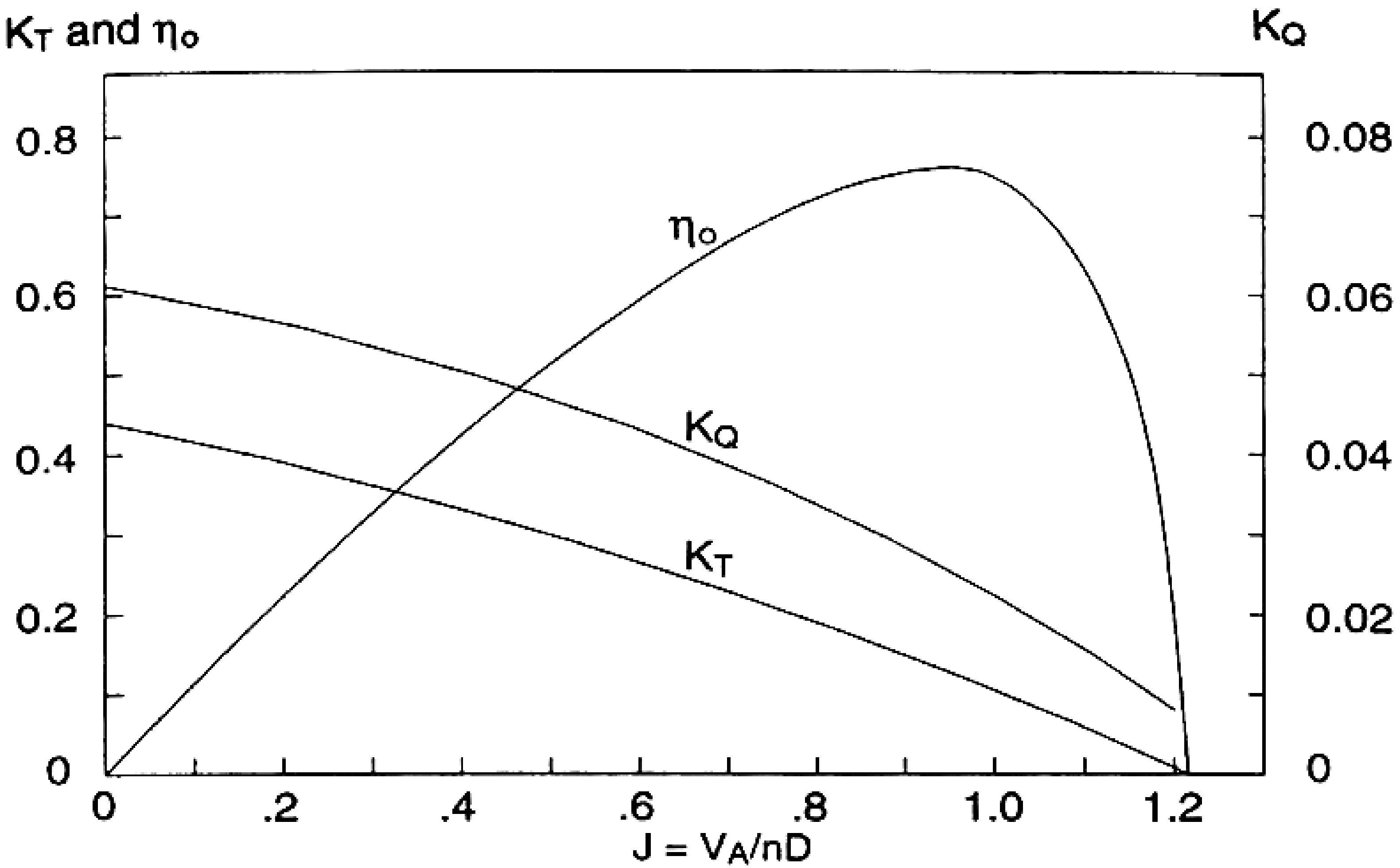
$$K_T = \frac{T}{\rho n^2 D^4} \quad ; \qquad \text{Thrust coefficient}$$

$$K_Q = \frac{Q}{\rho n^2 D^5} \quad ; \qquad \text{Torque coefficient}$$

$$\eta_0 = \frac{J}{2\pi} \cdot \frac{K_T}{K_Q} \quad ; \qquad \text{Open water propeller efficiency}$$

$$J = \frac{V_A}{nD} \; ; \qquad \text{Advance ratio,}$$

منحنی های عملکردی پروانه



اندرکنش بدنه - پروانه

- Wake
- Slip ratio
- Relative Rotative Efficiency
- Thrust deduction
- Hull efficiency
- Propulsive efficiency

