AERONAUTICS

LESSON FQ3



Lateral-Directional Stability

Test Objective 3

- **Evaluate Lateral-Directional Static Stability**
  - **MOP 3-1 :** *Turn Coordination*

Description	The ability to perform coordinated turns in level flight.
Test Methodology	*Establish a steady, coordinated 45o turn and assess control forces*.
Success Criteria	One turn in either direction.
Evaluation Criteria	The following MIL-STD-1797 paragraph(s) will be used for evaluation: 5.2.3.8.5 Control forces in steady turns

  - **MOP 3-2 :** *Static Directional Stability*

Description	The *initial tendency* of an aircraft to return to a trim sideslip angle. Note: instability in roll will result in directional instability as well.
Test Methodology	*Steady Heading Side Slip (SHSS) FTT* (Appendix C) Aileron forces will be measured using a handheld force gauge. Aileron deflection will be measured using a pair of inclinometers on the dash and yoke. Rudder deflection will set using a ruler positioned on the rudder pedal, calibrated in flight Rudder forces are given on the test card (historical data) as instrumentation doesn't exist.
Success Criteria	Four rudder deflections in each direction.
Evaluation Criteria	The following MIL-STD-1797 paragraph(s) will be used for evaluation: 5.2.3.8.1 Lateral-directional breakout forces. 5.2.3.9 Steady sideslips 5.2.3.9.1 Yaw control force and deflection in steady sideslips 5.2.3.9.2 Bank angle in steady sideslips 5.2.3.9.3 Roll control force and deflection in steady sideslips 5.2.3.9.4 Roll control power in steady sideslips 5.2.4.1 Longitudinal control forces in sideslips NOTE: "Wave off (Go-Around)" requirements will not be assessed

OUTLINE

- Lateral-Directional Stability (Lat-Dir)
  - Quick Refresher
  - Directional Static Stability
    - Terms
    - Rudder Fixed
    - Rudder Free
  - Lateral Static Stability
    - Terms
    - Aileron Fixed
    - Aileron Free
  - Flight Test Techniques
  - MIL-HDBK-1797 Requirements



Quick Refresher

- Forces and moments affecting stability
  - Aero (predominant at most operating altitudes)
  - Thrust
  - Gyroscopic (at low densities these become more significant)
  - Gravity

$$\left(C_y, C_\ell, C_n\right) = f\left(\beta, \dot{\beta}, p, r, \delta_a, \delta_r\right)$$

Side Force does not strongly affect angular motions

Dynamic Terms, ignore for steady state cases

Lateral-Directional Moment Equations

- Equations are coupled
  - Every input that affects one affects the other
  - $C_{\ell_{\delta_r}}$ and $C_{n_{\delta_a}}$ are cross control derivatives

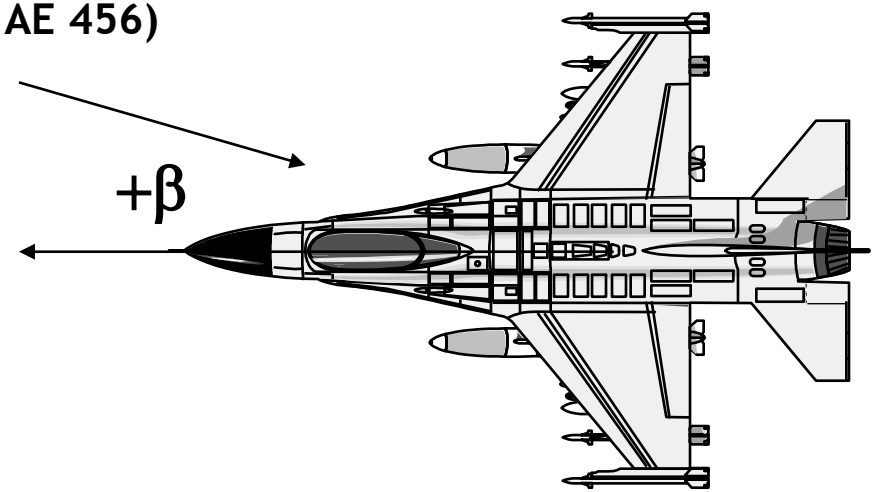
$$C_n = C_{n_\beta}\beta + C_{n_{\dot\beta}}\dot\beta + C_{n_p}p + C_{n_r}r + \boxed{C_{n_{\delta_a}}\delta_a} + C_{n_{\delta_r}}\delta_r$$

$$C_\ell = C_{\ell_\beta}\beta + C_{\ell_{\dot\beta}}\dot\beta + C_{\ell_p}p + C_{\ell_r}r + C_{\ell_{\delta_a}}\delta_a + \boxed{C_{\ell_{\delta_r}}\delta_r}$$



