AERO 456
FLIGHT TEST TECHNIQUES

AERONAUTICS

LESSON FQ4



Dynamic Stability

Dynamic Stability

STABILITY REVIEW QUESTION:

1) Diagnose the following stability problem



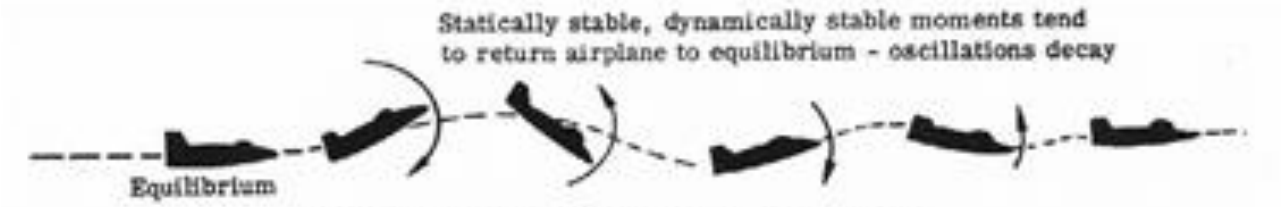
OUTLINE

- Dynamic Stability
  - Longitudinal Modes
    - Short Period
    - Phugoid
  - Lateral-Directional Modes
    - Dutch Roll
    - Spiral
    - Roll
  - Flight Test Techniques
  - Data Reduction Methods
  - MIL-STD-1797 Requirements

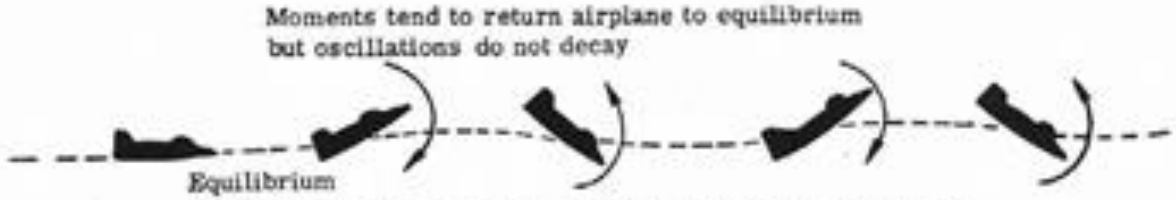
Suitcase Stability

Video

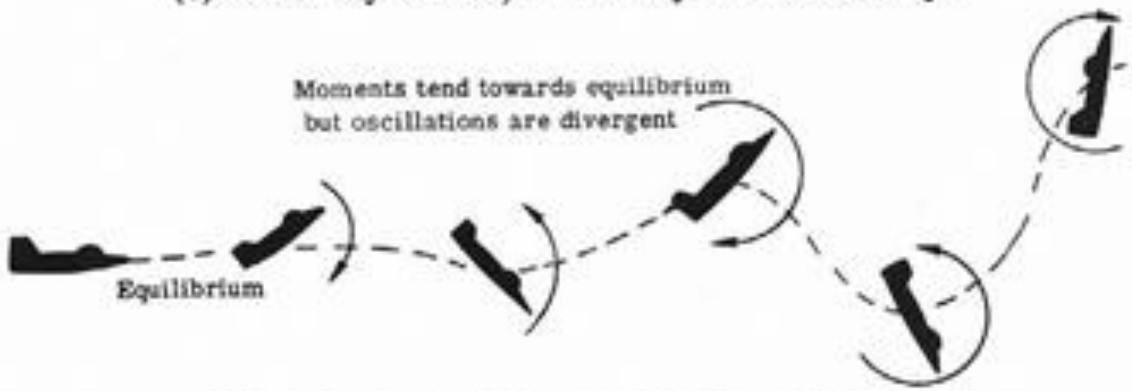
Dynamic vs Static Stability



(a) Statically and dynamically stable.



(b) Statically stable; neutral dynamic stability.



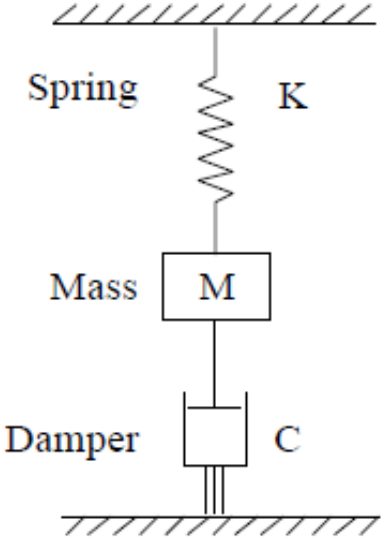
(c) Statically stable; dynamically unstable.

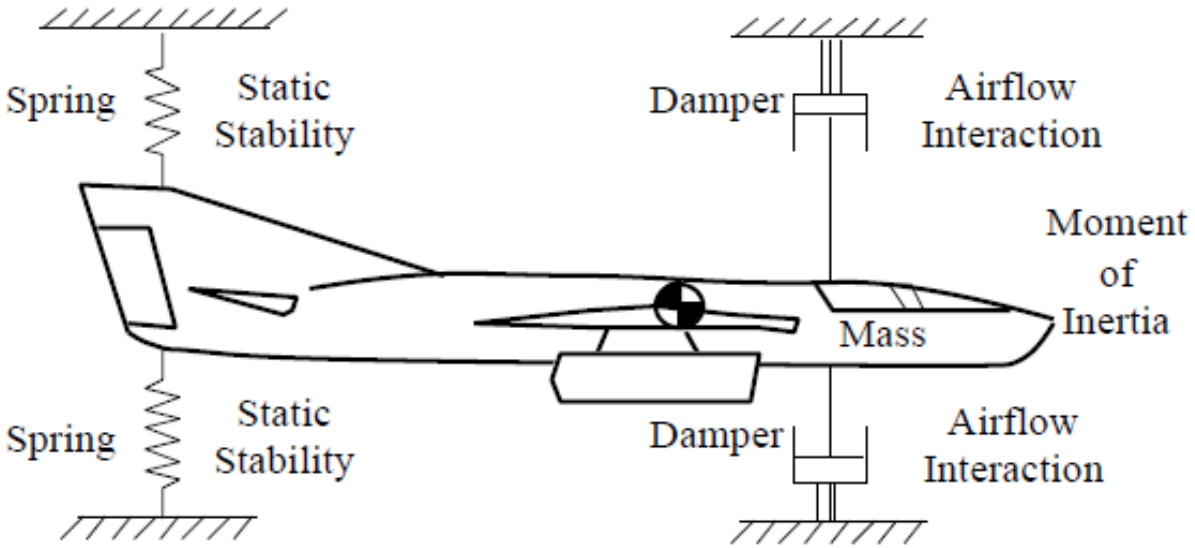
Why does it matter?

- F-8 DFBW, Stability Video
- Video 1
- Video 2
- F-4 (technically a PIO)

