IEEE Oceanic Engineering Society

Outline

Power

- Cables
- Circular mils
- Insulation
- Thermal Concerns

Propulsion

- Motors
- Shaft Sizing
- Thrusters

Power

Cables

Typical Cross Section of a sub sea cable

Picture courtesy South Bay Cable – www.southbaycable.com

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Power

Cables

75 OHM COAX-3 UNITS
AWG No. 22(Stranded) B/C

SHIELDED QUADS-3 UNITS
AWG No. 22(Stranded) B/C

FIBER OPTICS
3 MM FIBER OPTICS IN SS TUBE

DRAIN WIRE

POWER CONDUCTORS-15 UNITS
AWG No. 18(Stranded) B/C

INNER JACKET
Polyethylene

STRENGTH MEMBER
Kevlar Braid

OUTER JACKET
Thermoplastic Elastomer

CABLE CHARACTERISTICS

PHYSICAL	**ENGLISH**	**METRIC**
Outer Diameter	1.78 Inches	45.2 mm
Weight in Air	1,133 LBS/1000ft	1,686 KG/KM
Weight in Sea Water	27 LBS/1000ft	40 KG/KM
MECHANICAL		
Breaking Strength	14,000 LBF	62 KN
Maximum Load	2,000 LBF	9 KN
Minimum Bend Diameter	20 Inches	508 cm

Picture courtesy South Bay Cable – www.southbaycable.com

Power

Cables

SHIELDED PAIRS-3 UNITS
AWG No. 24(Stranded) B/C

SHIELDED PAIRS-4 UNITS
AWG No. 26(Stranded) B/C

SINGLE CONDUCTORS-11 UNITS
AWG No. 24(Stranded) B/C

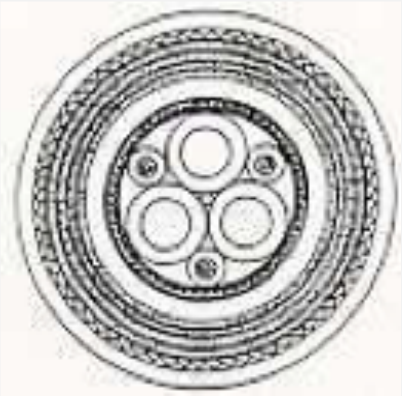
SINGLE CONDUCTORS-5 UNITS
AWG No. 21(Stranded) B/C

INNER & OUTER SHIELD
Bare Copper Braid

STRENGTH MEMBER
Aramid Braid

JACKET
Polyurethane

FLOTATION JACKET
Foam Polyurethane



CABLE CHARACTERISTICS

PHYSICAL	**ENGLISH**	**METRIC**
Outer Diameter	0.860 Inches	21.84 mm
Weight in Air	258 LBS/1000ft	384 KG/KM
Weight in Sea Water	NEUTRAL	NEUTRAL
MECHANICAL		
Breaking Strength	1,800 LBF	8 KN
Maximum Load	220 LBF	1 KN
Minimum Bend Diameter	20 Inches	51 cm

Picture courtesy South Bay Cable – www.southbaycable.com

Power

Cables

SHIELDED QUADS-4 UNITS
AWG No. 20(Stranded) B/C

COAXIAL RG-59 TYPE-3 UNITS
AWG No. 22(Stranded) B/C

SINGLE CONDUCTORS-6 UNITS
AWG No. 18(Stranded) B/C

POWER CONDUCTORS-17 UNITS
AWG No. 11(Stranded) B/C

INTERSTICES WATERBLOCKED

JACKET
Polyurethane

ARMOR-STEEL WIRES
Two Layers GIPS

PHYSICAL	**ENGLISH**	**METRIC**
Outer Diameter	1.680 Inches	42.67 mm
Weight in Air	3,330 LBS/1000ft	4,956 KG/KM
Weight in Sea Water	2,440 LBS/1000ft	3,631 KG/KM
MECHANICAL		
Breaking Strength	100,000 LBF	444 KN
Maximum Load	25,000 LBF	111 KN
Minimum Bend Diameter	36 Inches	91.4 cm
ELECTRICAL (DC Resistance @ 20°C		
RG-59 Center Conductor	14.6 OHMS/KM	53.8 OHMS/KM
RG-59 Braided Conductor	4.8 OHMS/KM	15.7 OHMS/KM
Shielded Quad Conductor	10.4 OHMS/KM	34.1 OHMS/KM
Shielded Quad Shield	4.3 OHMS/KM	14.1 OHMS/KM
AWG No. 18 (1 KV) Conductor	6.2 OHMS/KM	20.3 OHMS/KM
AWG No. 11 (3 KV) Conductor	1.6 OHMS/KM	5.2 OHMS/KM
Shield Over Inner Layer	2.0 OHMS/KM	6.6 OHMS/KM

