Electric motors for propulsion: Impact on vessel performance and propeller selection

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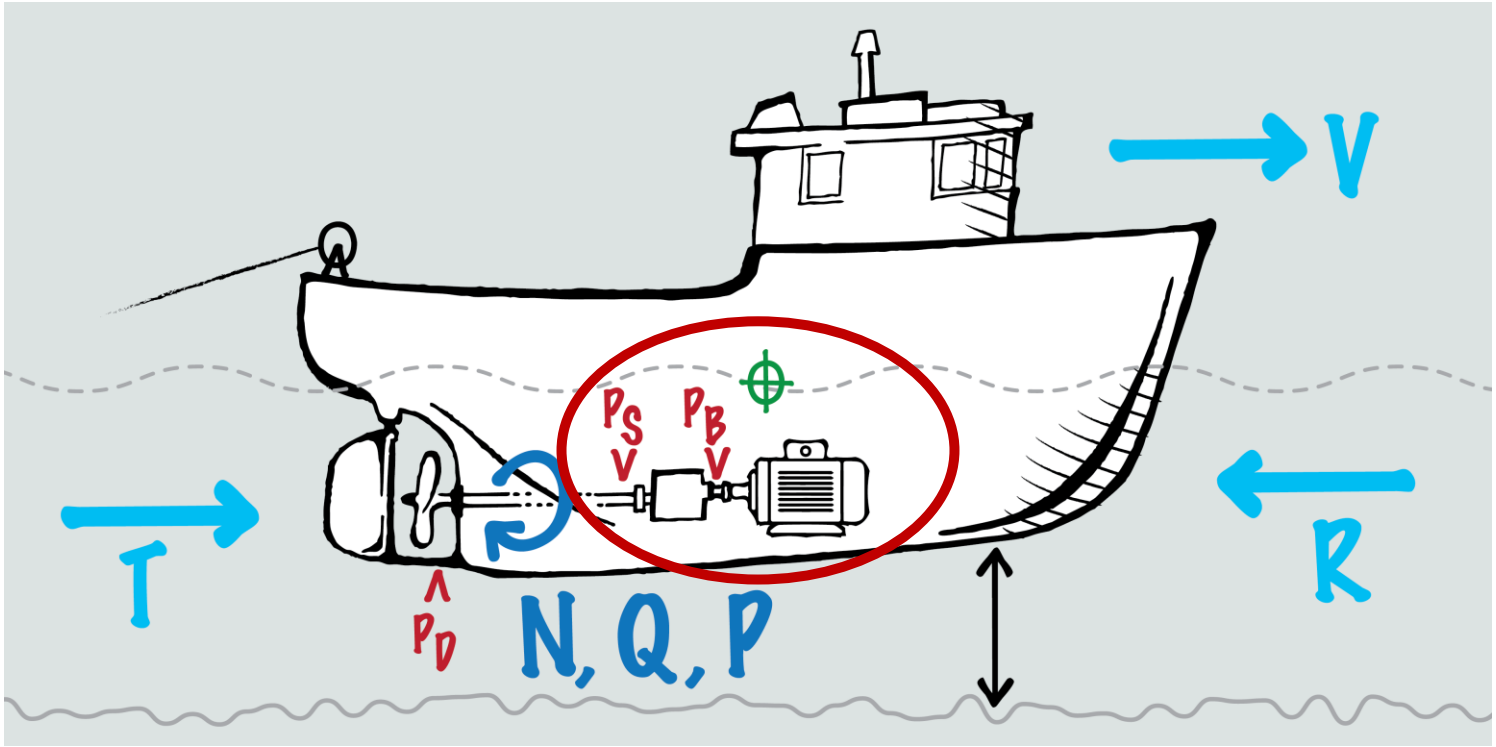
VESSEL-PROPULSOR-DRIVE: ELECTRIC DRIVE MOTOR