Sideslip

- Positive sideslip is defined as "wind in the right ear"
  - Note that negative yaw angles (stability axes) will create positive B
- Longitudinal C.G. changes:
  - Generally have no significant effects on lateral-directional stability
- Lateral C.G. changes/asymmetries:
  - Greatly affect lateral-directional stability
    - (we won't calculate this in AE 456)



Directional Static Stability

$$C_n = C_{n_\beta}\beta + C_{n_{\dot\beta}}\dot\beta + C_{n_p}p + C_{n_r}r + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r$$

Weathercock stability

Yaw damping due to lag effects

Yaw due to roll rate

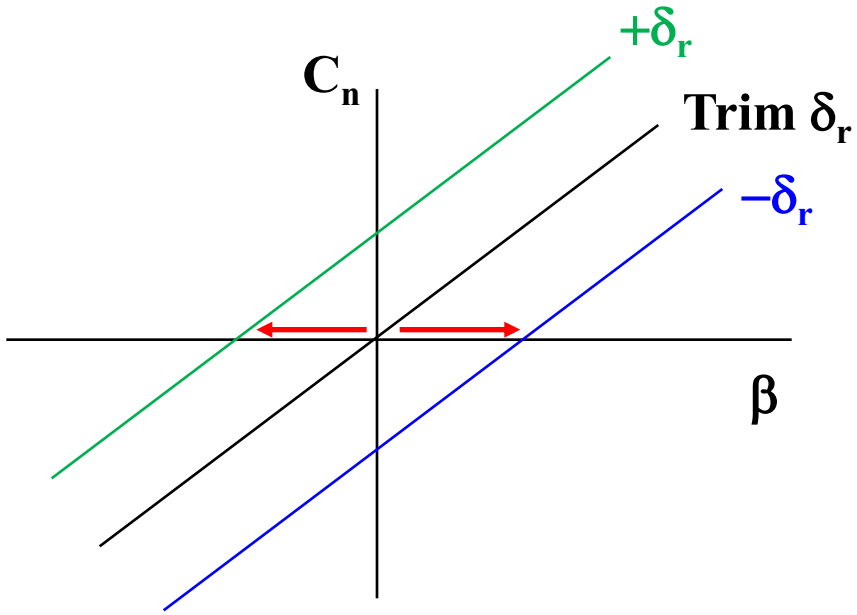
Yaw damping (due to wings and vertical tail)

Yawing moment due to δ_a
- $\Rightarrow$ Adverse Yaw
+ $\Rightarrow$ Proverse Yaw

Rudder Power

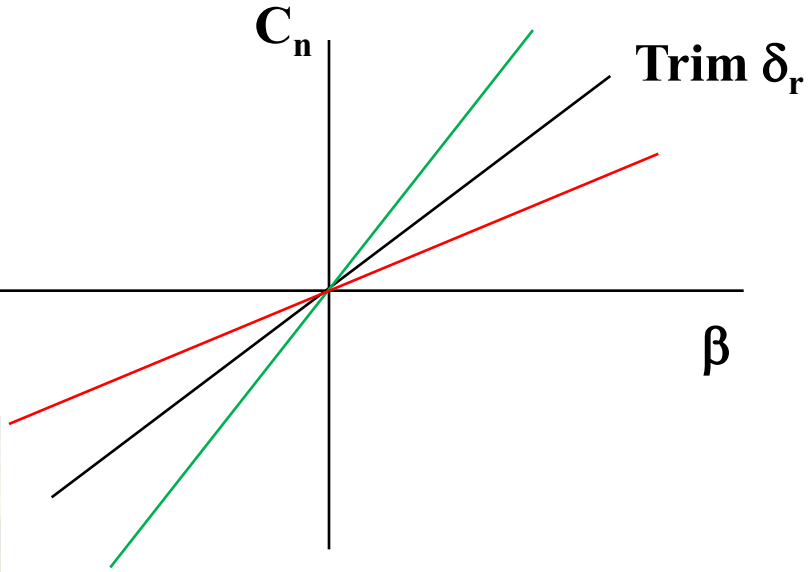
Terms

- C_{n_β}
  - Restoring moment
  - Akin to C_{m_α}
- $C_{n_{\delta_r}}$
  - Rudder Control Power