ویک

- The difference between the ship speed V and the speed of advance V_A is the wake speed.The wake fraction is defined as:
- $w = (V - V_A) / V$ so $V_A = V (1 - w)$

تک پروانه ای:

$$(Taylor)\quad w = -0.05 + 0.5\, C_B$$
$$(Heckscher)\quad w = 0.7\, C_p - 0.8$$
$$(Robertson)\quad w = 0.45\, C_p - 0.05$$

دو پروانه ای:

$$(Taylor)\quad w = -0.2 + 0.55\, C_B$$
$$(Heckscher)\quad w = 0.7\, C_p - 0.3$$
$$(Robertson)\quad w = 0.5\, C_p - 0.2$$

راندمان چرخش نسبی

open water propeller efficiency and efficiency behind the hull:

$$\eta_0 = \frac{TV_A}{2\pi n Q_0} \qquad \eta_B = \frac{TV_A}{2\pi n Q}$$

Their ratio is called the relative rotative efficiency:

$$\eta_R = \frac{\eta_B}{\eta_0} = \frac{Q_0}{Q}$$

0.95 -1.0 for twin screw ships

1.0 - 1.1 for single screw.

ضریب کاهش تراست

When a hull is towed, there is an area of high pressure over the stern which has a resultant forward component reducing the total resistance. With a self propelled hull, however, the pressure over some of this area is reduced by the action of the propeller in accelerating the water flowing into it, the forward component is reduced, the resistance is increased and so is the thrust necessary to propel the model or ship.

If R is the resistance and T the thrust, we can write for the same ship speed

$$R = (1 - t)T$$

where the expression (1-t) is called the thrust deduction factor .

راندمان بدنه

The work done in moving a ship at a speed V against a resistance R is proportional to the product RV or the effective power PE. The work done by the propeller in delivering a thrust T at a speed of advance V_A is proportional to the product TV_A or the thrust power P. The ratio of the work done on the ship with that done by the propeller is called the hull efficiency

$$\eta_H = \frac{P_E}{P_T} = \frac{RV}{TV_A} = \frac{1-t}{1-w}$$

For most ships this is greater than ۱.

At first sight this seems an anomalous situation in that apparently something is being obtained for nothing. It can,however, be explained by the fact that the propeller is making use of the energy which is already in the wake because of its forward velocity.

راندمان کل رانش

$$\eta_H = \frac{P_E}{P_T} = \frac{RV}{TV_A} = \frac{1-t}{1-w}$$

$$\eta_0 = \frac{TV_A}{2\pi n Q_0}$$

$$\eta_B = \frac{TV_A}{2\pi n Q}$$

$$\eta_R = \frac{\eta_B}{\eta_0} = \frac{Q_0}{Q}$$

$$\eta_P = \eta_H \eta_R \eta_0 \eta_S$$

- Need to select a propeller such that h_P is maximized.

مرور مطالب

- Thrust Coefficient (K_T)
- Torque Coefficient (K_Q)
- Advance Coefficient (J)
- Open-water Propeller Efficiency (η_0)
- Pitch-diameter ratio (P/D)
- Expanded area ratio (A_E/A_0)
- Thrust deduction, t
- Wake fraction, w
- Speed of advance, V_A

$$K_T = \frac{T}{\rho n^2 D^4}$$

$$K_Q = \frac{Q}{\rho n^2 D^5}$$

$$J = \frac{V_A}{nD}$$

$$\eta_0 = \frac{T V_A}{2\pi n Q} = \frac{J}{2\pi}\frac{K_T}{K_Q}$$

$$R = (1-t)T$$

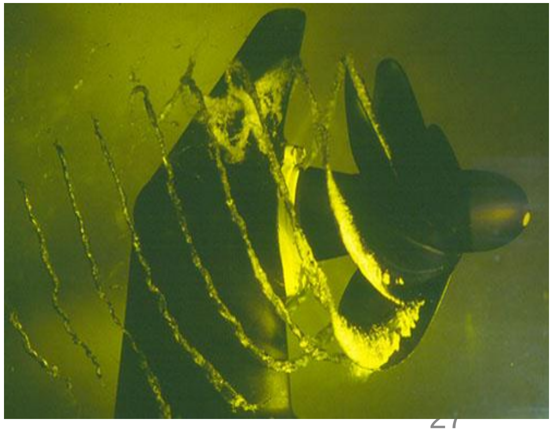
$$V_A = (1-w)V$$

کاویتاسیون

- Cavitation occurs when pressure on back or suction side of blade becomes so low that water vaporizes and vapor-filled cavities of bubbles form.
- Occurs on heavily loaded propellers
- high rotational speed