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COMMUNICATING ENERGY

- Speak in terms of **power**, and not torque
  - Better relates transfer of energy
  - It is independent of RPM
- Power is common among all system components
  - *Vessel:* Resistance → **Effective power (P_E)**
  - *Propulsor:* Thrust/Torque → **Developed power (P_D)**
  - *Drive:* Torque → **Brake power (P_B)**

ELECTRIC MOTOR POWER DESCRIPTION

- "Rating" point: mechanical power & RPM
- Typical power curve forms
  - AC/DC PM ("const Q", "const Q/P" FW); AC Ind (NEMA)

Electrical data — **Class I Division 1 Groups D**

U [V]	Δ / Y	f [Hz]	P [HP]	P [kW]	n [rpm]	I Load [Amps] 4/4	3/4	1/2	0	LRC	Nom. Eff Load [%] 4/4	3/4	2/4	Pwr. Factor Load [%] 4/4	3/4	2/4	Torque [lb-ft]	T_A/T_N LRT [%]	T_k/T_N BDT [%]
460		60	75.00	-/-	1,780	85.00	64.70	47.10	25.00	543.0	95.4	95.8	95.6	87.0	85.0	78.0	221.0	180	240
230		60	[illegible]	-/-	[illegible]	170.00					95.4	95.8	95.6	87.0	85.0	78.0	221.0	180	240

Frame Type: 365T	Type of constr.: (A) Foot mounted - End shield	Ins. Cl.:Insulation class F	Motor Prot.:(A) No winding protection	NEMA Des.: B	S.F.: 1.15
Mtr. WT:947		Temp. Rise Cl.: B	Amb. Temp.: + to -20 °C @1000 m	kVA: G	I.P.: IP65

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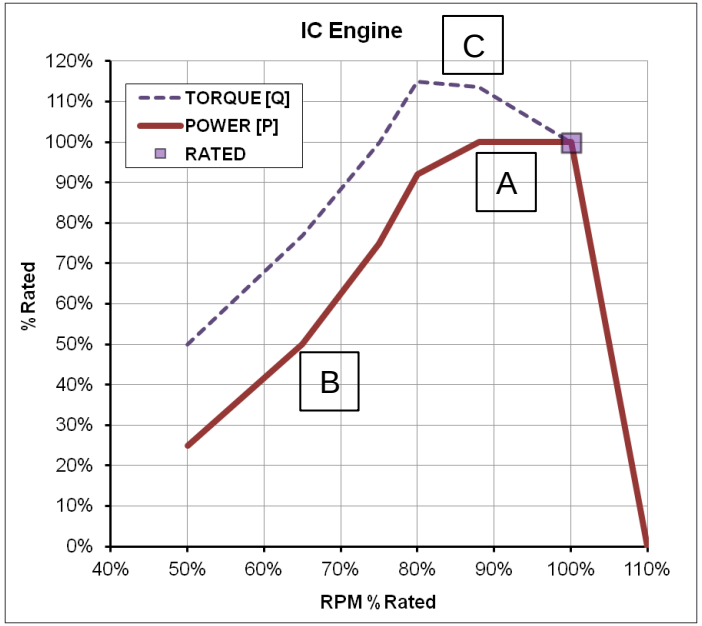
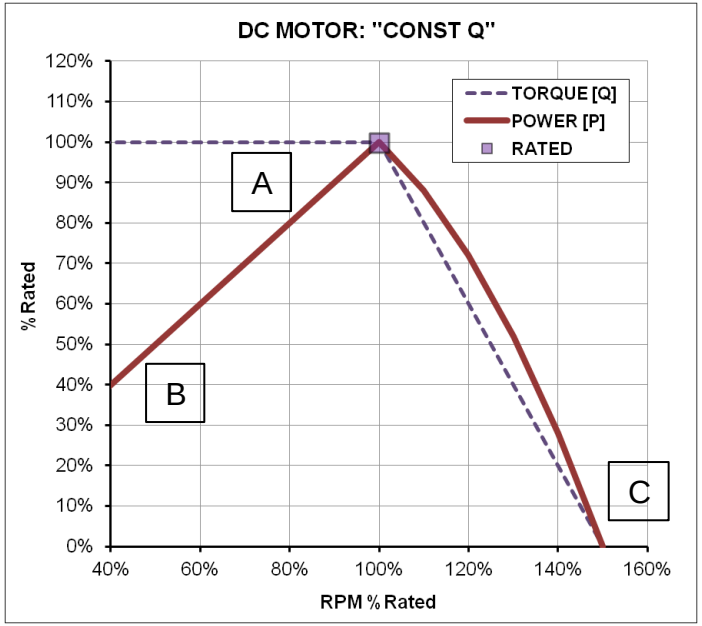
TORQUE & POWER CURVES: IC ENGINE