Picture courtesy South Bay Cable – www.southbaycable.com

Power

- Circular mils

<u>A circular mil the area of a circle .001 in. in Diameter</u>

The resistance of copper one circular mil a foot long is taken as 10.8 ohms

Power

DC Cable Calcs

$R = 10.8\ L / A$ ohms

L = Length of the cable

A = cross section in circular mils

e = the acceptable voltage drop

$= 21.6\ i\ d / A$ << what happened here?

d = distance

If $e = xE$ with x some percentage of E

Then $A = 2160\ i\ d / x\ E$

Power

DC Cable Calcs

1 Horsepower motor at 300 Volts, 30 volt drop OK
86 percent efficient, cable length 500 ft.

i = (HP * 746) / (eff * Vdc)
i = (1*746) / (.86 *300)
i = 2.89 amps

Substituting into the equation for A
and using the ratio of Length to Voltage drop

A = 21.6 * 2.89 * (500 / 30)
A = 1040.4 circular mils

Using the American Wire Gage (B&S) standard the closest wire next size up is <u>19 gage</u>

Power

AC Cable Calcs

R = 10.8 L / A   ohms

L = Length of the cable

A = cross section in circular mils

= 10.8 i d / e   << Notice

For AC circuits

i = (P * 1000) / (E * pf)

P = power in Kilowatts, E = the load voltage, pf = the power factor

Power

AC Cable Calcs

for a 3 phase system the voltage is $\sqrt{3}$ E

Substituting in for 3 phase voltage

$$i = (580 * P) / (E * pf)$$

The voltage drop should be expressed as the percentage drop between any wire to neutral

$$\text{percent drop} = [e / (E / \sqrt{3}) / 100] \text{ or } [\sqrt{3}\, e / E]\, 100$$

Power

AC Cable Calcs

for an AC system

Power Factor when not known

Incandescent lamp load - .95 to 1.00
Lamps and motors together - .75 to .85
Motors - .5 to .8

Power

AC Cable Calcs

For a system at 480 volts AC and 2000 feet of cable and a load of 5 kilowatts for a motor load, the allowable voltage drop on each line is 20 volts

i = (580 *P) / (E * pf)

i = (580 *5) / (480 * .8)

i = 4.83 amps

Power

AC Cable Calcs

Substituting into the equation for A
and using the ratio of Length to Voltage drop

$$A = 10.8\ i\ d\ /\ e$$

$$A = 10.8 * 4.83 * (2000 / 20)$$

A = 5216.4 circular mils

Using our wire gage table the closest standard wire size is <u>12 gage.</u>

Power

- Insulation

Power

Insulation

Insulation resistance is generally high enough that it is measured and specified in Mega-Ohms

The dark material shown is common application of insulation material

$$\text{minimum insulation resistance in megaohms} = \frac{\text{rated voltage}}{\text{rating in kW} + 1000}$$

Power

Insulation

$$\text{minimum insulation resistance in megaohms} = \frac{\text{rated voltage}}{\text{rating in kW} + 1000}$$

ROV voltage for a standard system – 2400 VAC

Power of the system - 25 Kilowatts

Substituting: $$\text{Megs} = \frac{2400}{25 + 1000} = 2.34 \text{ MegOhms minimum}$$

Power

- Thermal Concerns

Power

Thermal Concerns

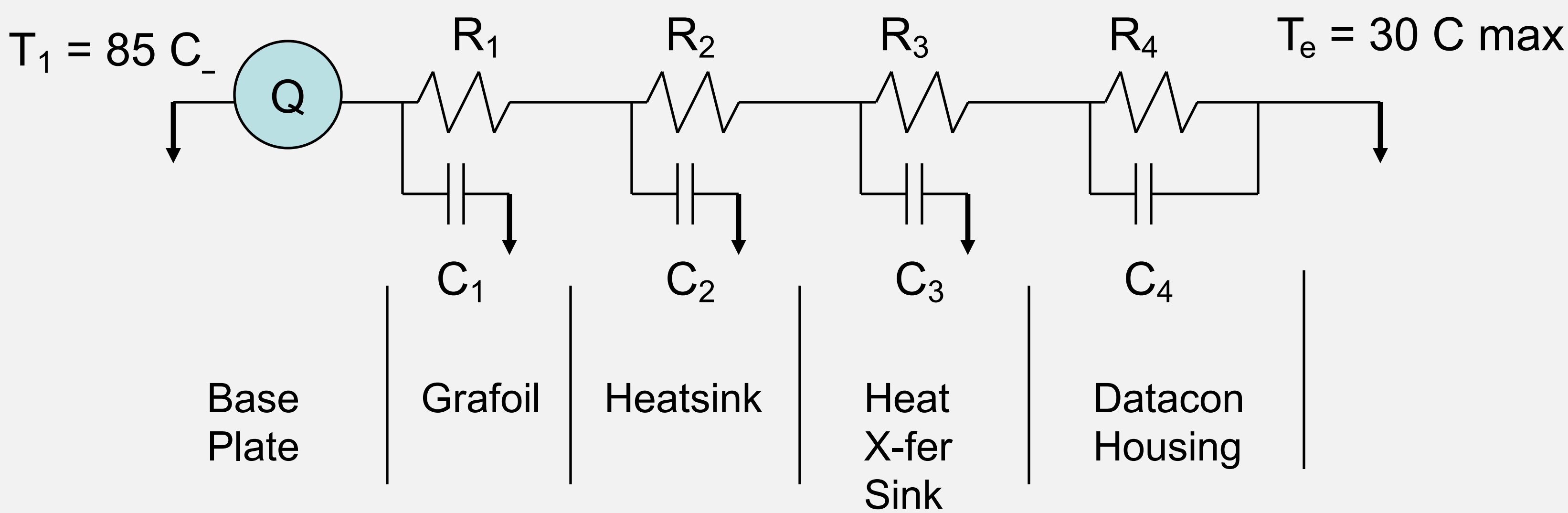
Thermal issues are difficult since the system will usually be designed with the ocean as a heat sink. Do not forget the “on deck” condition where the devices will usually be operated and checked out, also run for long times during maintenance and repair. Make the thermal constraints known or better yet install some form of protection.

