Lab (S/L3) – Tunnel Testing of a 3-D Wing
Unified Engineering
27 Feb 04

Learning Objectives

- Measure lift, drag, moment from load cell data, using reference-axis conversions
- Perform lift and drag predictions for a 3-D wing, and compare to measurements
- Use smoke visualization to see tip vortices
- Interpret tufts and acoustic-probe noise to detect flow separation

Secondary Objectives, for Flight Competition Project

- Get familiar with wing performance parameters for 3-D wings
- Get experimental data for stock Dragonfly wing, to serve as a baseline for redesign work

Experimental Rig

- Test Article: Dragonfly wing in WBWT
- Instrumentation:
  - Tunnel's pitot-static probe
  - Wing load cell
- Wing parameters:

  $S = 448\,\text{in}^2$ wing area
  $b = 47\,\text{in}$ wing span
  $c_{\text{avg}} = 9.5\,\text{in}$ average chord
  $e = 0.95$ span efficiency, estimated

Test Conditions

Nominal tunnel speeds: $V = 10,\ 15,\ 20$ mph
Angles of attack: $\alpha = -2° \ldots 20°$, in increments of 2°.

Raw Data Acquired

- q_∞, p_∞, T_∞ for each (V, α) point, from tunnel's pitot-static probe
- Six load-cell voltages for each (V, α) point
- Observe flow separation regions indicated by tufts, expected at lowest and highest α
- Observe of tip vortices with smoke wand

Data Recording

- All flow properties and cell voltages are sampled continuously at ~ 1 Hz, and stored to an Excel file
- One Excel file will contain all α points for one nominal V (or all three V's if you choose). You must manually snip out the multiple-data lines for each α, and average these to get data for a single (V, α) point.

- Data labels for voltages are:

$$\begin{aligned}(F_x)_{\text{Volt}} &= \text{“Lift”}\\(F_y)_{\text{Volt}} &= \text{“Drag”}\\(F_z)_{\text{Volt}} &= \text{“Sideforce”}\\(M_x)_{\text{Volt}} &= \text{“Yaw”}\\(M_y)_{\text{Volt}} &= \text{“Roll”}\\(M_z)_{\text{Volt}} &= \text{“Pitch”}\end{aligned}$$

Data processing

- Convert cell voltages into F_x, F_y, M_z using the appropriate 3×6 subset of the 6×6 JR-3 load cell calibration matrix (given on separate sheet).

$$\begin{bmatrix} F_x \\ F_y \\ M_z \end{bmatrix} = \begin{bmatrix} \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot & \cdot \end{bmatrix} \begin{bmatrix} (F_x)_{\text{Volt}} \\ (F_y)_{\text{Volt}} \\ (F_z)_{\text{Volt}} \\ (M_x)_{\text{Volt}} \\ (M_y)_{\text{Volt}} \\ (M_z)_{\text{Volt}} \end{bmatrix}$$

- Convert F_x, F_y, M_z, into L, D, $M_{c/4}$, with $\Delta X = 1.5\,\text{in}$, $\Delta Y = -2.0\,\text{in}$.

$$\begin{aligned}L &= -F_x \cos\alpha \;+\; F_y \sin\alpha\\D &= -F_x \sin\alpha \;-\; F_y \cos\alpha\\M_{c/4} &= -M_z \;+\; F_x \Delta X \;-\; F_y \Delta Y\end{aligned}$$