- Typical marine diesel
  A. Full power to lower RPM (contemporary diesels)
  B. Low RPM power curve follows typical prop demand curve
  C. Peak torque below rated RPM



TORQUE & POWER CURVES: AC/DC PM MOTOR

- "Constant Torque"
  A. Full torque to lower RPM, not power; max power is tucked into a peak
  B. Still generous power at low RPM vs diesel
  C. "No-load" RPM can vary greatly (+10% to +100%)



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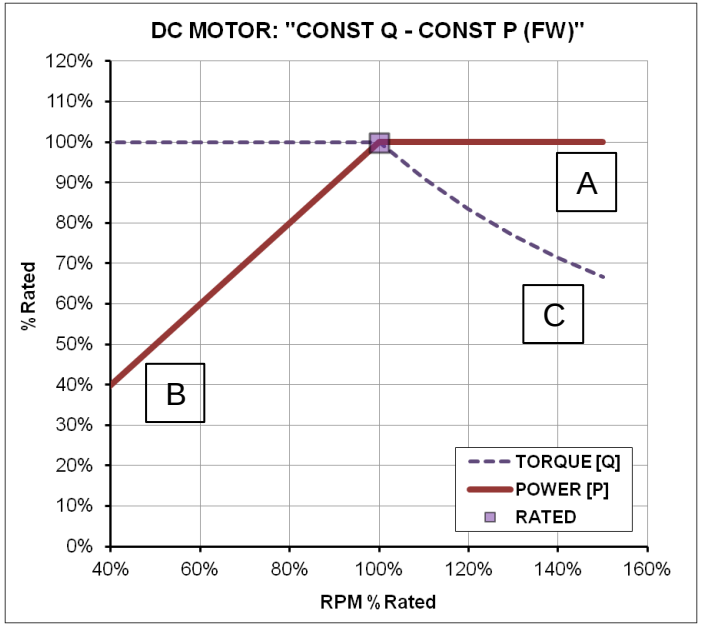
TORQUE & POWER CURVES: AC/DC PM MOTOR

- "Const Torque / Const Power"
  - A. Full power to higher RPM (via magnetic field weakening or phase advance); broad RPM range of max power
  - B. Abundant power at low RPM (with proper sizing strategy!)
  - C. Upper RPM can vary greatly



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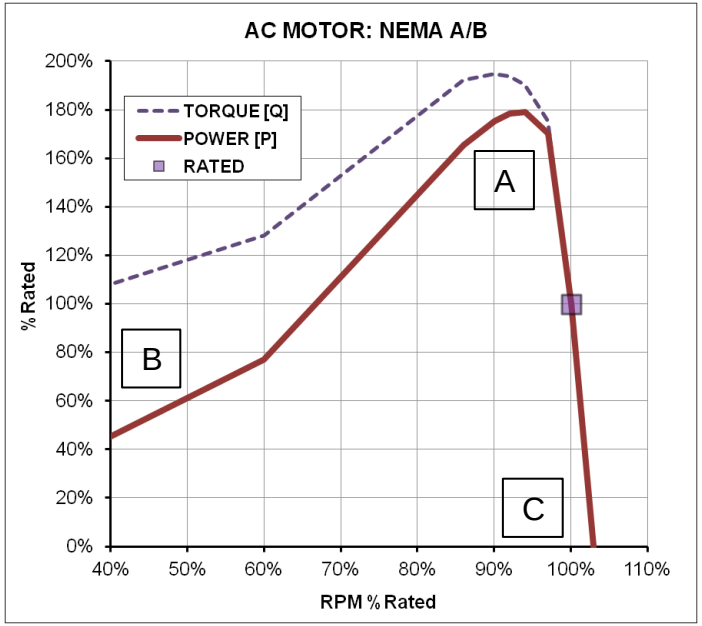
TORQUE & POWER CURVES: AC IND MOTOR

