Lab 3 – DC Motor / Propeller Characterization

Unified Engineering

27 Feb 06

Learning Objectives

- Measure thrust, torque, electrical power with prop test rig and wind tunnel
- Create motor/prop performance curves

Secondary Objectives, for Flight Competition Project

- Get familiar with propulsion terminology and propeller performance parameters

Experimental Rig

- Test Article: Propeller/motor unit in $1' \times 1'$ tunnel in Bldg 33 hangar
- Instrumentation:
  - Tunnel's pitot-static probe for airspeed measurement
  - Prop test rig with thrust and torque gauges
  - Power supply with voltage and current meters
  - Strobe for measuring RPM

Test Conditions

- Fixed motor terminal voltages: $v \;=\; 3\,\mathrm{Volts}\,,\; 6\,\mathrm{Volts}$
- Nominal wind tunnel speeds: $V \;=\; 0 \ldots V_o$ (static to zero-load condition)

Suggested tunnel speed increments: $\Delta V \;\simeq\; 1\,\mathrm{m/s}$ for $v = 3\,\mathrm{Volts}$, $2\,\mathrm{m/s}$ for $v = 6\,\mathrm{Volts}$

Wind-off Sensor Tare data, prop mounted, wind off.

- T_{tare} , Q_{tare} from load sensor. Enter these in T_{read} , Q_{read} columns for convenience.

Take tares before and after each tunnel-speed sweep to check for drift. Use average values.
Note: Do not bump the rig during a run. This is likely to disturb the tare values.

Motor-mount Aero Tare data.

The motor mount has a small negative thrust (i.e. drag) T_0, and a very small aerodynamic torque Q_0, both of which must be corrected for. To reduce your test time, we provide this aero tare data in the form of aero-tare thrust area and torque volume:

$$CTA_0 \;\equiv\; \frac{T_0}{q_\infty} \;=\; -1.6 \times 10^{-3}\,\mathrm{m}^2$$

$$CQA_0 \;\equiv\; \frac{Q_0}{q_\infty} \;=\; +1.1 \times 10^{-6}\,\mathrm{m}^3$$

Raw Prop Data Acquired for each each tunnel speed sweep

- Wind-off tares T_{tare} , Q_{tare} from load cells, at beginning and end of tunnel-speed sweep.
- v from voltmeter (in Volts). Adjust power supply to hold v fixed for all tunnel speeds.
- q_∞ from tunnel's pitot-static probe in Torr. Convert to Pascals.
- T_{read} , Q_{read} from load cells.
- i from ammeter (in Amps).
- RPM using strobe. Convert to Ω (in rad/s). To avoid aliasing, start with strobe in a too-high setting, say 15000 RPM, and then reduce setting until you see the prop stop.

Data processing

• The data recording sheet can be used for hand data reduction, but a spreadsheet will be much faster and less error-prone.
• Load cell tare correction, calibration conversions, and aero-tare correction.

$$\begin{aligned} T\ [\,\mathrm{N}\,] &= 5.00 \times 10^{-3} \times (T_{\mathrm{read}} - T_{\mathrm{tare}}) \ - \ q_\infty\, CTA_0 \\ Q\ [\,\mathrm{Nm}\,] &= 1.47 \times 10^{-4} \times (Q_{\mathrm{read}} - Q_{\mathrm{tare}}) \ - \ q_\infty\, CQA_0 \end{aligned}$$

• Thrust and power coefficient calculations. These are analogous to C_L and C_D for a wing. (note extra R factor in C_P denominator!).

$$C_T \;=\; \frac{T}{\frac{1}{2}\rho(\Omega R)^2 \pi R^2} \qquad , \qquad C_P \;=\; \frac{Q}{\frac{1}{2}\rho(\Omega R)^2 \pi R^3}$$

• Advance ratio λ (analogous to α for a wing), efficiency calculations.

$$\lambda \;=\; \frac{V}{\Omega R} \quad , \quad \eta_p \;=\; \frac{TV}{Q\Omega} \;=\; \lambda\,\frac{C_T}{C_P} \quad , \quad \eta_m \;=\; \frac{Q\Omega}{iv} \quad , \quad \eta \;=\; \frac{TV}{i\,v} \;=\; \eta_p\,\eta_m$$

Lab Report Contents

• Name of author, and members of the lab group
• Abstract
• Sketch of experimental setup
• State the propeller being tested: APC7x4. Motor: Speed-400-7V.
• One plot of dimensional $T(V)$, two curves, one for each voltage (see Fig 2 in Lab notes).
• One plot of rotation rate $\Omega(V)$, two curves, one for each voltage (see Fig 2 in Lab notes)
• One plot of efficiency $\eta(V)$, two curves, one for each voltage (see Fig 2 in Lab notes)
Comment on how the best-efficiency speed V appears to vary with voltage.
• One plot of motor current $i(V)$, two curves, one for each voltage (see Fig 2 in Lab notes)
• Two plots of component and total efficiency $\eta_p(V)$, $\eta_m(V)$, $\eta(V)$ curves, one plot for each voltage (see Fig 7 in Lab notes). Comment on whether this prop and motor are well matched.
• Determine V_o and aerodynamic pitch $\mathrm{P}_{\mathrm{aero}}$ for each voltage. Compare your $\mathrm{P}_{\mathrm{aero}}$ values with manufacturer's stated pitch P
• Three dimensionless coefficient plots. Two curves on each plot, one for each voltage:
  – $C_T(\lambda)$
  – $C_P(\lambda)$
  – $\eta_p(\lambda)$

Comment on the usefulness of these curves for determining the propeller's dimensional thrust and torque for <u>any</u> V, Ω combination.
• Estimates of uncertainty and errors in results.

Propeller: ________________ Diameter: ______ Pitch: ______ $R = \mathrm{D}/2 =$ ______ [m]

Motor: __________________

$v_1 = 3\,\mathrm{V}$

q_∞	T_{read}	Q_{read}	i	RPM	q_∞[Pa]	T [N]	Q [Nm]	V [m/s]	Ω[rad/s]	λ	C_T	C_P	η_p
Tares:					—	—	—	—	—	—	—	—	—
Tares:					—	—	—	—	—	—	—	—	—

$v_2 = 6\,\mathrm{V}$

q_∞	T_{read}	Q_{read}	i	RPM	q_∞[Pa]	T [N]	Q [Nm]	V [m/s]	Ω[rad/s]	λ	C_T	C_P	η_p
Tares:					—	—	—	—	—	—	—	—	—
Tares:					—	—	—	—	—	—	—	—	—