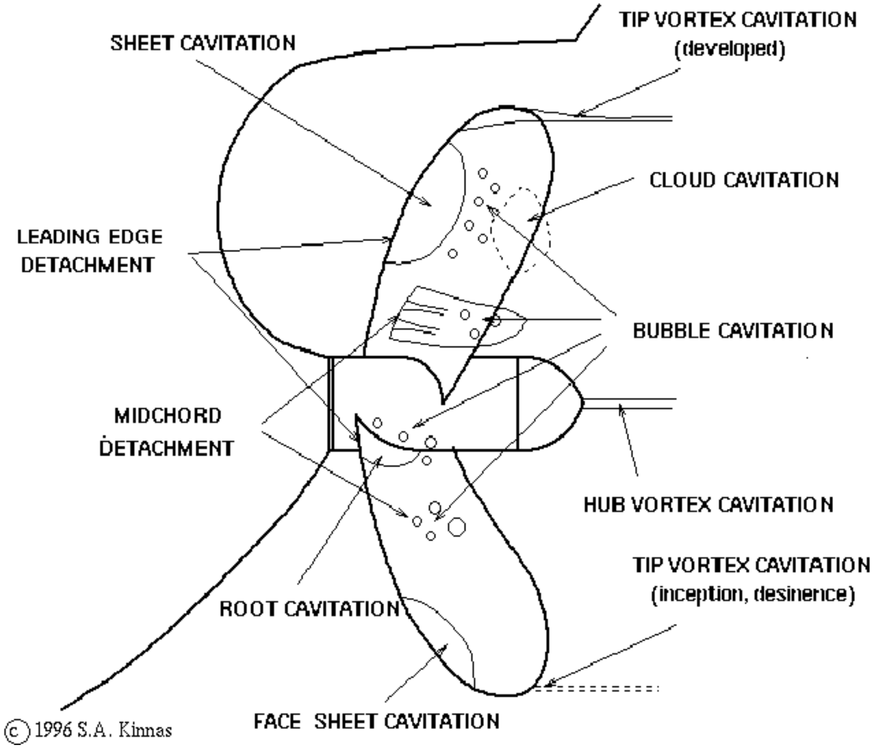
Bubbles can collapse on blades and cause:

- erosion
- serious noise problems
- rapid decrease in propeller efficiency
- fluctuating forces that give rise to severe vibrations



کاویتاسیون پروانه

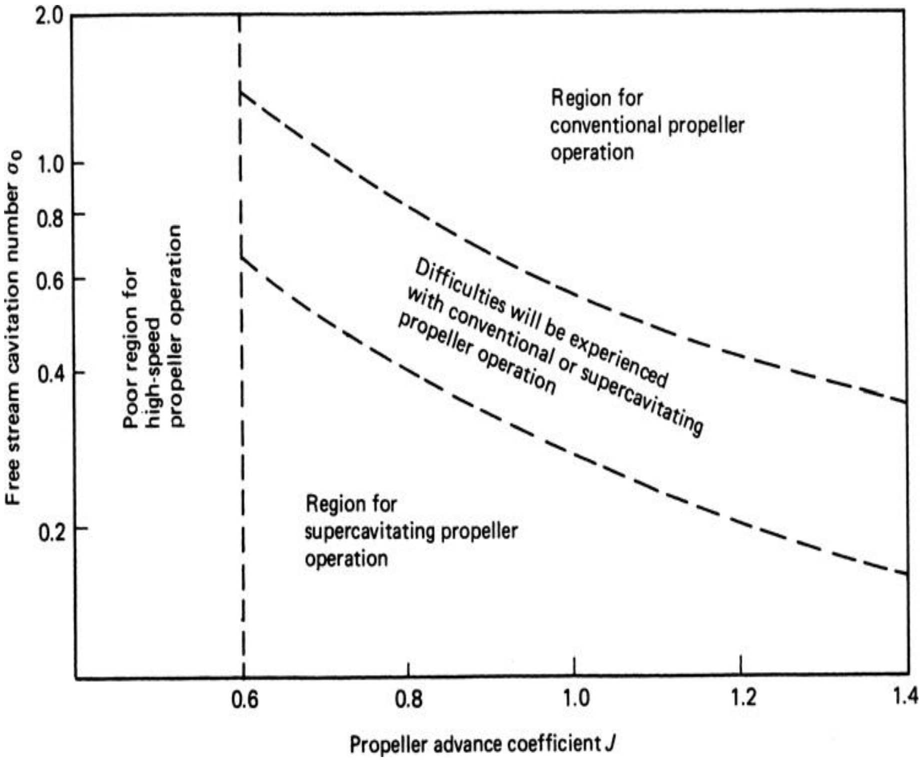
- Sheet
- Bubble
- Cloud
- Tip and Hub Vortex