- NEMA A/B
  - A. Very high peak torque/power at 90% to 95% rated RPM (“breakdown torque”)
  - B. Generous power at low RPM (minimum “pull-up” power equal or greater than rated)
  - C. Steep decline to no-load RPM



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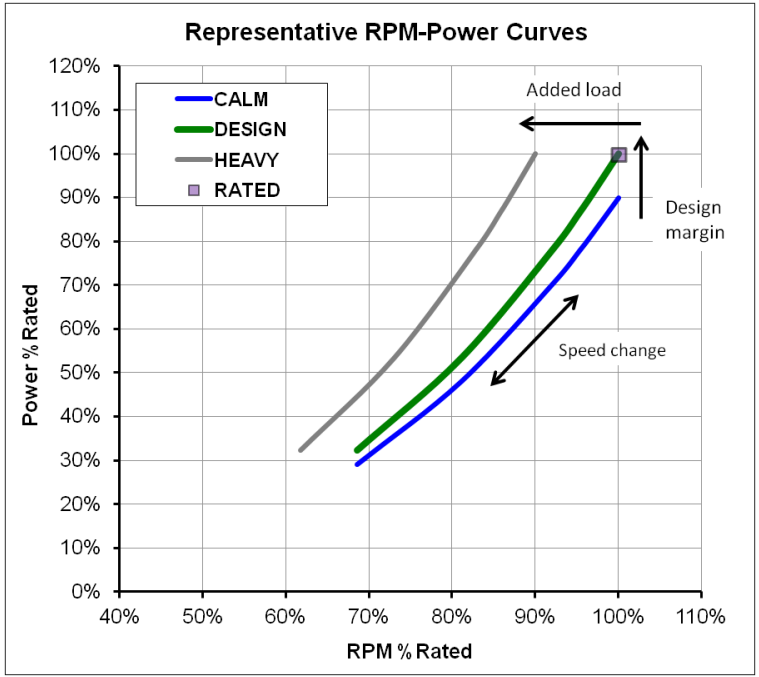
PROPULSOR LOAD ON A DRIVE

- Critical to determine first
- Power vs RPM
- Relevant curves
  - Rated power (“cubic”)
  - Predicted calm-water curve
  - With design margin
  - With added load (seas, etc)



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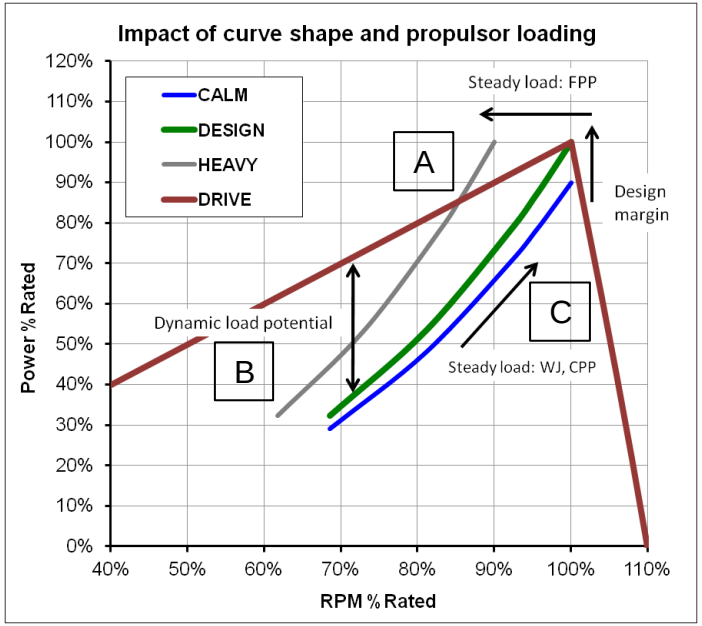
HOW DRIVE CURVE SHAPE AFFECTS PERFORMANCE