- **Bad flying/handling qualities can cause a crash**

Aircraft Dynamics

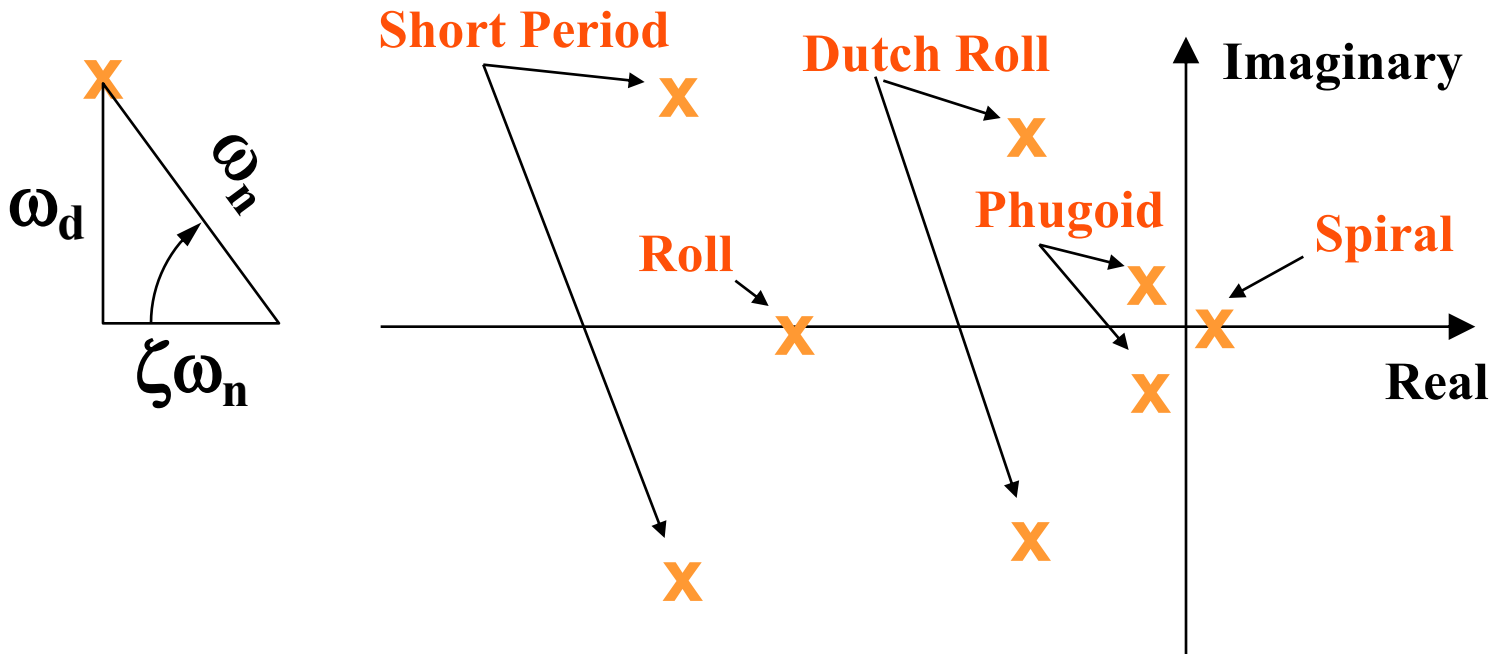




Frequency Domain

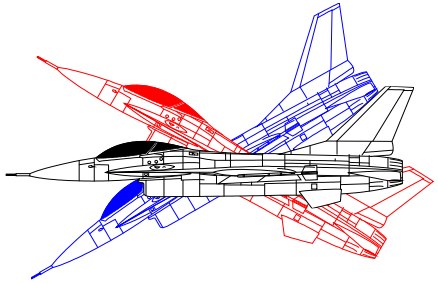
- **Characteristic Equation:**

$$s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$$

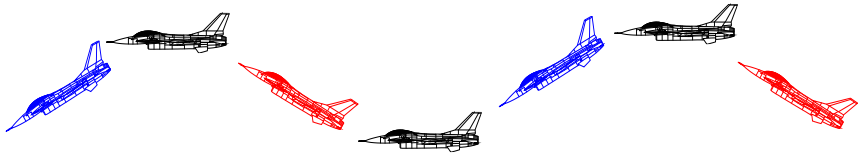


Longitudinal Modes

- **Short Period**
  - High frequency
  - Typically heavily damped
  - Changing pitch and angle of attack
  - Airspeed & altitude essentially constant
  - *Determines ability to capture and hold a pitch angle*



- **Phugoid (Long Period)**
  - Low frequency
  - Typically lightly damped
  - Changing airspeed, altitude, (ie potential and kinetic energy), and then pitch angle
  - Angle of attack essentially constant
  - Period usually greater than 30 seconds
  - *Determines ability to maintain altitude and airspeed*



Phugoid Characteristic Eq.

$$V = V_o \, e^{-t/\tau} \, \sin(\phi + \omega_d)$$

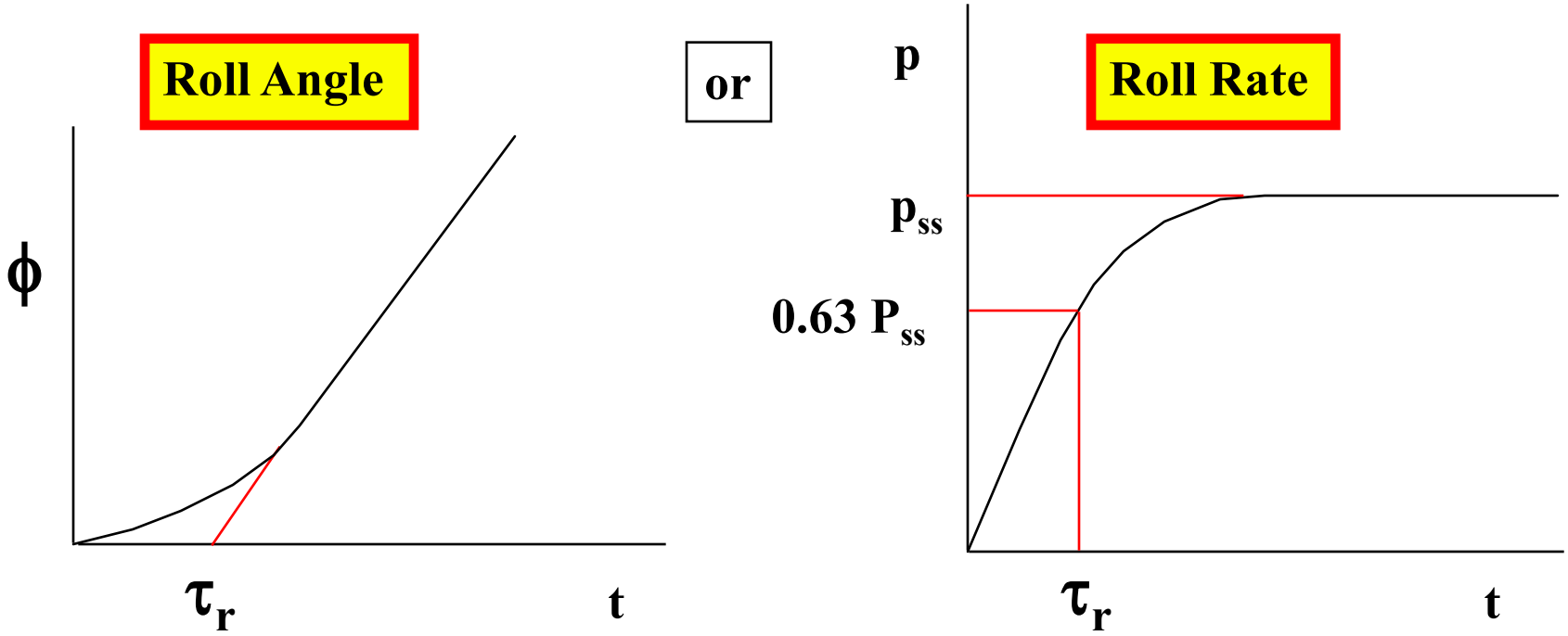
- **Where:** V_o is the trim velocity
  - t is time in seconds
  - τ is the time constant (sec)
  - ϕ is the phase shift (sec)
  - ω_d is the damped frequency (rad/sec)

Lateral-Directional Modes

- **Roll**
  - **Defined by Roll-mode time constant:**
    - **Time required to reach 63% of steady-state roll rate**
  - **Too high of a time constant makes the airplane appear sluggish**
    - **Caused by relatively high inertia with low control power**
    - **Requires pilot compensation**
      - Large gliders are sluggish in roll
      - P-38 could not roll with Japanese Zeroes
      - B-52 very difficult to aerial refuel
  - **Too high of a roll rate can lead to roll coupling**
    - **Causes pitch up and possible departure**
      - A-4 max roll rate: 720 deg/sec
      - T-38 : 720 deg/sec
      - F-16 : 300 deg/sec
      - Barn Swallow: 5000 deg/sec

Data Reduction

- Manual Data Reduction (continued)
  - Time Constant (aperiodic motion)
    - 2 ways