روش های کاهش کاویتاسیون

- Must sufficient blade area
- Sufficient hub immersion

- Burrill Cavitation Diagram
- Keller Criterion.



Keller Criterion

$$\frac{A_E}{A_O} = \frac{(1.3 + 0.3Z)T}{(p_o - p_v)D^2} + k$$

Where:

T	=	Thrust, N
Z	=	Number of Blades
$p_o - p_v$	=	Pressure at propeller centerline (N/m^2)
k	=	Constant varying from 0 for transom - stern naval vessels to 0.20 for high - powered single screw vessels

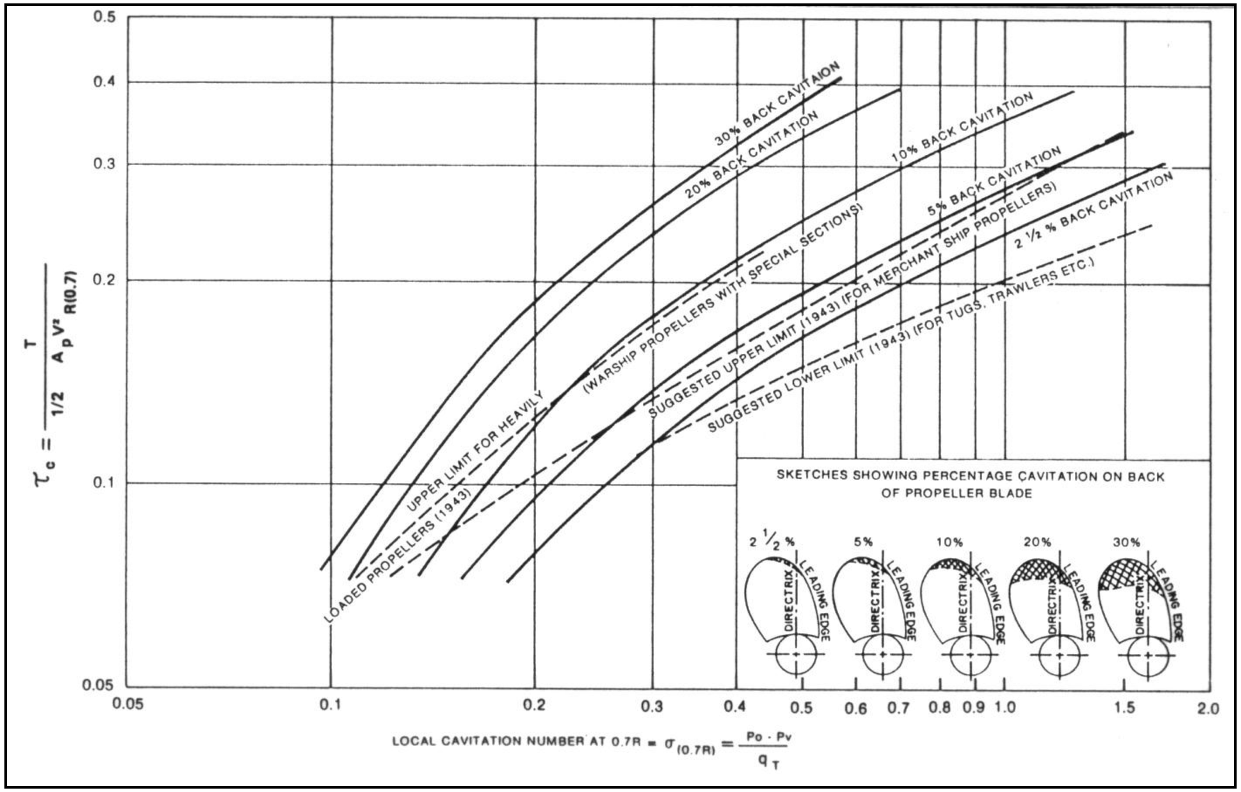
Burrill Cavitation Diagram

Diagram gives the local cavitation number