- Power curve key to handling steady and dynamic loads
  - A. Steady loads (seas, towing): shape matters most with FPPs
  - B. Dynamic loads (planing hump): shape at low RPM
  - C. WJ & CPP propulsors tend to follow steady-state curve



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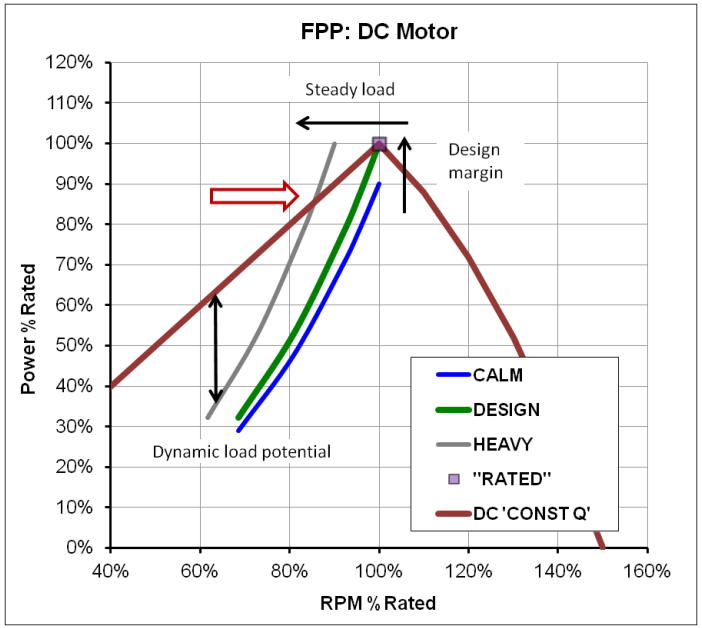
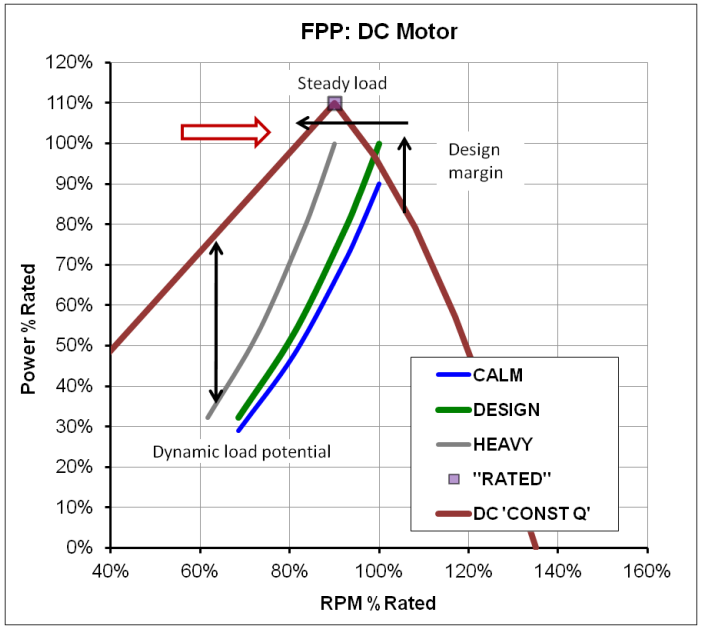
FPP SIZING STRATEGY: AC/DC PM “CONST Q”