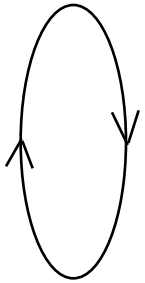
Lateral-Directional Modes

- Dutch Roll
  - Oscillatory motion combining yawing and rolling motions
  - High or low frequency
  - High or low damping
  - Greatest when dihedral effect is large compared to weathercock stability
  - Motion is very unsettling to passengers
  - Video

"Dutch roll – the third element in the [lateral] motion [of an airplane] is a yawing to the right and left, combined with rolling.
Aeronautical Engineer Jerome C. Hunsaker 1916

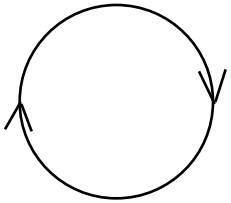
Dutch Roll

- ϕ/β ratio
  - Wingtip traces one of the following

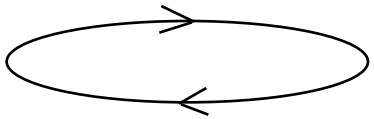


$\phi/\beta > 1$

"Rolly"



$\phi/\beta \approx 1$

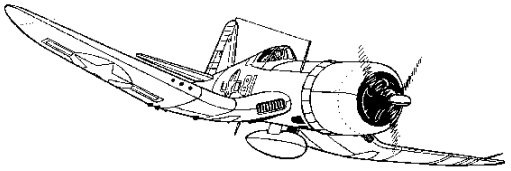


$\phi/\beta < 1$

"Snakey"

Lateral-Directional Modes

- Spiral
  - Tendency to roll out of a bank angle to wings-level (or increase)
  - Aperiodic
  - Typically unstable with reasonably large time to double amplitude
  - Unstable if weathercock stability is greater than dihedral effect
    - Note that trying to improve spiral stability will typically aggravate the dutch roll
  - Torque of prop will usually cause different responses left vs right



Flight Test Techniques

Flight Test Techniques (FTTs)

1. Frequency Sweep (Short Period/Dutch Roll)
2. Pitch Doublet (Short Period)
3. Phugoid
4. Roll Mode
5. Rudder Doublet (Dutch Roll)
6. Spiral Mode



Short Period/Dutch Roll
1. Frequency Sweep

Procedure:

- Perform Trim Shot
- Determine damped frequency by pumping stick at varying frequency
  - Keep constant amplitude
- Damped frequency is where aircraft response is greatest
  - Response falls off quickly after ω_d
- Time Period at ω_d
- n/α note (or videotape) g and θ during Frequency sweep
- Record:
  - H_i, V_i, T, θ, g

Assumptions/Constraints:

- SLUF

NOTE: use rudder for Dutch Roll Frequency Sweep

Data Reduction:

$\omega_d = 1/T$

$n/\alpha \sim g / \theta$

Control Anticipation Parameter

$CAP = Wn(sp)^2/(n/\alpha)$

You'll need to calculate CAP versus ζ then compare to Mil Std 1797

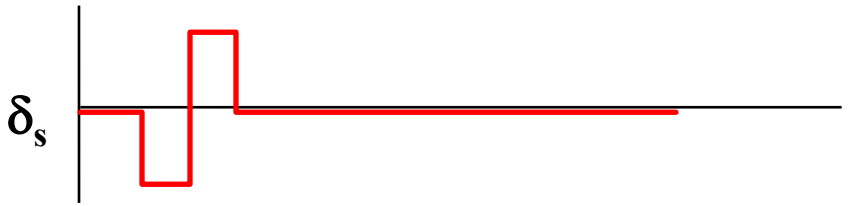
Short Period 2. Pitch Doublet

Procedure:

- Perform Trim Shot
- Perform frequency sweep
- Input symmetric fore-and-aft longitudinal yoke input (doublet)
  - Match ω_d from the frequency sweep
- Count the number of overshoots to determine damping ratio
- Repeat aft-to-fore
- Record:
  - H_i, V_i, *overshoots*

Assumptions/Constraints:

- SLUF



Data Reduction:

$$\zeta \approx \frac{7 - \#\text{overshoots}}{10}$$

3. Phugoid

Procedure:

- Perform Trim Shot
- Push or pull on yoke to set target A/S
  - delta from trim A/S
  - leave power & trim constant
- Return controls to trim position and release

Assumptions/Constraints:

- Yoke left to float
- Power & Trim left alone
- Alpha ~ const

AE456 Methods (your choice):

- Record data every 5 sec OR Hack clock every XX knots YY feet
- Time for at least 1.5 cycles, or 2 minutes (whichever longer)
- Record:
  - H_i, V_i, t

TPS method:

- Time between VVI reversals
- At VVI = 0, these will be the peaks
- Record maximum and minimum Hi and Vi for each peak
- May occur right before VVI reversal (due to VVI lag)

Data Reduction:

Use Phugoid.xls to reduce data

$$V = V_o \, e^{-t/\tau} \, \sin(\phi + \omega_d)$$

4. Roll Mode

Procedure:

- Perform trim shot
- Set target bank angle (30°)
- Perform a step-input, roll command opposite the bank
- Roll through the target bank angle on other side
  - Do not attempt to capture the target bank angle on the other side
- Repeat for varying control deflections (1/4, ½, ¾, FULL)
- Repeat in both directions, with and without rudder coordination
- Record:
  - time to achieve total bank angle change, roll rate/angle (DAS)

Assumptions/Constraints:

- SLUF

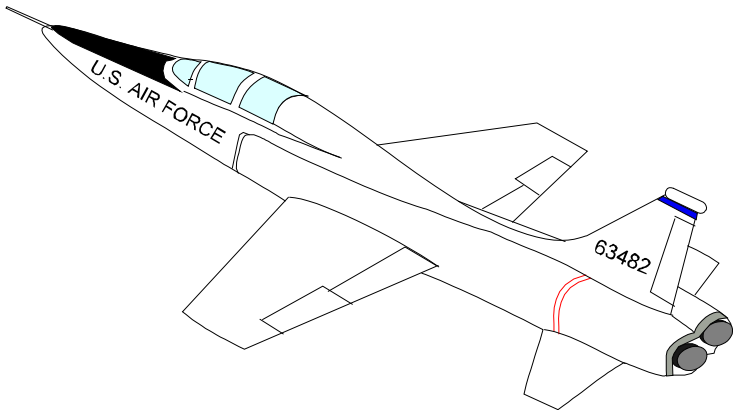
Data Reduction:

τ = time to reach 63% of steady-state roll rate

Plot rate and angle over time

T-38 Roll Mode FTT

- **Roll (T-38)**
  - Stick Deflections: 1/4, 1/2, 3/4, and full
    - T-38 has non-linear aileron scheduling
  - Rudder: fixed, free, and best coordination
  - In high performance aircraft (e.g. T-38), full stick deflection rolls are started wings level, recovering after passing through wings level after 360° of roll
    - Watch out for roll coupling!



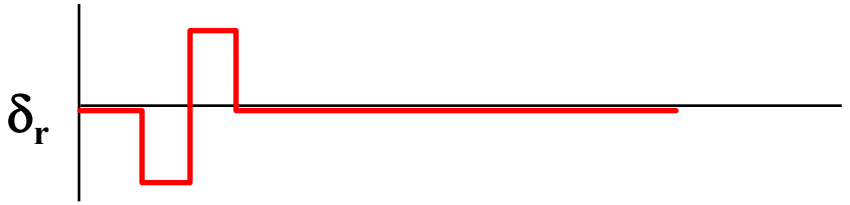
Dutch Roll
5. Rudder Doublet

Procedure:

- Perform Trim Shot
- Perform frequency sweep
- Input symmetric left-and-right rudder input (doublet)
  - Match ω_d from the frequency sweep
- Count the number of overshoots to determine damping ratio
- Observe ϕ/β
- Repeat right-to-left
- Record:
  - H_i, V_i, *overshoots*