The best way to quickly understand the thermal issues and get a handle on the issues with removal of heat from power components is modeling.

Power

Thermal Concerns

Thermal modeling of a Solid State power supply to the atmosphere



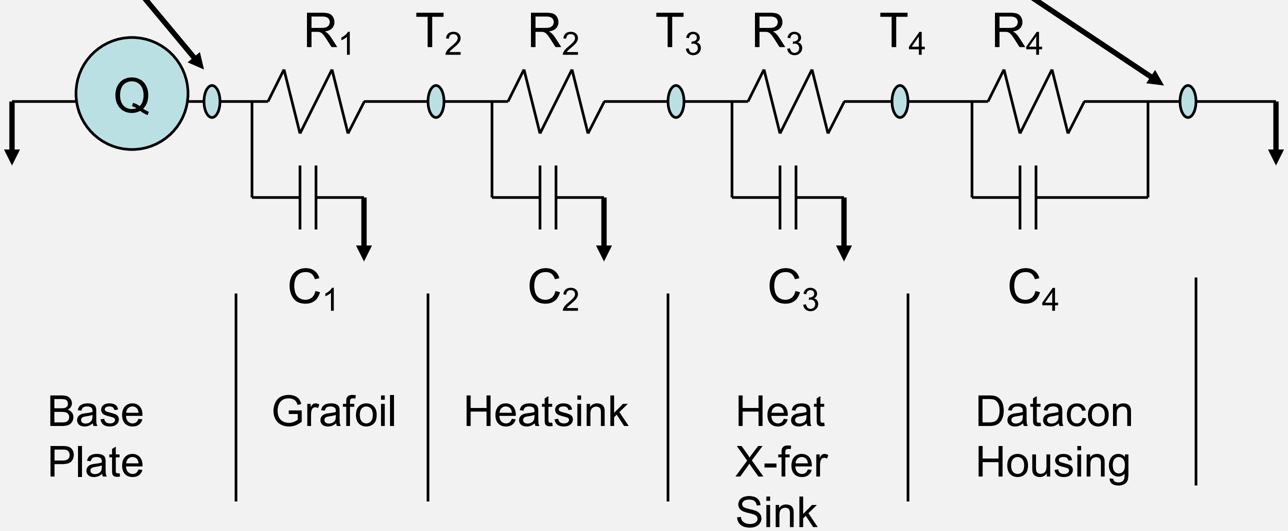
Q is a source of 50 Watts allowed to reach 85 degrees C max.