- *Propulsor* design point: Power -10%; RPM +10%





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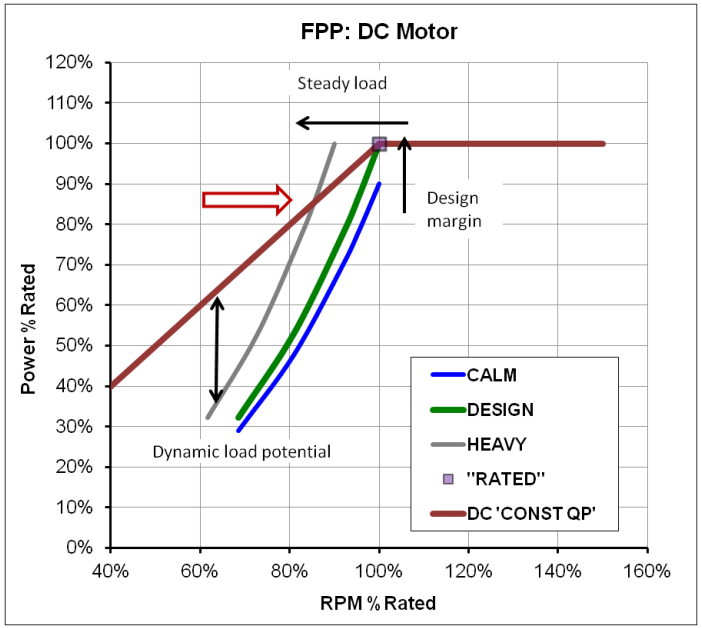
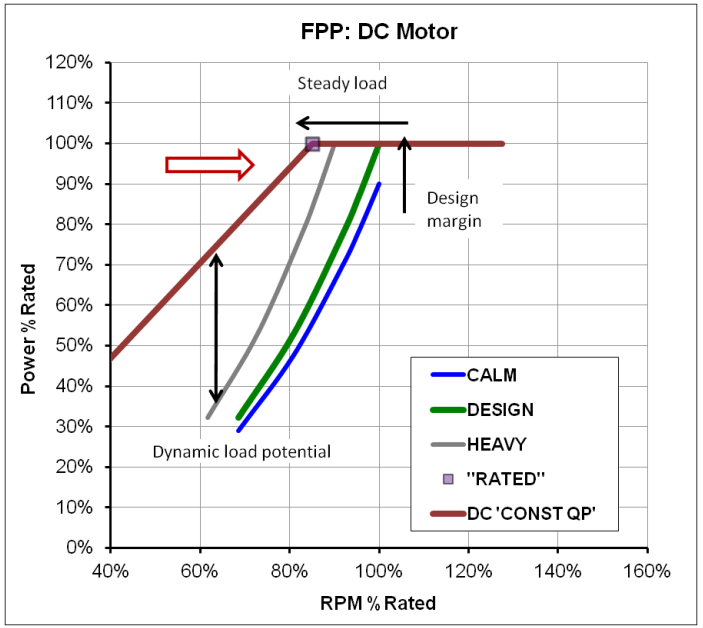
FPP SIZING STRATEGY: AC/DC PM “CONST Q/P”

- *Propulsor* design point: Power rated; RPM +15%





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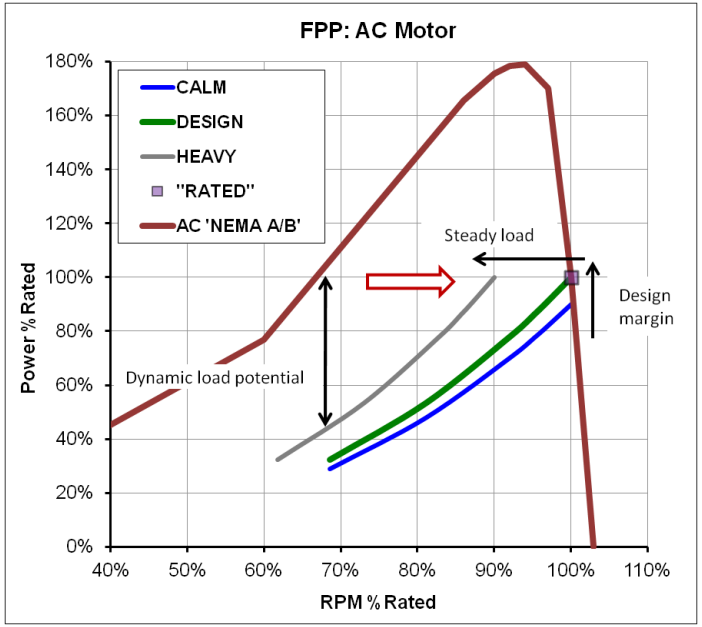
FPP SIZING STRATEGY: AC IND “NEMA A/B”