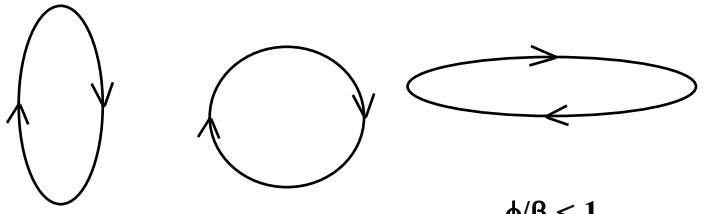
Assumptions/Constraints:

- SLUF



Data Reduction:

$$\zeta \approx \frac{7 - \#\text{overshoots}}{10}$$



6. Spiral Mode

Procedure:

- Perform Trim Shot
- Roll into target bank angle (20°)
- Release controls and observe
  - May use pure-aft yoke pressure (or trim) to keep nose from falling
- Repeat opposite direction
- Record:
  - H_i, V_i, *Time to double / half amplitude, bank angle at 12 & 20 seconds*

Assumptions/Constraints:

- SLUF

Data Reduction:

Time to double or half amplitude, etc – see MIL-STD-1797

General Data Reduction

- **Manual Data Reduction (continued)**
  - Time Constant (periodic motion)

$$\tau = \frac{1}{\zeta \omega_n}$$

  - Time to 1/2 amplitude

$$t_{1/2} = \tau \ln 2 = \frac{\ln 2}{\zeta \omega_n}$$

Short Period & Dutch Roll Data Reduction

- **Manual Data Reduction**
  - **Damping Ratio (Flight Test Approximation)**

$$\zeta \approx \frac{7 - \#\text{overshoots}}{10}$$

    - No overshoots: $\zeta >= 0.7 \Rightarrow$ Deadbeat
    - 7 or more overshoots: $\zeta < 0.1 \Rightarrow$ lightly damped
  - **Damped Frequency**

$$\omega_d = \frac{2\pi}{T}$$

  - **Natural Frequency**

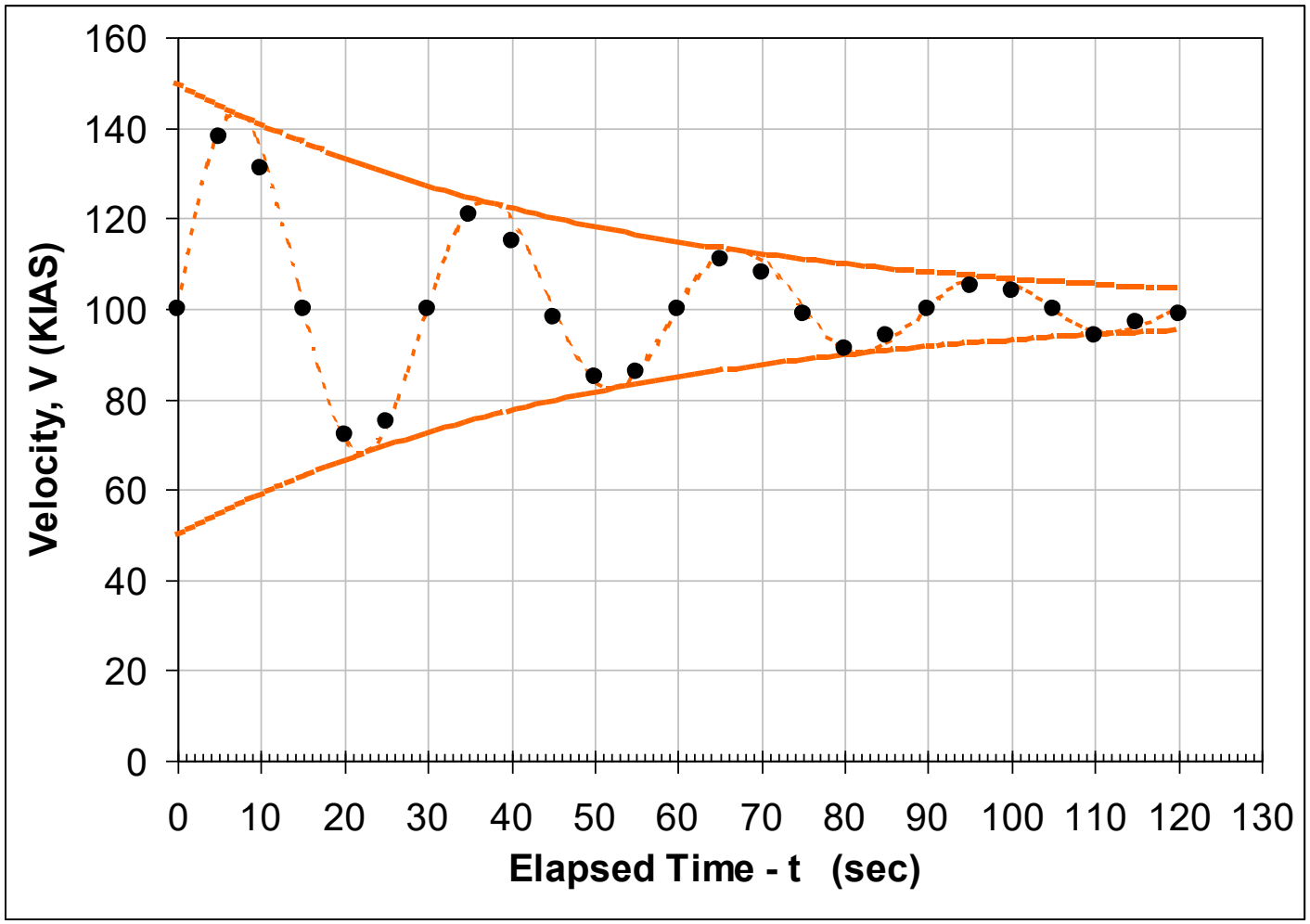
$$\omega_n = \frac{\omega_d}{\sqrt{1-\zeta^2}}$$