Power

Thermal Concerns

$T_1 = 85\ C = 185\ F$

$T_e = 30\ C\ max = 86\ F$



$T_1 - T_e = 99\ F$

Power

Thermal Concerns

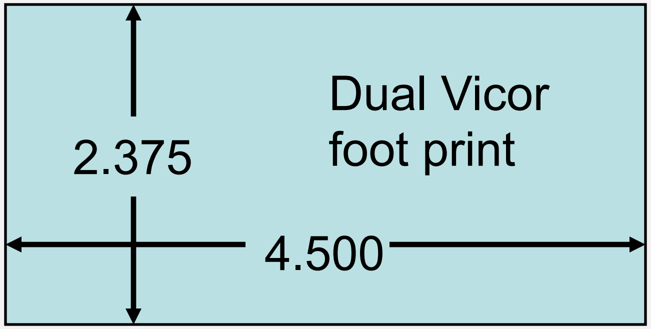
$$Q = \frac{T_1 - T_e}{R_T}$$

$$R_T = \frac{\Delta T}{Q}$$

$$Q = 50 \text{ W} >> 170 \text{ BTU /HR}$$

$$R_T = \frac{99}{170} = .58 \quad [\text{BTU/HR F}]^{-1}$$

$$R_1 + R_2 + R_3 + R_4 = .58$$



Power

Thermal Concerns

$R_1 + R_2 + R_3 + R_4 = .58$

$$R_1 = \frac{L}{Ak}$$

T_{BS} >> (T1 –T2) = .2 C / W per the Vicor Handbook

L = .010 inches

A = 4.500 * 2.375 = 10.6875 in^2

T_{BS} = .2 * 50 = 10 C >> 18 F

Power

Thermal Concerns

$$Q = \frac{Ak\,\Delta T}{L}$$

Solving for k: $$170 = \frac{(10.6875)\,(18)\,k}{.010} \qquad \frac{BTU}{HR} = \frac{in^2\,F\,k}{in}$$

$$k = \frac{170\,(.010)}{(10.6875)(18)} = .00884\,\frac{BTU}{HR\ in\ F}$$

$$R_1 = \frac{.010}{10.6857(.00884)}$$

$$R_1 = .106\left[\frac{BTU}{HR\ F}\right]^{-1}$$

Power

Thermal Concerns

Continue with the process and then solve the circuit. Just like electronic circuits the system is an RC circuit with a time constant and you can solve for the rate of temperature rise and plot the expected outcome of the heat rate based on an environmental temperature. I've found it to be surprisingly accurate.

The reference for this type of modeling is:

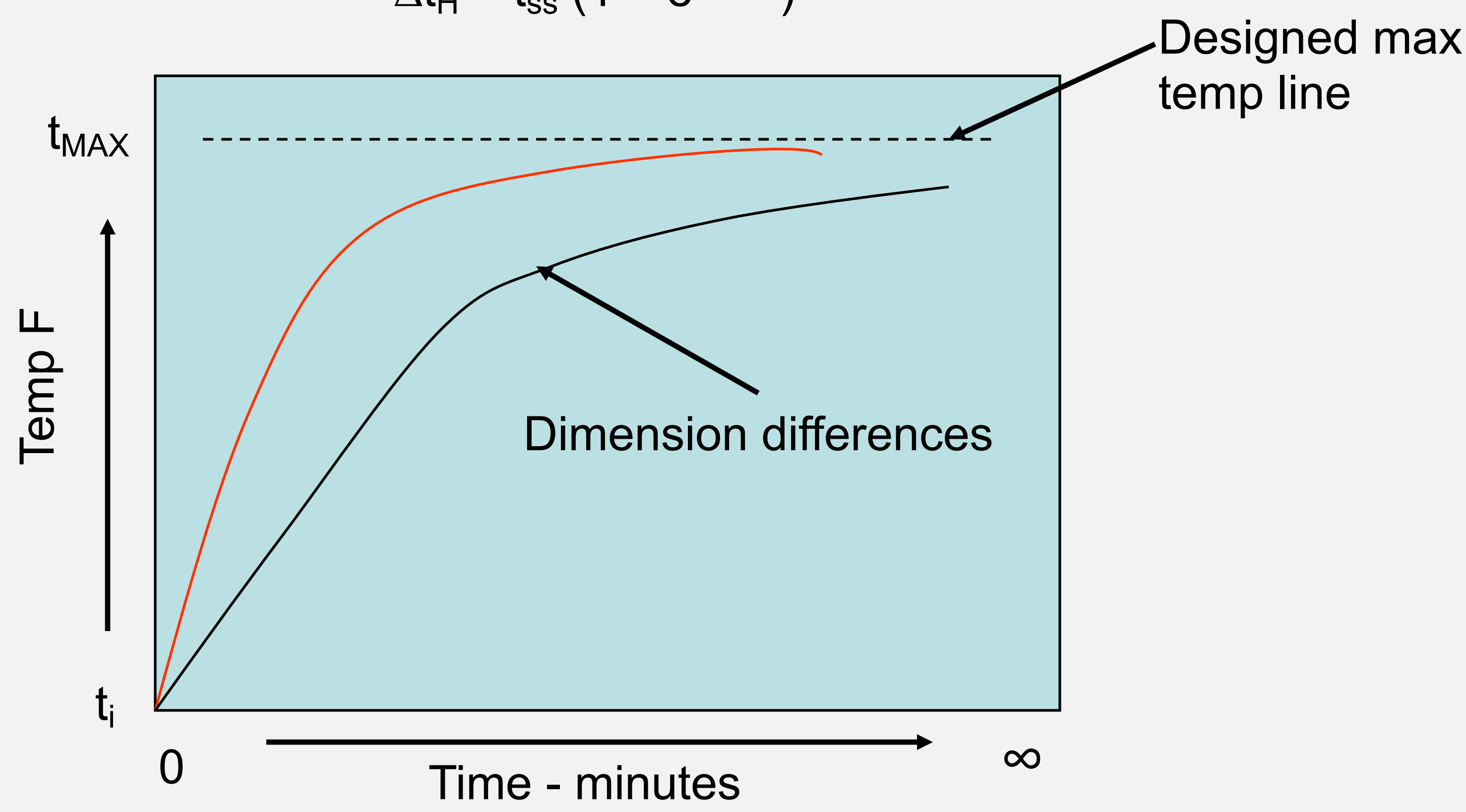
Steinberg, Dave S. "Cooling Techniques for Electronic Equipment" 2^{nd} Ed. , 1991, John Wiley and Sons, New York