Directional Static Stability

- Stabilizing
  - Vertical Tail, Aft Sweep
- Destabilizing
  - Fuselage





Directional Static Stability

- $C_{n_{\delta_a}}$
  - (-) ⇒ Adverse Yaw
    - Slight amount preferred
    - Caused by ailerons
  - (+) ⇒ Proverse Yaw
    - Caused by spoilers
      - F-111, B-52, T-1A



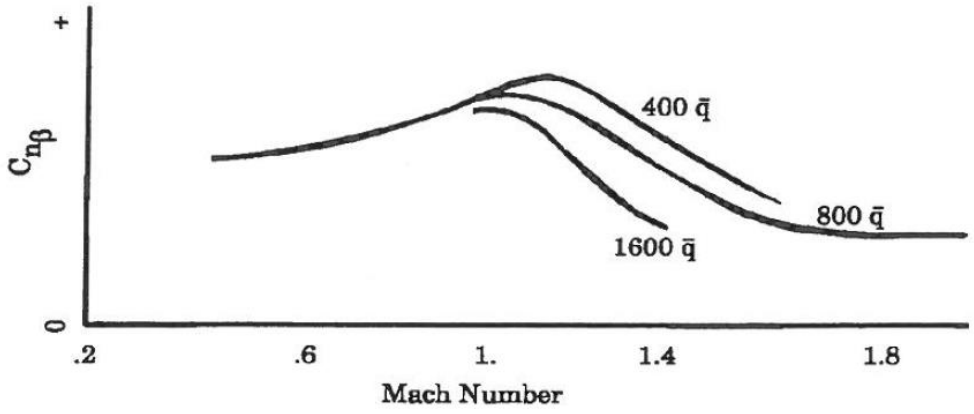
- $C_{n_{\dot{\beta}}}$
  - Lag due to time required for side-wash to stabilize

High Mach Considerations

- At high Mach numbers (~ M > 3)
  - C_{n_β} decreases with Mach - Destabilizing
- Chuck Yeager spins the X-1A
- X-2 crash
  - Mel Apt killed on his first flight of the X-2
  - Ran out of C_{n_β} around Mach 3







Solution:

- More vertical surface area
- Strakes (improves stabilizing effect of wing)

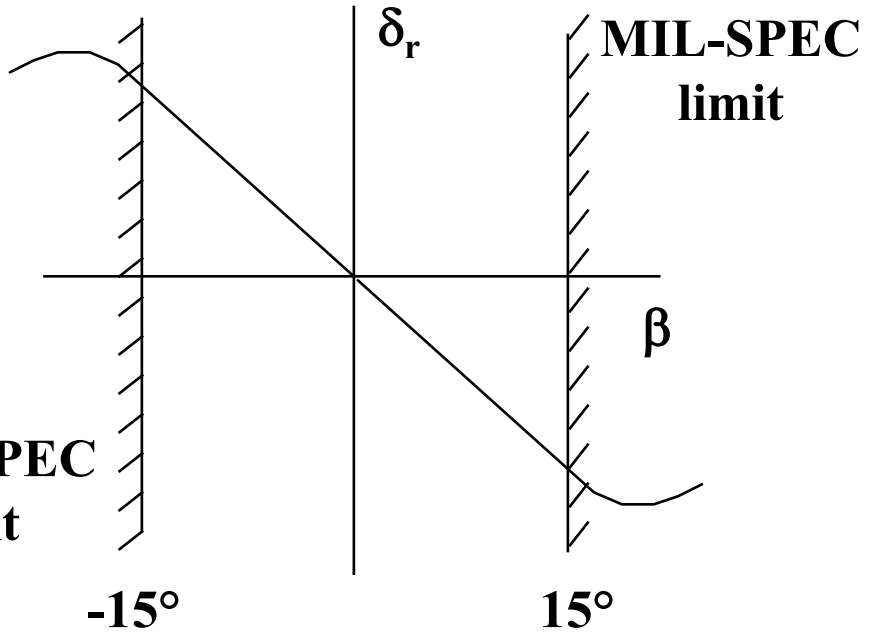
Rudder-Fixed Stability

- Solve for δ_r and differentiate with respect to β

$$C_n = C_{n_\beta}\beta + C_{n_{\dot\beta}}\dot\beta + C_{n_p}p + C_{n_r}r + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r$$

$$\frac{\partial \delta_r}{\partial \beta} = -\frac{C_{n_\beta}}{C_{n_{\delta_r}}} \quad \begin{matrix}(+)\\(+)\end{matrix}$$