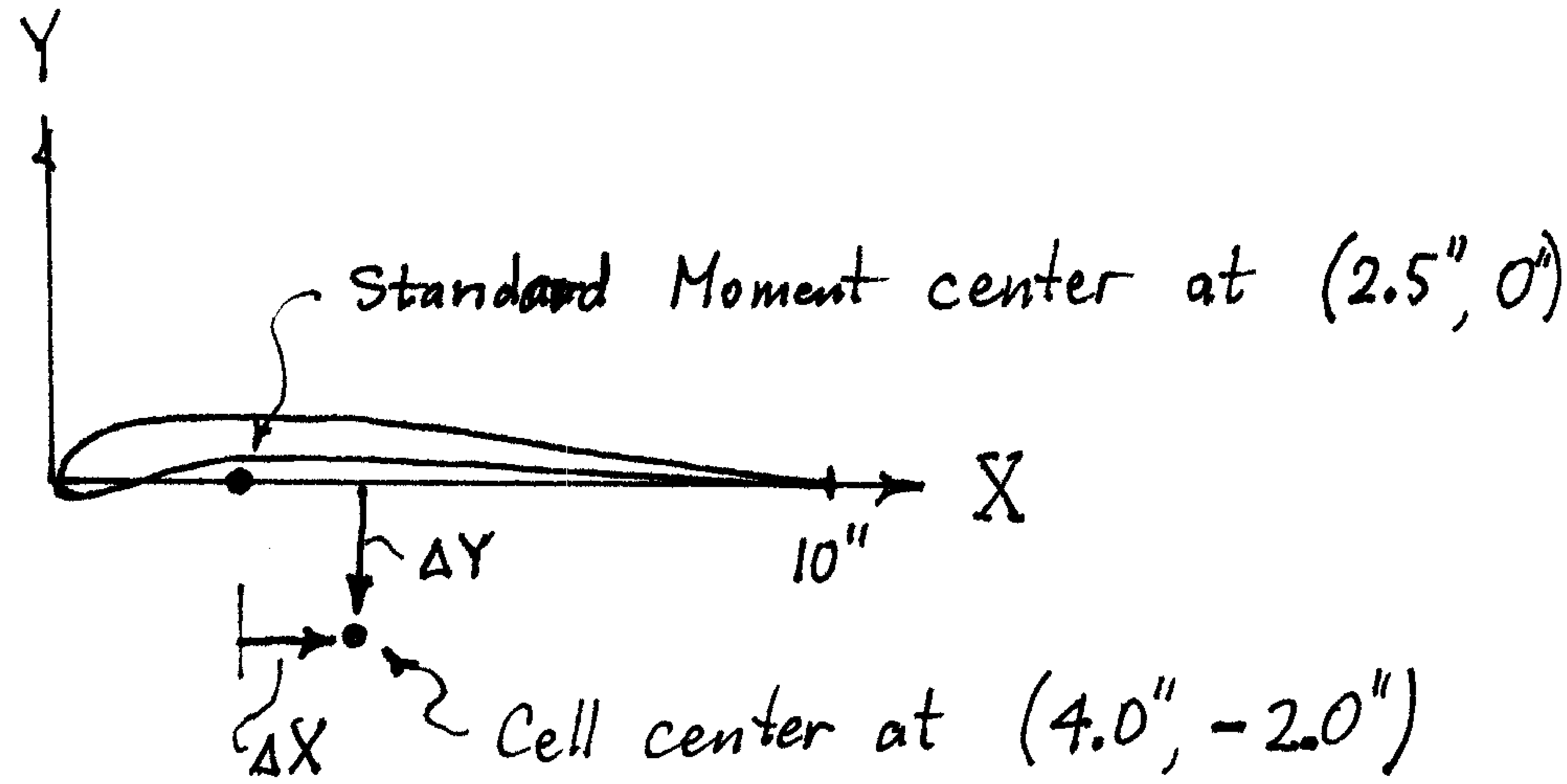
- Convert all units into a common unit system of your choice
- Compute C_L, C_D, C_M for each (V, α) point
- Compute c_{avg} Reynolds number for each nominal tunnel speed