Power

Thermal Concerns

Ultimately the problem reduces to a simple equation in a form like:

$$\Delta t_H = t_{ss} (1 - e^{T/RC})$$



Propulsion

- Motors

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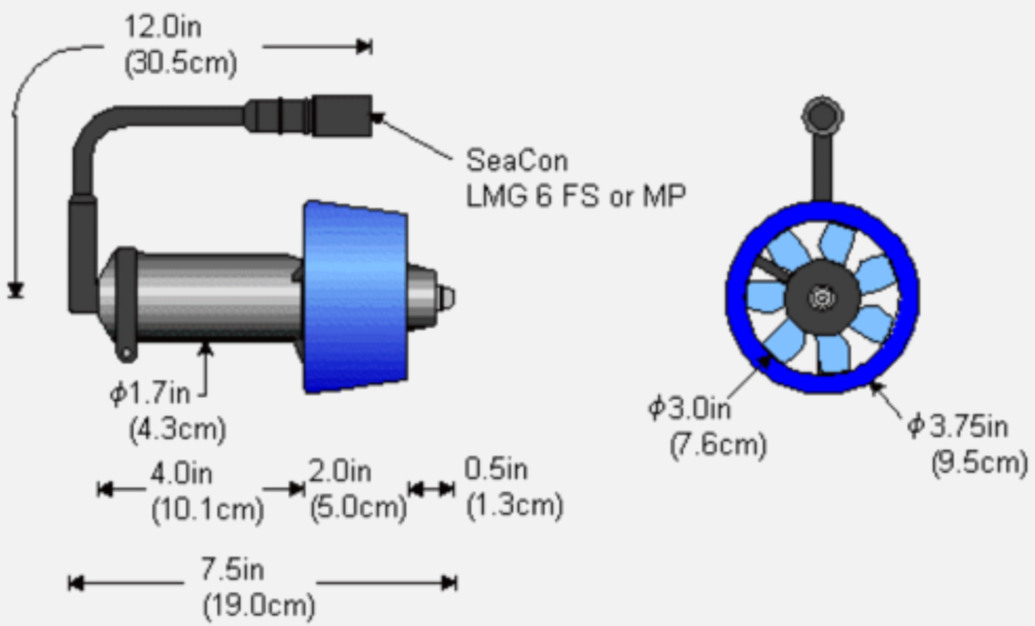
Motors



Bollard Output	*Input*	*Weight*	*Depth*
12lbf (5.4kg) forward	**150 VDC, 1.9A power**	**2.0lb (0.9kg) in air**	**2,500ft (750m) std**
8lbf (3.6kg) reverse	**Power ground**	**1.5lb (0.7kg) in water**	**5,000ft (1,500m) opt'nl**
	+12V elex power		**Oil filled (full ocean depth) opt'nl**
	+/-5 V command		**Note: Due to motor tolerances**

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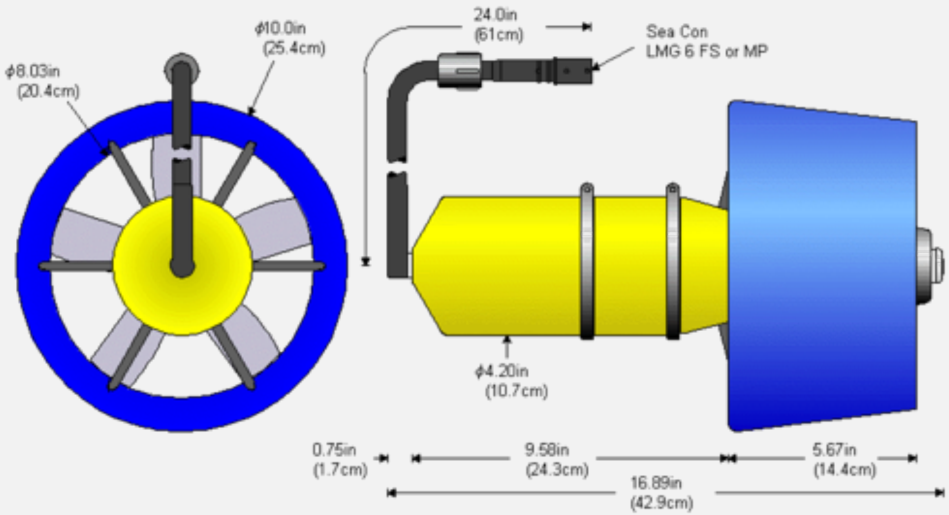
Motors