  - **Time Constant (periodic motion)**

$$\tau = \frac{1}{\zeta \omega_n}$$

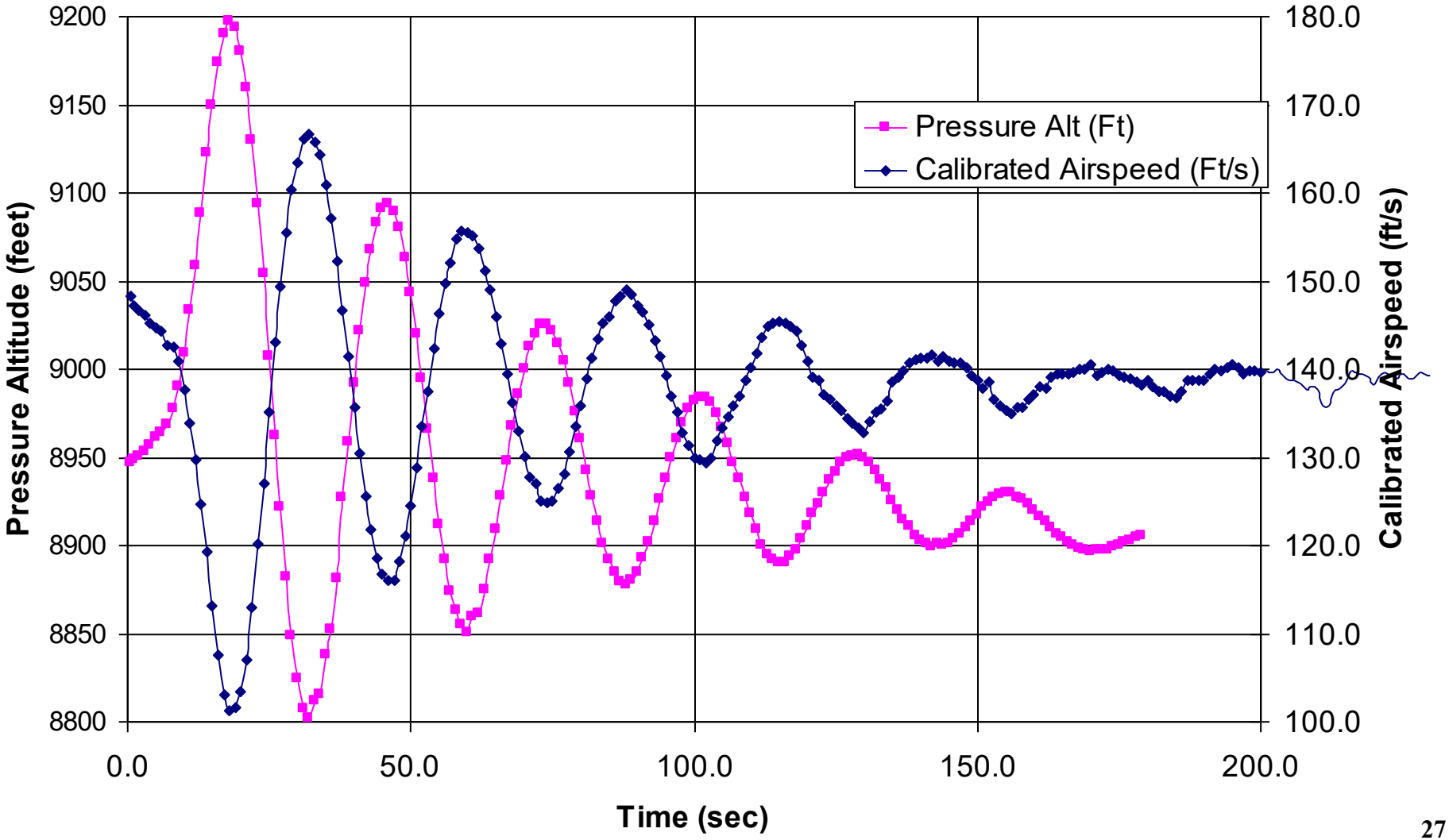
Phugoid.xls

Time Response Data Reduction



t_{MAX}	(sec)	120
V_{TRIM}	(KIAS)	100
DV_{MAX}	(KIAS)	50
ζ	(-)	0.095
T	(sec)	30
ϕ	(sec)	0
ω_d	(rad/sec)	0.209
ω_n	(rad/sec)	0.210

Phugoid DAS Data Trace

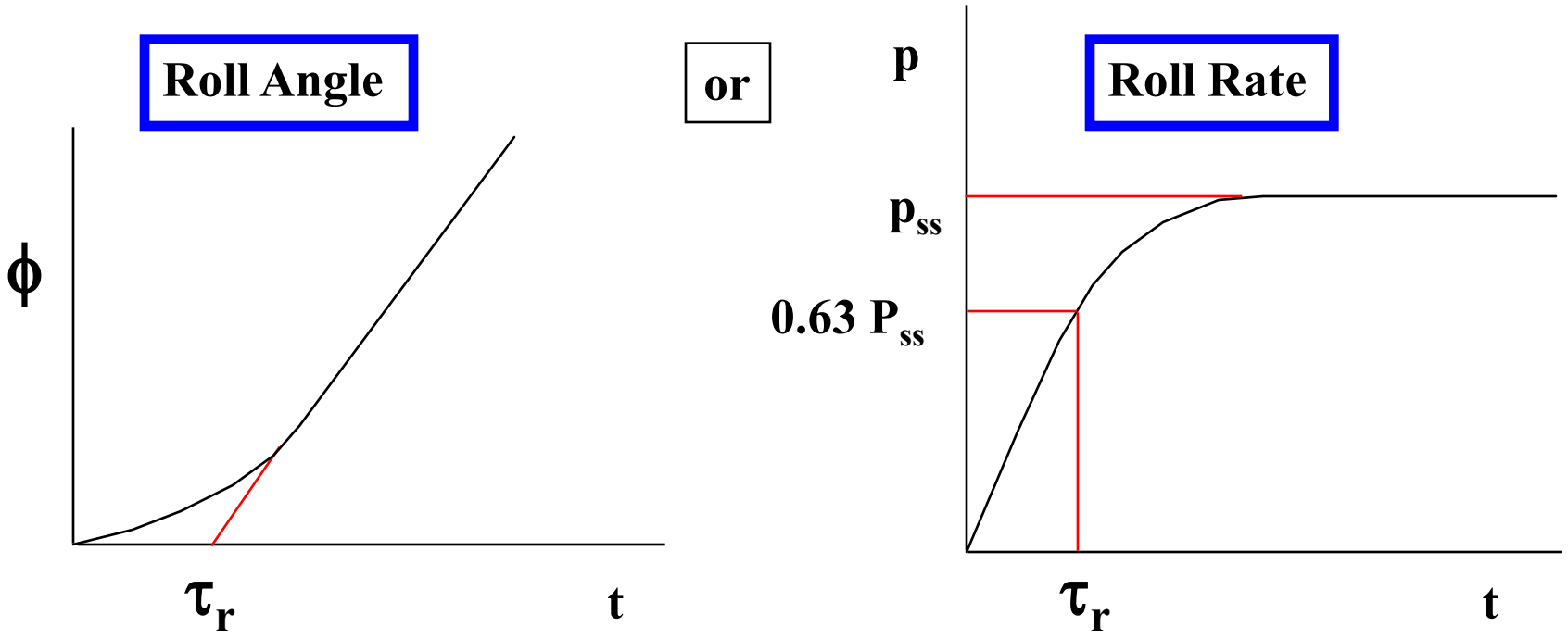


More Phugoid Data Reduction

- DAS Data Reduction (Payne)
  - Transient Peak Method
    - $\zeta < 0.5$
    - 3 or more overshoots
  - Time Ratio Method
    - $0.5 < \zeta < 1.5$
    - 2 or less overshoots
  - Techniques detailed in Payne

Data Reduction

- Manual Data Reduction (DAS plot)
  - Time Constant (aperiodic motion)
    - 2 ways



Why?





Why?