$$\sigma_{0.7R} = \frac{188.2+19.62h}{V_A^2+4.836n^2D^2}$$

versus the mean thrust blade loading

$$\tau_c = \frac{(T/A_P)}{0.5\rho[V_A^2+(0.7\pi nD)^2]}.$$



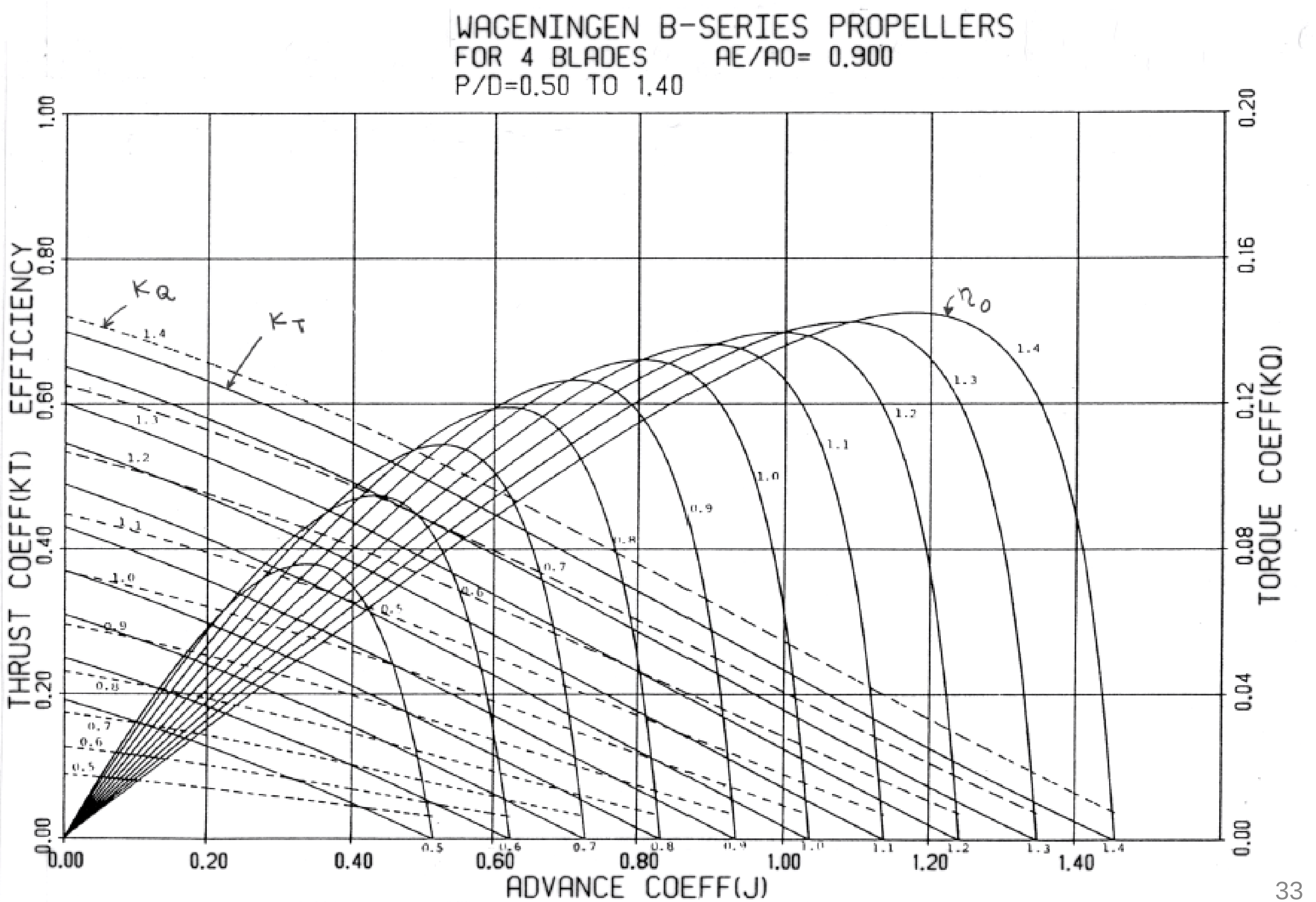
h is the head of the water (m), D the propeller diameter (m), n is revolutions per second, V_A the speed of advance (m/sec), T the thrust (kN), and A_P the projected blade area (m^2). This is related to the more commonly used developed area A_D by the following approximate formula $\frac{A_P}{A_D} = 1.067 - 0.229\frac{P}{D}$.