- *Propulsor* design point: Power rated; RPM rated



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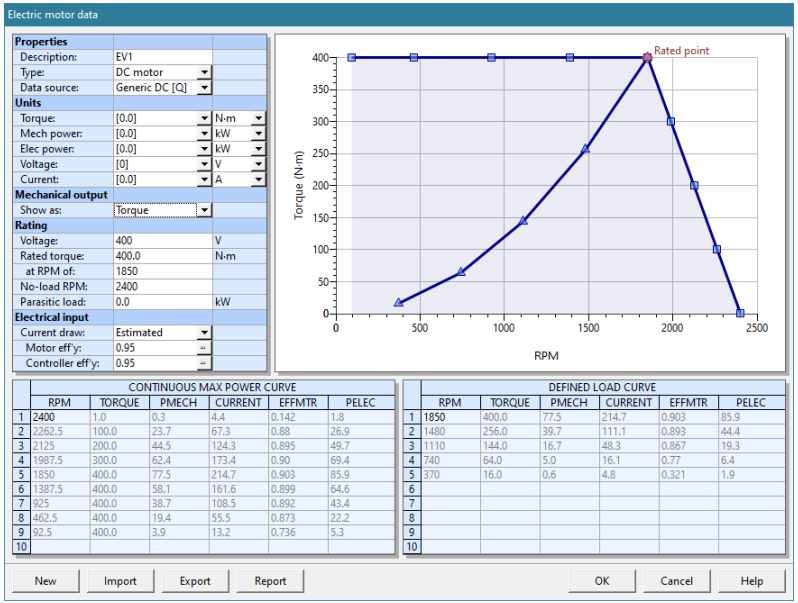
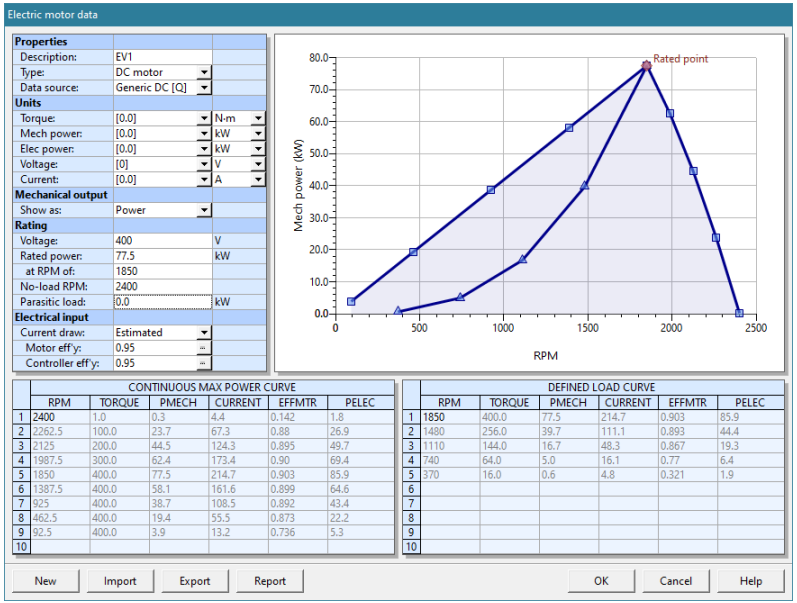
CASE STUDY: 9M PLANING CRAFT