Next Time



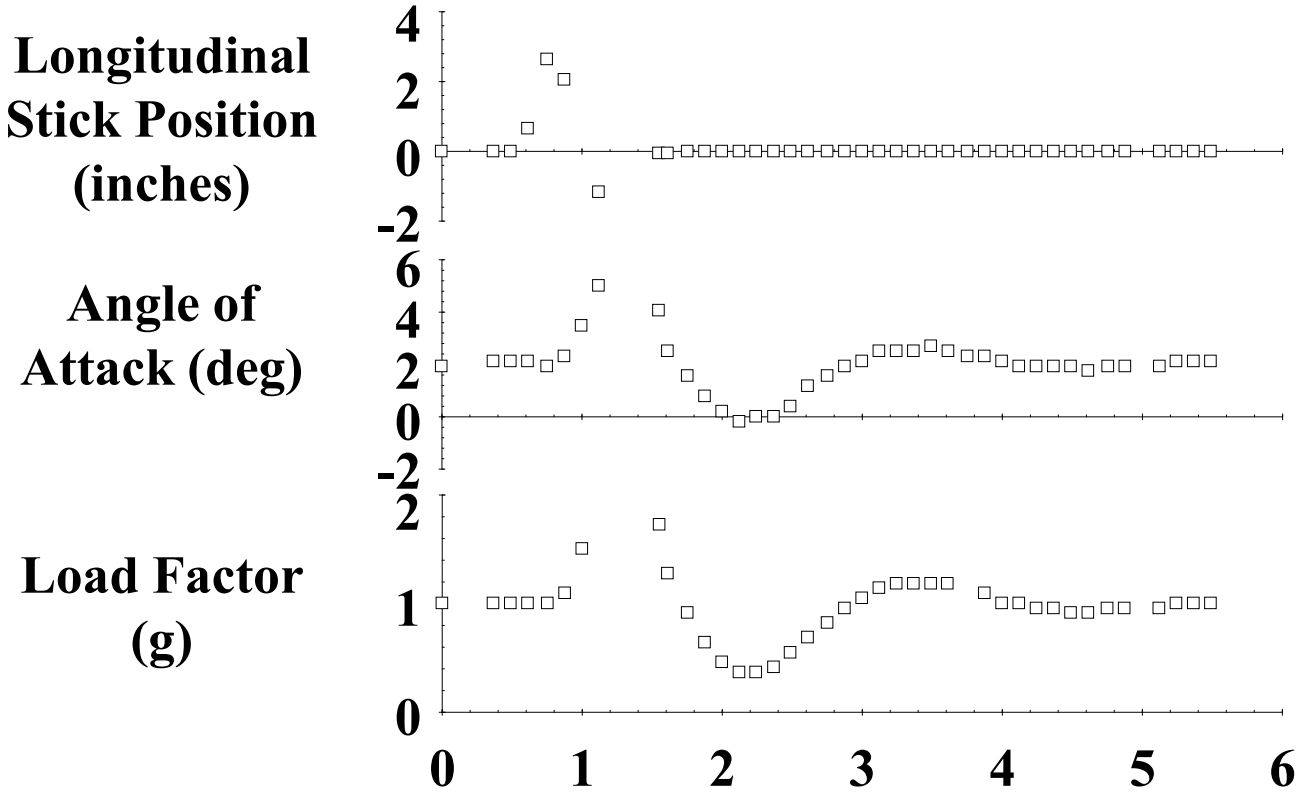
FQ5 - Stalls and Spins

In Class Exercise

- Given T-38 example data in slides FQ4-36 through FQ3-42, determine PASS/FAIL for these MIL-F-8785C paragraphs:
  - 3.2.1.2, 3.2.2.1.1, 3.2.2.1.2, 3.3.1.1, 3.3.1.2, 3.3.4, 3.3.4.5
- Determine ϕ/β ratio for the Dutch Roll
- Determine why the T-38 has a Yaw Damper
- Be prepared to explain your ratings.
- Short Period Demo (K:Campus\DF\DFAN\AE456\Simulations\SP.exe)
  - Allow moment to calibrate, then see following instructions