سری های استاندارد پروانه

- Open water tests of geometrically related propellers with pitch and other variables varied systematically.
- Thrust, torque coefficients and open water efficiency measured and plotted versus speed of advance.
- Comprehensive series, such as B –Wageningen&Gawn series.

Blade number Z	Blade area ratio A_E/A_O				
2	0.30				
3	0.35	0.50	0.65	0.80	
4	0.40	0.55	0.70	0.85	1.00
5	0.45	0.60	0.75	1.05	
6	0.50	0.65	0.80		
7	0.55	0.70	0.85		

نمودارهای پروانه سری B-Wageningen



ملاحظات طراحی پروانه

- Inputs:
  - Design speed
  - Diameter constraints
  - EHP at design speed
  - Type and number of propellers (skew angle, blades, etc.).
  - Wake fraction (w) and thrust deduction (t)
- Approach
  - Select number of blades based on frequency of excitation (similar designs).
  - Select area ratio based on cavitation limitations
  - The minimum area ratio allowed by cavitation or strength will have the best efficiency.
  - In general, larger diameter is better.
  - In general, lower RPM is better.
  - If machinery sets RPM, then seek the optimum diameter.

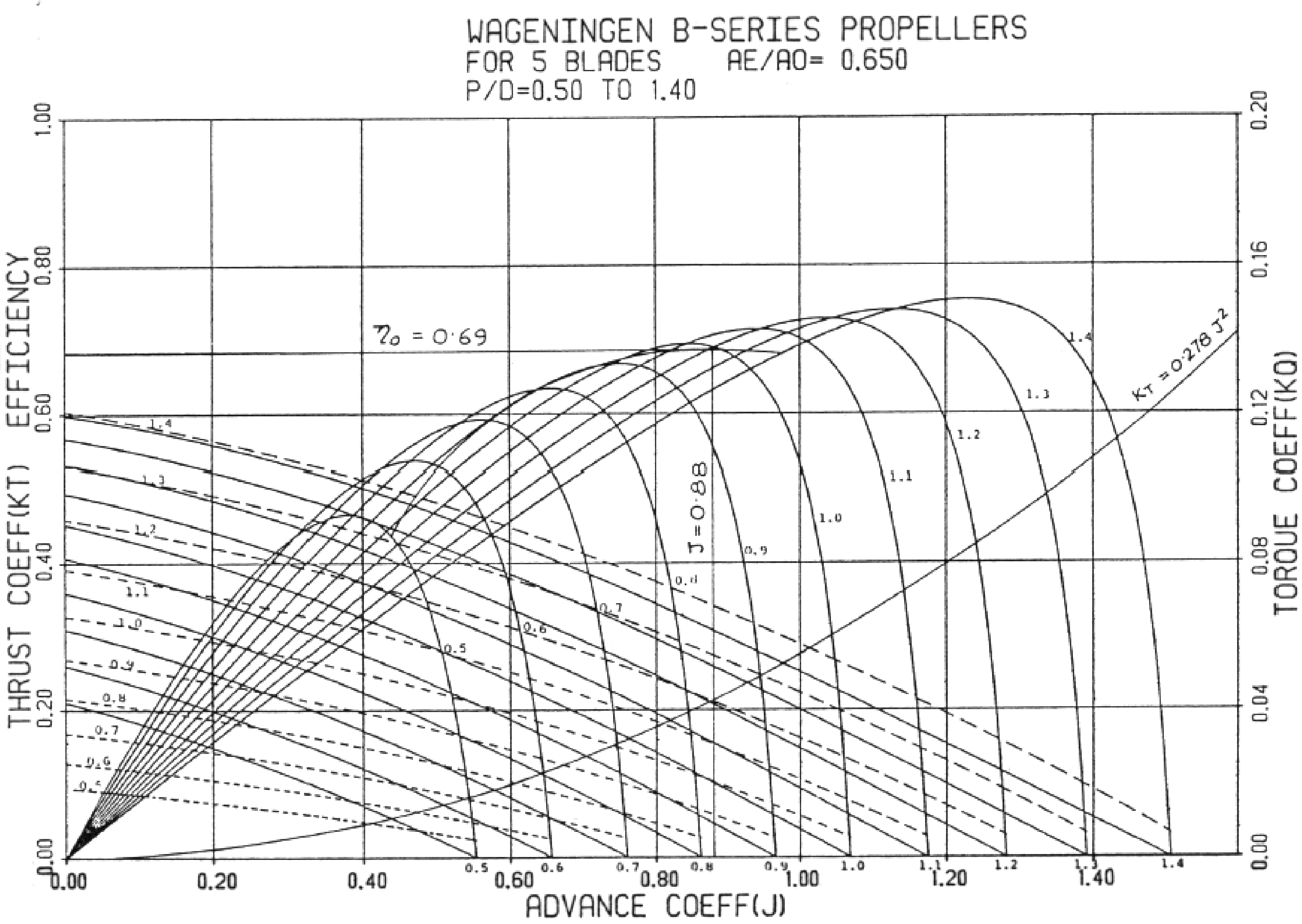
طراحی با قطر ثابت از طریق ضریب تراست

Case 1: From the hull requirements we might have a required ship speed and resistance:

- Select a blade number.
- Select a minimum acceptable A_E/A_0.
- Work with K_T and J.
- Form the ratio K_T/J^2 to eliminate the unknown n.
- Optimize for maximum open water propeller efficiency.

$$\frac{K_T}{J^2} = \frac{T}{\rho V_A^2 D^2}$$

نمونه ای از نمودارهای طراحی سری B-Wageningen



طراحی با قطر ثابت از طریق ضریب گشتاور