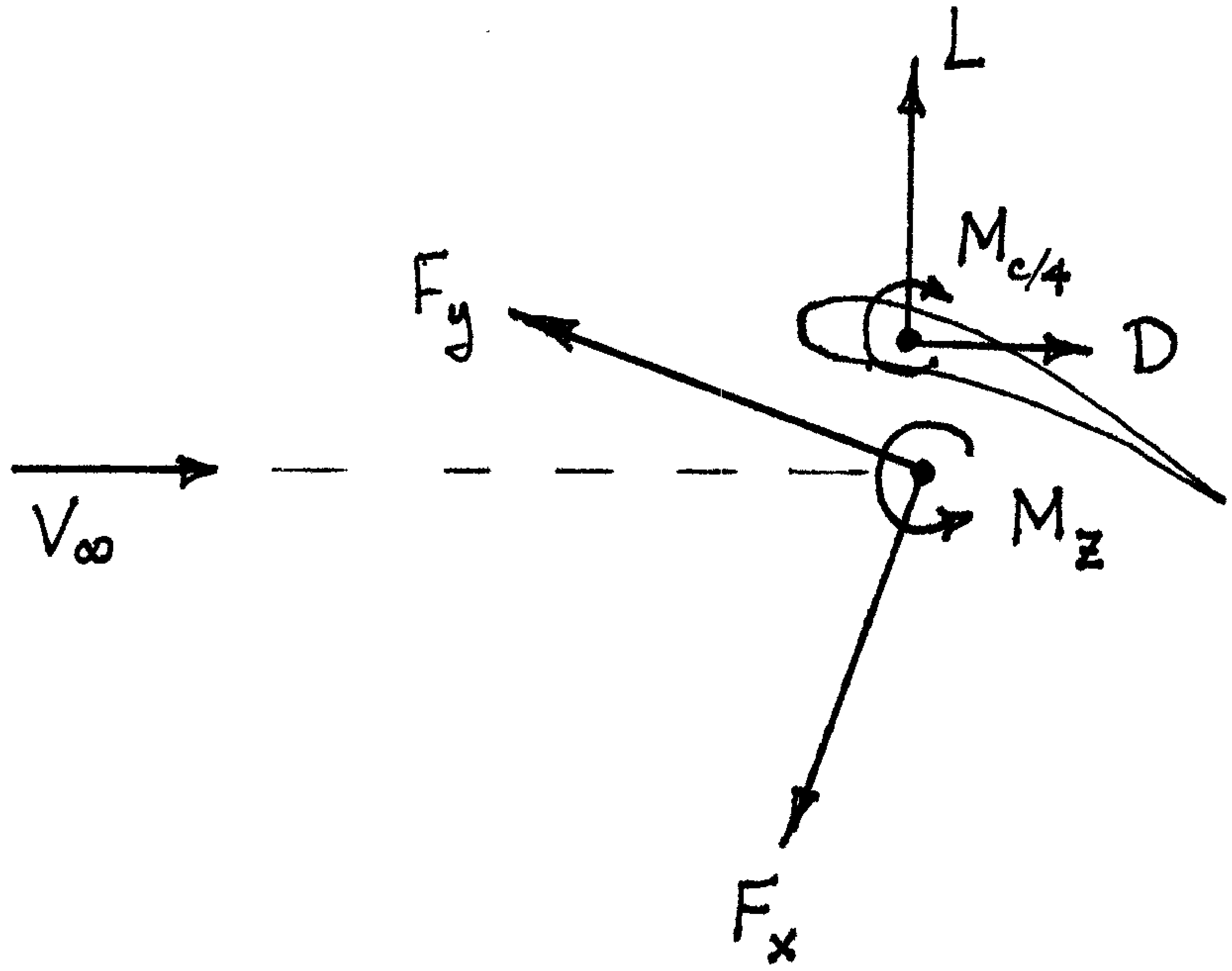
Prediction calculations

- Compute c_d, c_ℓ, c_m polars with XFOIL for test Reynolds numbers
  Airfoil coordinate file: `/mit/drela/Public/dfly.dat`
  This was obtained by tracing and digitizing an actual Dragonfly wing cross-section.
- Assume $C_L = c_\ell$
- Compute $C_D = c_d + C_{Di}$ for each polar point
- Assume $C_M = c_m$
- Compute $\alpha_{3D} = \alpha + \alpha_i = \alpha + C_L/(\pi\, AR\, e)$ for each polar point.

Lab Report Contents

- Name of author, and members of the lab group
- Abstract
- Sketch of experimental setup, showing key dimensions
- Plots of $C_L(\alpha)$, for measurements and predictions, the latter being $C_L(\alpha_{3D})$
- Plots of $C_D(C_L)$ for each Reynolds number, for measurements and predictions, overlaid
- Plots of $C_M(C_L)$, for measurements and predictions
- Estimates of uncertainty and errors in results.
- Discussion of data and comparison with predictions


Y
Standard Moment center at (2.5", 0")
X
ΔY
10"
ΔX
Cell center at (4.0", -2.0")


L
$M_{c/4}$
F_y
D
V_∞
M_z
F_x

JR3

Multi-Axis Load Cell Technologies

JR3. Inc.
22 Harter Avenue
Woodland, CA 95776

(530) 661-3677
Fax (530) 661-3701
e-mail: jr3@jr3.com

FORCE-MOMENT SENSOR SYSTEM SPECIFICATION SHEET

14 MAR 01

JR3 Sensor Model No. 20E12A-I25 15L30 Ser. No. 2230
Nominal Diameter: 2.0" Nom. Height: 1.25" Nom. Weight: 0.4 lbs

	Electrical Load Settings	Sensor Load Ratings	Calibration Loads used
Fx	15.0 lbs	15. lbs	15.0 lbs
Fy	15.0 lbs	15. Lbs	15.0 lbs
Fz	30.0 lbs	30. lbs	30.0 lbs
Mx	30.0 in-lbs	30. in-lbs	27.5 in-lbs
My	30.0 in-lbs	30. in-lbs	27.5 in-lbs
Mz	30.0 in-lbs	30. in-lbs	27.5 in-lbs

Factory Shunt Voltage Vector

Fx	Fy	Fz	Mx	My	Mz
5.259	5.235	5.246	5.715	5.703	5.415

Calibration Matrix: Multiply the calibration matrix by the sensor output voltage vector to determine the calibrated loads in lb and in-lb.

1.7357	0.0094	0.0252	-0.0402	-0.0060	0.0962	Fx Volts
-0.0116	1.7403	-0.0007	0.0012	-0.0752	-0.0054	Fy Volts
-0.1519	0.1234	3.5511	0.0282	-0.1533	-0.0218	Fz Volts
0.0493	-0.0118	0.0766	3.4583	-0.0023	0.2041	Mx Volts
0.0503	-0.0291	-0.0834	0.0010	3.5586	-0.1969	My Volts
-0.0317	0.0068	0.0258	-0.0372	-0.0069	3.6100	Mz Volts