Example Data

Short Period Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89

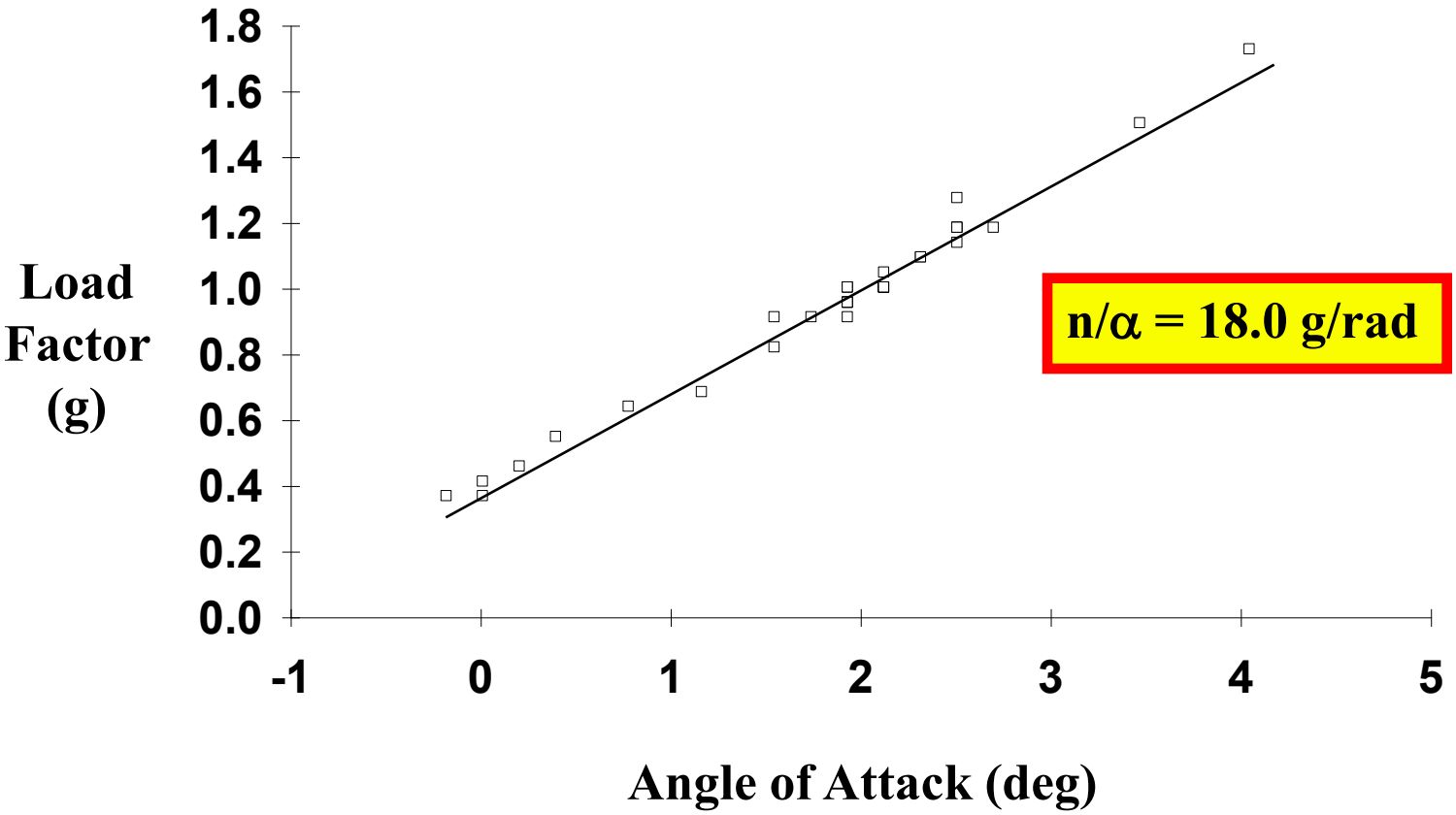


$\zeta_{sp} = 0.27$
$\omega_{n_{sp}} = 2.61$ rad/sec

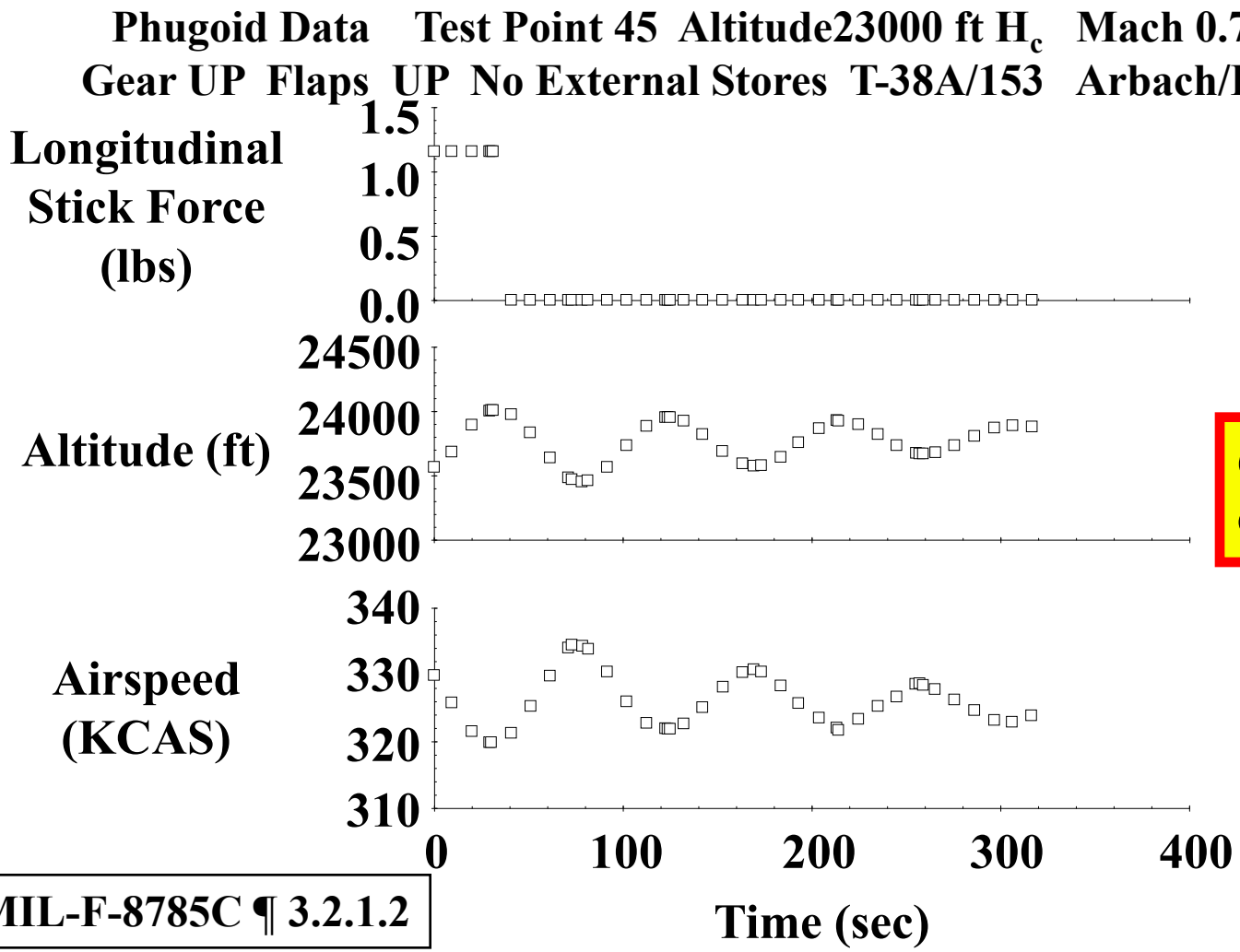
MIL-F-8785C ¶ 3.2.2.1.1, 3.2.2.1.2

Example Data

Short Period Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89



Example Data

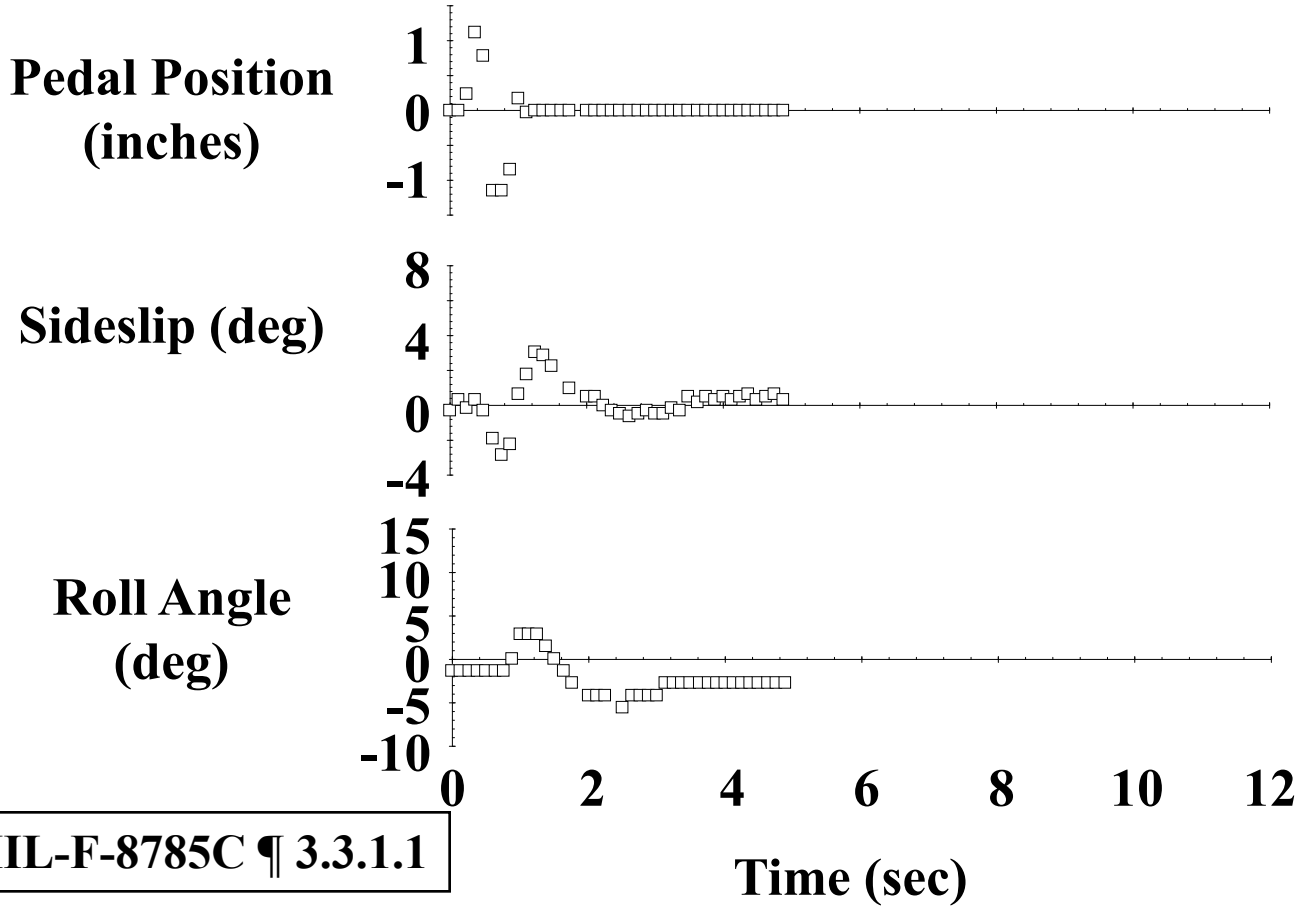


$\zeta_p = 0.06$
$\omega_{n_p} = 0.069$ rad/sec

MIL-F-8785C ¶ 3.2.1.2

Example Data

Dutch Roll Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89



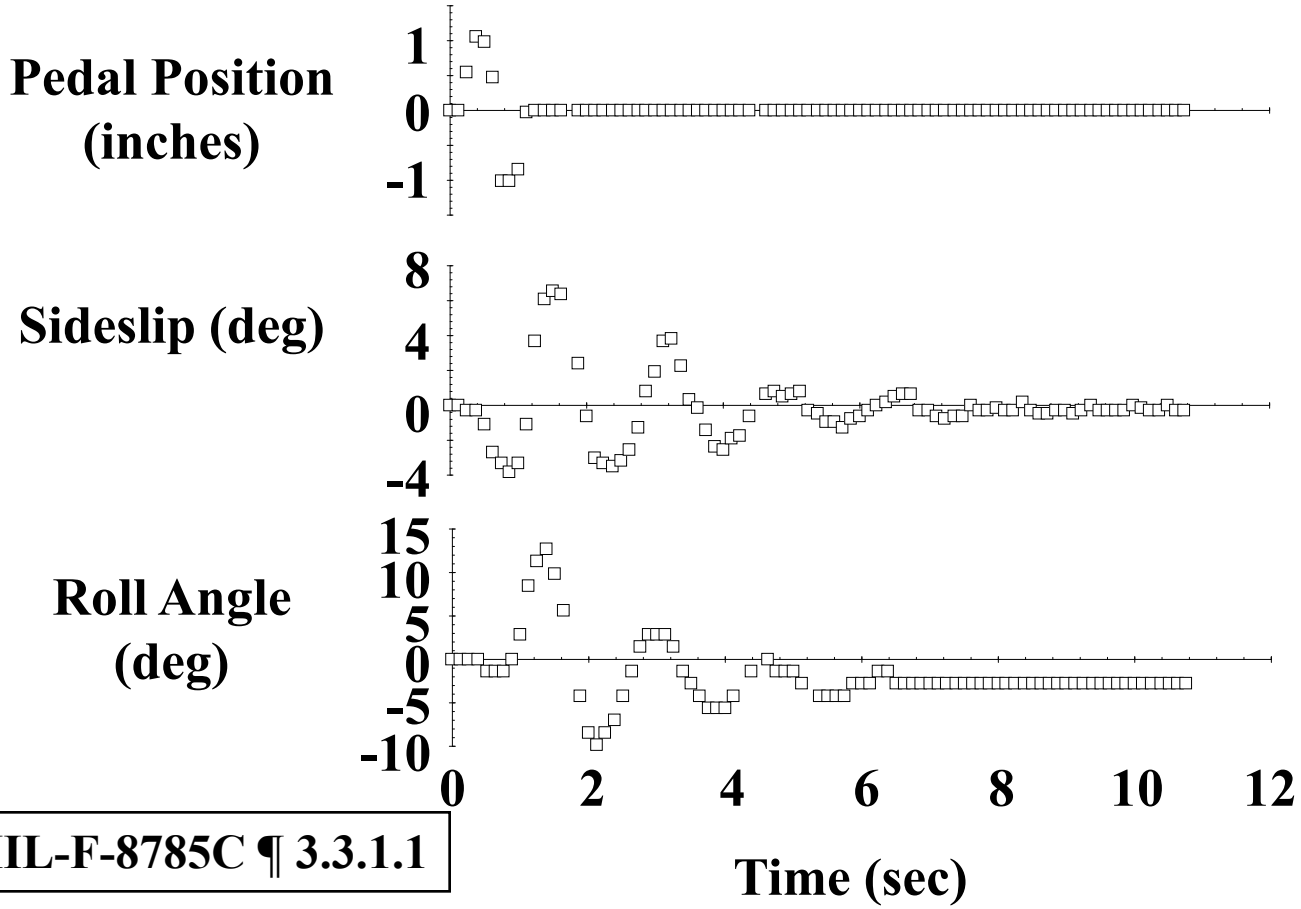
Yaw Damper ON

$\zeta_{dr} = 0.50$
$\omega_{n_{dr}} = 2.0$ rad/sec

MIL-F-8785C ¶ 3.3.1.1

Example Data