Bollard Output	*Input*	*Weight*	*Depth*
145lbf (65.9kg) forward @ 10A input current	260 VDC, 9.0A power	23.2lb (10.5kg) in air	2,500ft (750m) std
205lbf (93.0kg) forward @ 17A input current	Power ground	17.4lb (7.9kg) in water	5,000ft (1,500m) opt'nl
80lbf (36.4kg) reverse @ 10A input current	+/-5 V command		Oil filled (full ocean depth) optional
115lbf (52.2kg) reverse @ 17A input current	Signal ground		

Technadyne : www.technadyne.com_

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Propulsion

Motor Calcs – Useful Constants

SOME USEFUL NUMBERS AND PROPERTIES

Density	Seawater 1020 kg/m3	Freshwater 1000kg/m3
Force	1lbf = 4.45 N	
Mass	1 slug = 1 lbf s2/ft, = 14.592 kg	
Length	1 meter = 3.28 ft.	
Kinematic Viscosity	Seawater 0.0105 cm2/sec	Freshwater 0.01 cm2/sec
Speed	1 knot = 0.5151m/s	
Angles	1 rad = 57.2957 degrees	

Chart : Courtesy Prof. Healy - NPS_

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Propulsion

- Shaft Sizing

Propulsion

Motor Calcs – Shaft Sizing

$$d = \sqrt[3]{(321{,}000\,(hp) / nS)}$$

d = diameter of shaft – in.

n = revolutions per minute

S = shear strength of material – psi

NOTES:

1. The generally accepted factor of safety for motor shafts is 8 times the calculated area

2. Round stock generally comes in increments of $^{1}/_{16}$ inch for sizes under 1 inch diameter and ¼ for over in the US, generally round up to the nearest standard size in $^{1}/_{16}$ or ⅛ increments unless your application forces otherwise

Propulsion

Motor Calcs – Shaft Sizing

Our motor outputs 5 HP at 1800 rpm
What is the shaft size in Titanium 6Al-4V?

$$d = \sqrt[3]{(321{,}000\,(hp) / nS)}$$

$n = 1800$ $hp = 5$ $S = 100{,}000$ psi

Substituting:

$$d = \sqrt[3]{[(321{,}000 * 5) / (1800 * 100{,}000)]}$$

$d = .207$ inches

Propulsion

Motor Calcs – Shaft Sizing

d = .207 inches

The area for this section is

$A = \pi r^2 = .0336525\ in^2$

The area with the safety factor is 8 times the calculated

$8 * .0336525 = .26922\ in^2$

$.26922 = \pi r^2 \gg r = .2927422\ in.$

The rod diameter is .585 > the closest standard is **5/8 diameter**

Propulsion

- Thrusters

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Propulsion

Thrusters

The forces to be overcome are inertial and drag

Drag Force: $D_f = ½ \rho V^2 C_d A$

D_f = drag force, must be overcome to maintain a constant velocity

ρ = the density of seawater

V^2 = the square of the advance velocity

C_d = non-dimensional coefficient of drag based on Reynolds number

A = the area presented to the fluid while in motion

Horner: Fluid Dynamic Drag

Propulsion

Thrusters

Drag Coefficients Depend on Flow Separation

Can be Reduced by Reducing Separation at the Aft End

FLUID-DYNAMIC DRAG

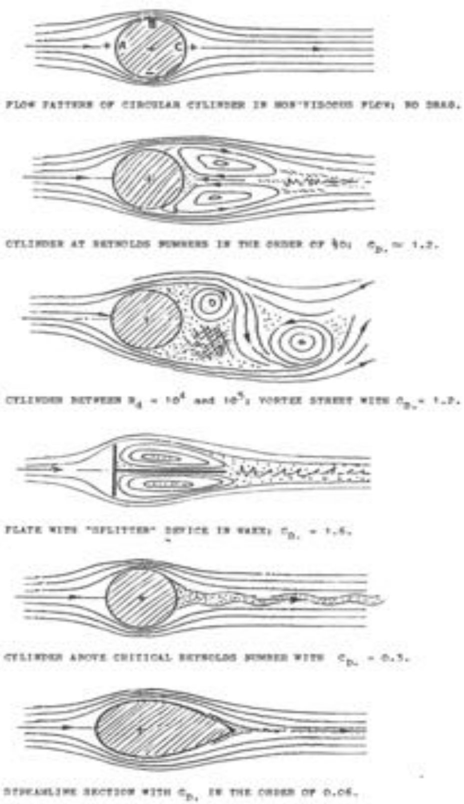

Figure 1. Theoretical and actual flow pattern of two-dimensional bodies.