Case 2: From the engine requirements we might have a delivered power and ship speed:

- Select a blade number.
- Select a minimum acceptable A_E/A_0.
- Work with K_Q and J.
- Form the ratio K_Q/J^3 to eliminate the unknown n.
- Optimize for maximum open water propeller efficiency.

$$K_Q = \frac{Q}{\rho n^2 D^5} = \frac{P_D \eta_R}{2\pi \rho n^3 D^5}$$

طراحی با دور ثابت به از طریق ضریب تراست

Case 1: From the hull requirements we might have a required ship speed and resistance:

- Select a blade number.
- Select a minimum acceptable A_E/A_0. Iterations may be necessary since some cavitation criteria involve the diameter D.
- Work with K_T and J.
- Form the ratio K_T/J^4 to eliminate the unknown D.
- Optimize for maximum open water propeller efficiency.

$$\frac{K_T}{J^4} = \frac{Tn^2}{\rho V_A^2}$$

طراحی با دور ثابت به از طریق ضریب گشتاور

Case 2: From the engine requirements we might have a required ship speed and delivered power:

- Select a blade number.
- Select a minimum acceptable A_E/A_0. Iteration may be necessary since some cavitation criteria involve the diameter D.
- Work with K_Q and J.
- Form the ratio K_Q/J^5 to eliminate the unknown D.
- Optimize for maximum open water propeller efficiency.

قدرت مورد نیاز موتور در حالت سرویس

- To maintain contracted design speed on average over ship's service life in actual sea conditions (referred to as "sustained speed" by USN), installed power must be greater than P_S.
- A service power allowance is added, expressed as fraction of P_S.
- USN determines sustained speed at 80% of maximum continuous installed power.
- This covers added resistance due to sea waves.