Dutch Roll Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89



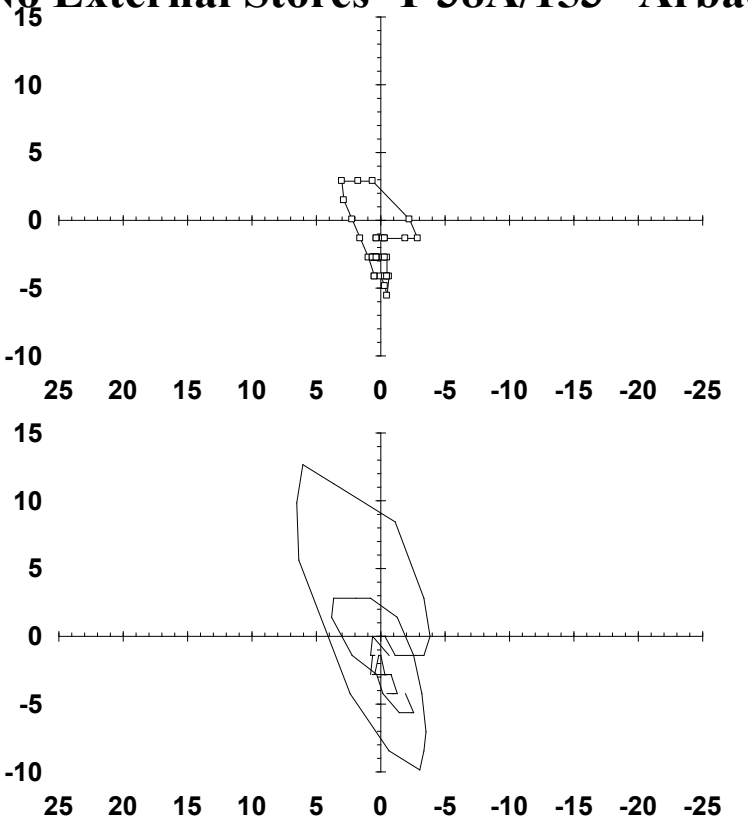
Yaw Damper OFF

$\zeta_{dr} = 0.094$
$\omega_{n_{dr}} = 3.82$ rad/sec

MIL-F-8785C ¶ 3.3.1.1

Example Data

Dutch Roll Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89



Yaw Damper ON

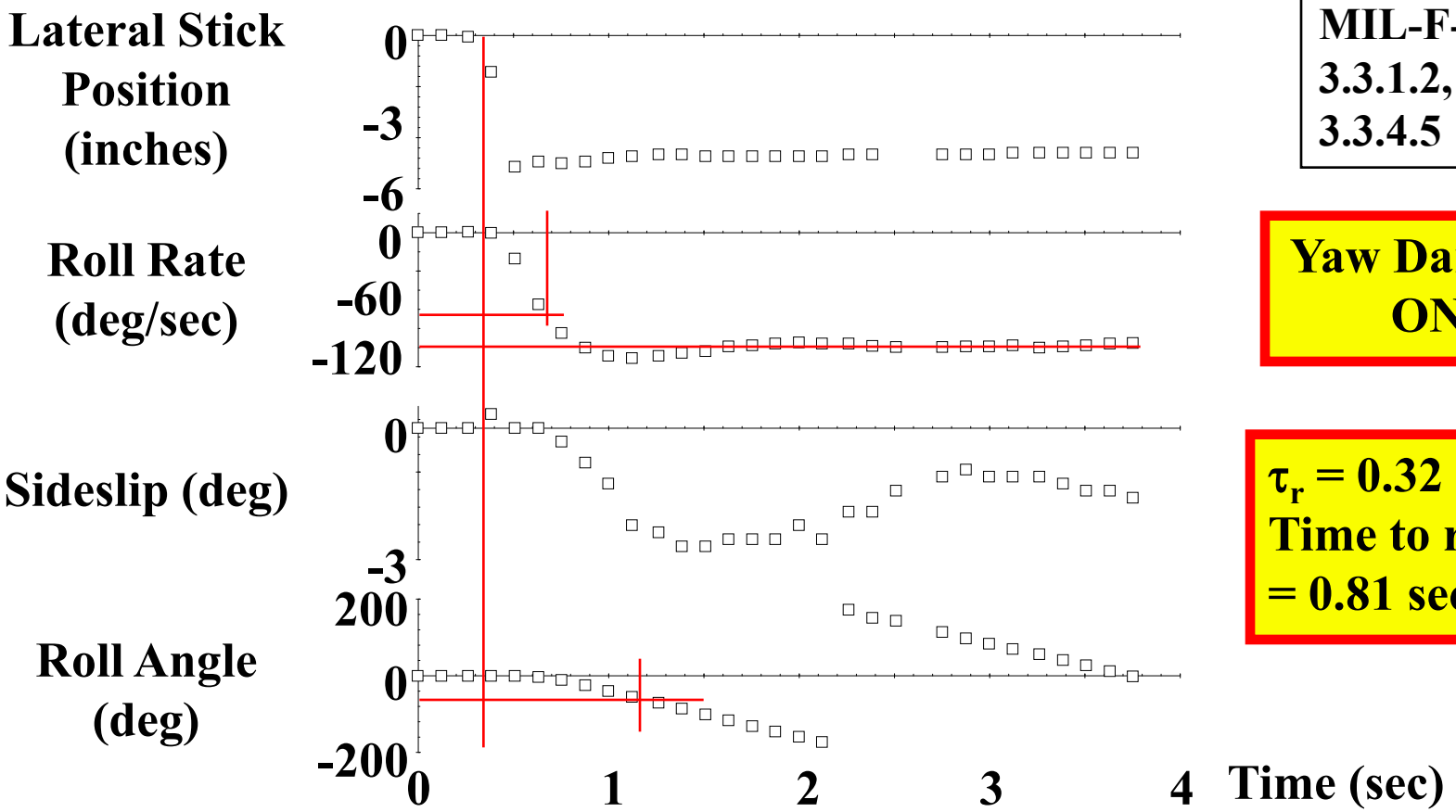
Yaw Damper OFF

Watch Scales! Size of x increment must equal size of y increment for truthful shapes

MIL-F-8785C ¶ 3.3.1.1

Example Data

Roll Mode Data Test Point 45 Altitude23000 ft H_c Mach 0.75 CG 19.8%
Gear UP Flaps UP No External Stores T-38A/153 Arbach/Erb 21 Nov 89



MIL-F-8785C ¶ 3.3.1.2, 3.3.4, 3.3.4.5

Yaw Damper ON

τ_r = 0.32 sec
Time to roll 60° = 0.81 sec