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Propulsion

Thrusters

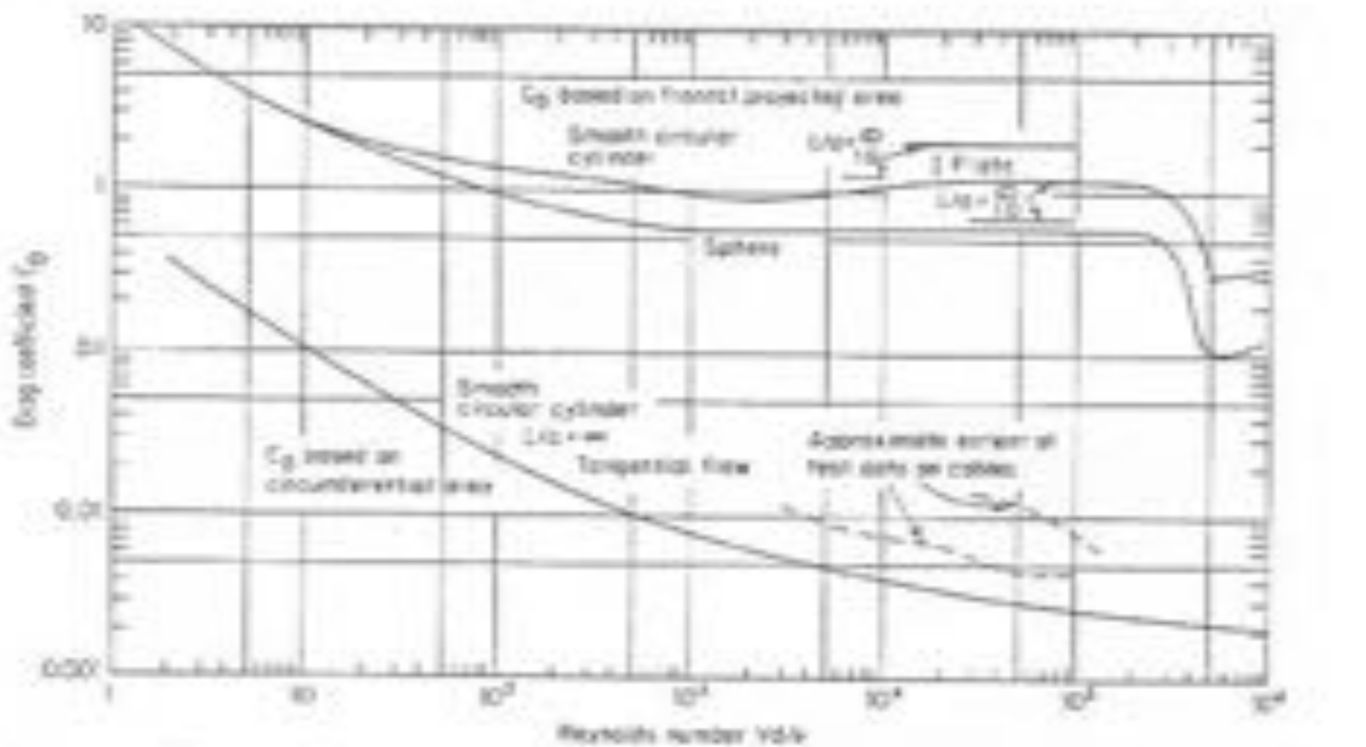

Fig. 2-24 Drag coefficients for cylinders, spheres, and other shapes.

Propulsion

Thrusters

Drag Force: $D_f = ½ \rho V^2 C_d A$

Example: We are pushing a flat plate through the water to construction sight. The plate is 2 feet by 2 feet. The plate needs to be moved at 1 meter per second.

The area of the plate is 4 sq.ft.

Per Mark's Engineering Handbook $C_d = 1.16$

ρ = water density (1.99 lb-sec^2/ft^4)

1 m/sec = 3.281 ft/sec

Propulsion

Thrusters

Drag Force: $D_f = ½ \rho V^2 C_d A$

$D_f = ½ (1.99) (3.281)^2 1.19 * 4$

D_f = 50.985 Lbs drag

We have selected a thruster 15 inches in diameter

turning at 300 rpm

Does this make sense?

Propulsion

Thrusters

Torque of a DC motor is $T = E\ I_a\ 33{,}000\ / (2\pi * 746 * N)$

E is the EMF of the motor $E = V - I_a R_a$

with V being terminal voltage, I being the armature current, and R being the armature resistance

The total mechanical power developed is EI_a which will be call P_h

The total mechanical power developed is $P_h = V\ I_a\ \eta / 746$

η = efficiency

Reducing $T = 5260\ P_h / N$

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Propulsion

Thrusters

Advance Coefficient: $\mathbf{J_s} = V / nD$

V = advance speed, fps

n = rps, revolutions per second

D = rotor diameter, ft.