- NavCad's "Generic" simple definition models





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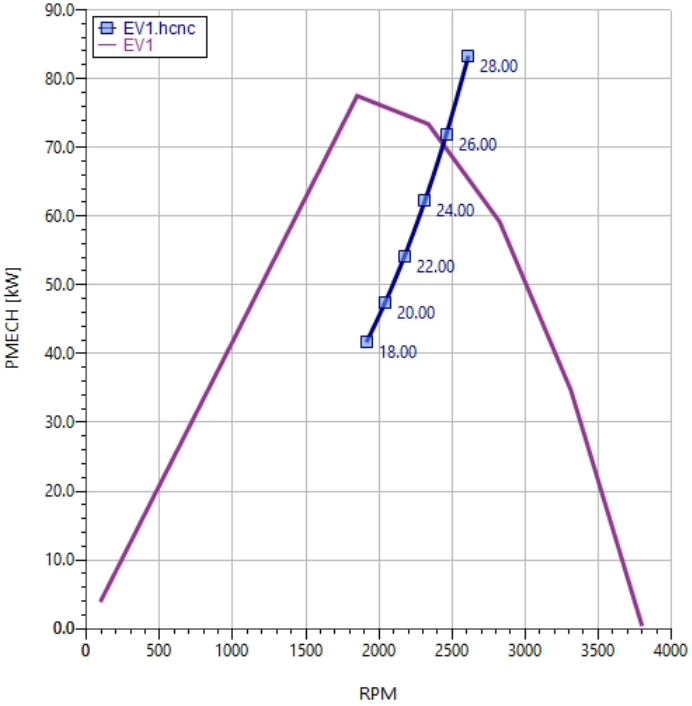
CASE STUDY: 9M PLANING CRAFT

- Design objectives
  - 25+ kt speed (incl added loads)
  - Only “Const Q” motor available; but with generous no-load RPM
- Sizing solution
  - Motor with +10% power margin
  - Optimize gear ratio & pitch for operational RPM at +20% “rated”



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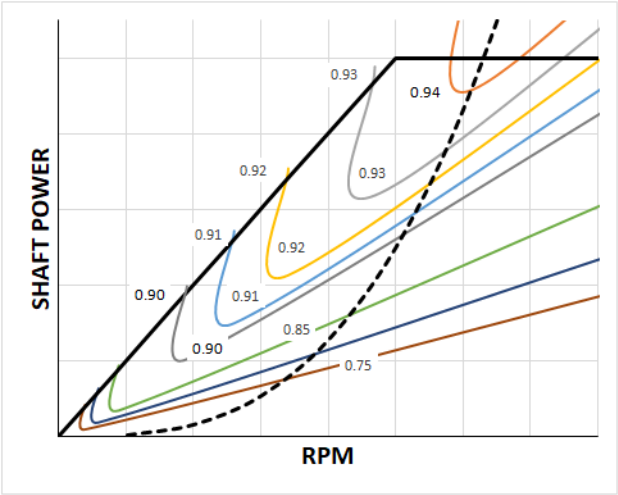
CASE STUDY: 9M PLANING CRAFT

- Current demand (amps="fuel")
  - Partial load eff'y (incl control loss)
  - Roughly 3%-4% loss at 50% power



Electrical input	
Current draw:	Estimated
Motor eff'y:	0.95
Controller eff'y:	0.95

SPEED COEFS			PRIME MOVER			ELEC DEMAND PER MOTOR		
SPEED [kt]	FV	FNB	RPM [RPM]	PMECH [kW]	LOADPCT [% max]	PELEC [kW]	CURRENT [A]	EFFMTR
18.00	2.473	2.126	1914	41.7	53.8	46.7	116.8	0.891
20.00	2.748	2.363	2041	47.4	61.2	53.1	132.7	0.893
22.00	3.022	2.599	2175	54.2	69.9	60.5	151.4	0.895
24.00	3.297	2.835	2315	62.3	80.4	69.4	173.6	0.897
26.00	3.572	3.071	2461	71.9	92.8	80.0	199.9	0.900
28.00	3.847	3.308	2612	83.3	107.6	92.6	231.5	0.900

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FINAL THOUGHTS:

- For successful electric drive motor selection
  - Assess operation profile (environmental, towing tasks, ...)
  - Calculate and lay out RPM-Power demand curves
  - Fit motor power curve to enclose demand curves
- **Thank you!**
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