واتر جت

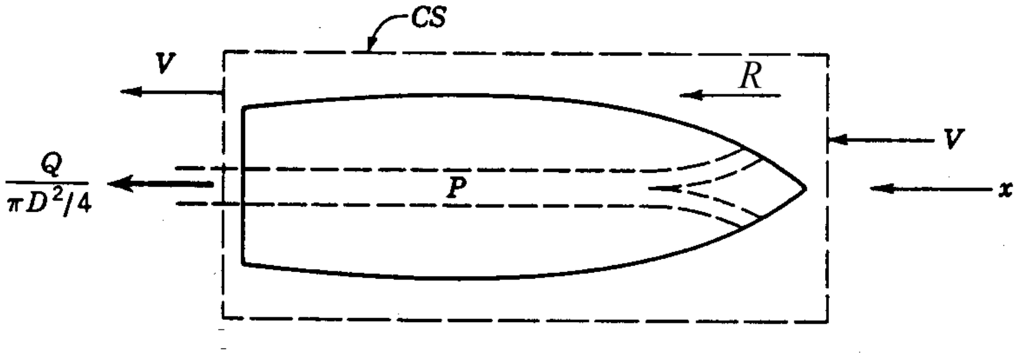
Basic variables and assumptions:

Ship speed V, Resistance R

Water jet diameter D.

100% efficient pumping system.

Basic equations:



$$R = \rho Q\left(V_{\text{jet}} - V\right), \quad V_{\text{jet}} = \frac{Q}{\pi D^2/4}$$

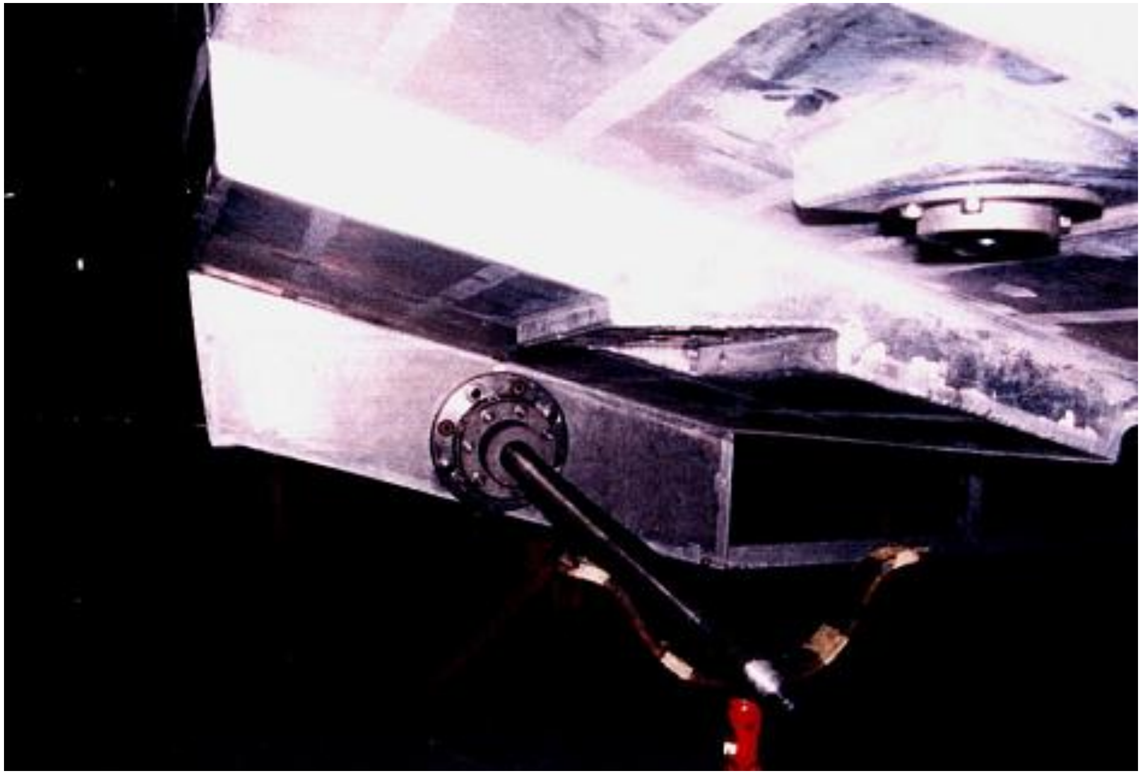
Power in: $\frac{1}{2}\rho Q\left(V_{\text{jet}}^2 - V^2\right)$

Power out: RV

Efficiency: $$\frac{\text{Power out}}{\text{Power in}} = \frac{\rho Q\left(V_{\text{jet}} - V\right)V}{\frac{1}{2}\rho Q\left(V_{\text{jet}}^2 - V^2\right)} = \frac{2V}{V_{\text{jet}} + V}$$

Efficiency goes down as V becomes smaller.

آب بندی شفت



با تشکر از حضور و توجه شما