Thrust Coefficient: $\mathbf{K_T} = T / \rho n^2 D^4$

T = Thrust, lbs.

ρ = water density (1.99 lb-sec^2/ft^4)

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Propulsion

Thrusters

Torque Coefficient: $\mathbf{K_Q} = Q / \rho n^2 D^5$

Q = torque, ft-lbs.

Quasi-propulsive Coefficient: **QPC** = TV / P_d

Or **QPC** = $(J_s/2\pi)\, K_t/K_q$

$\mathbf{P_d}$ = delivered power = $2\pi Q n$ ft-lbs / sec

Propulsion

Thrusters

Bollard Thrust is more commonly associated with tugs and towing vessels, basically it is a measure of how "hard" your boat can pull. It does not imply that your vessel is actually making any headway, it just <u>calculates the strain</u> you could put on a tow rope.

Formula

62.72 x ((SHP at propeller x (Ideal Propeller dia / 12) exp 0.67)

Propulsion

Thrusters

Bollard Formula

62.72 x ((SHP at propeller x (Ideal Propeller dia / 12) exp 0.67)

Let the drag force be directly equal to our thrust as a first check for sanity

$$50.985 = 62.72\ (Z * (15/12)^{0.67})$$

$$Z = 0.700\ \text{HP}$$

Rounding off a bit we get ¾ horse motor

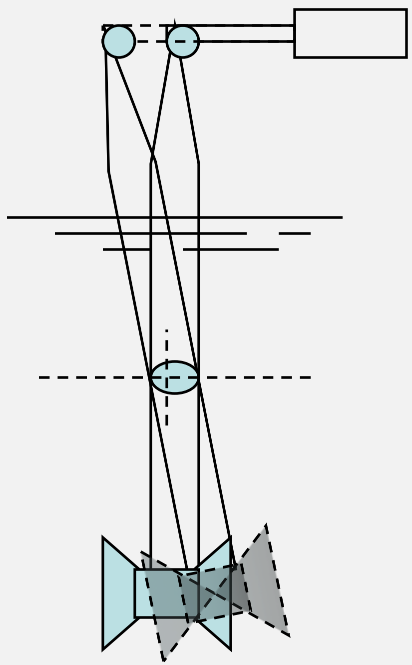
(Not bad but a 15 inch prop seems large for this problem)

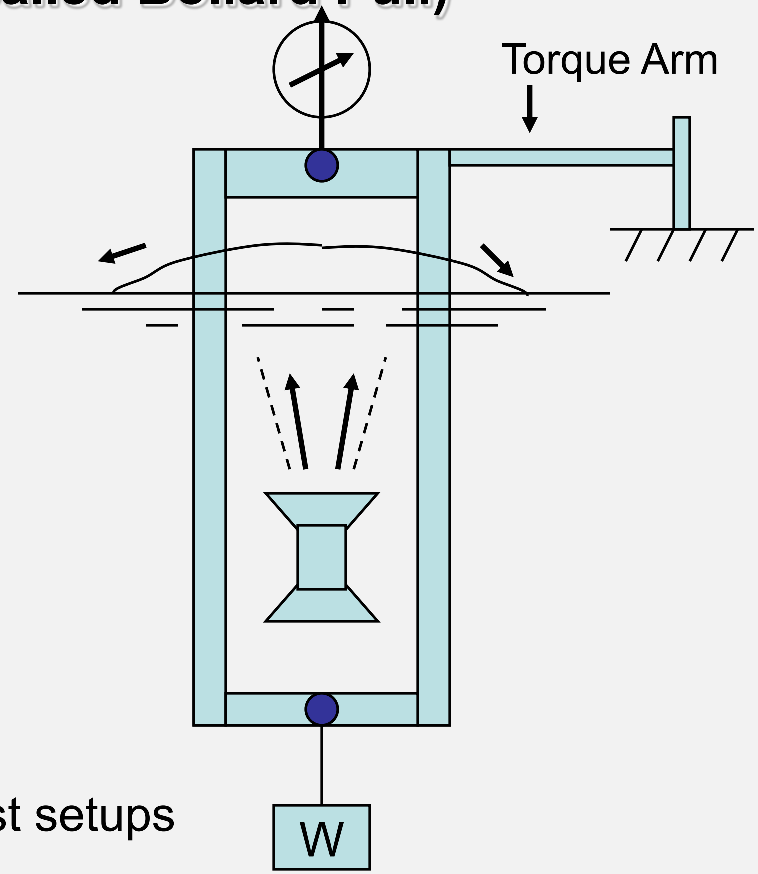
Propulsion

Thrusters

Bollard Thrust (sometimes called Bollard Pull)

Very hard to get an accurate reading on so it is often a theoretical value stated for brochures and so forth. The problem is making Js go to zero within the structure of a test setup.





Typical test setups