Directionally Stable Airplane

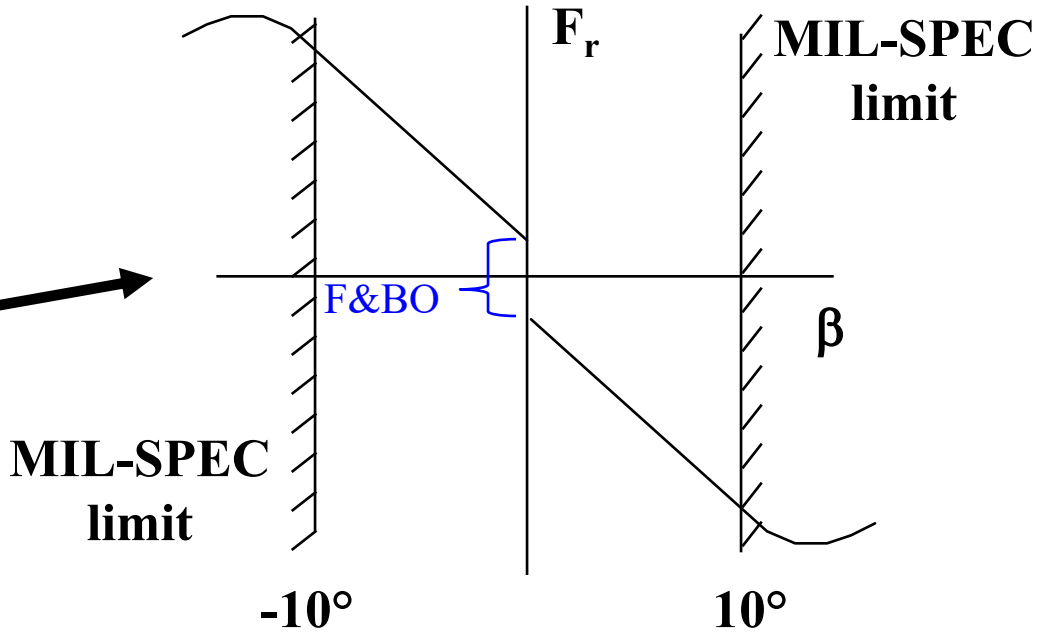


Rudder-Free Stability

- Similarly, we can find pedal force variation with β

$$\frac{\partial F_r}{\partial \beta} = G q_r S_r c_r \frac{C_{h_{\delta_r}}}{C_{n_{\delta_r}}} C_{n_\beta}$$

Directionally Stable Airplane



Lateral Static Stability

$$C_\ell = C_{\ell_\beta}\beta + C_{\ell_{\dot\beta}}\dot\beta + C_{\ell_p}p + C_{\ell_r}r + C_{\ell_{\delta_a}}\delta_a + C_{\ell_{\delta_r}}\delta_r$$

- **Dihedral Effect**
- **Roll damping due to lag effects**
- **Roll Damping**
- **Roll due to yaw rate**
- **Lateral Control Power**
- **Rolling moment due to δ_r**

Terms

- C_{l_β} - Dihedral Effect
  - Tendency to roll when some sideslip exists
  - Both wing and tail contribute
    - Geometric dihedral or anhedral
    - Wing sweep
    - Wing fuselage junction (high wing - stabilizing)
    - Vertical tail
    - Aspect ratio
    - Taper ratio
    - Tip Tanks
    - Flaps



Terms

- $C_{\ell_{\delta_a}}$
  - Lateral control power
    - Ailerons
    - Spoilers
    - Differential (rolling) Tail
      - (B-1, F-111, F-15, F-16)



- $C_{\ell_{\dot{\beta}}}$
  - Lag due to time required for sidewash to stabilize
- $C_{\ell_{\delta_r}}$
  - Rolling moment because rudder force is applied above C.G. (low α)
  - Generally overpowered by C_{ℓ_β}

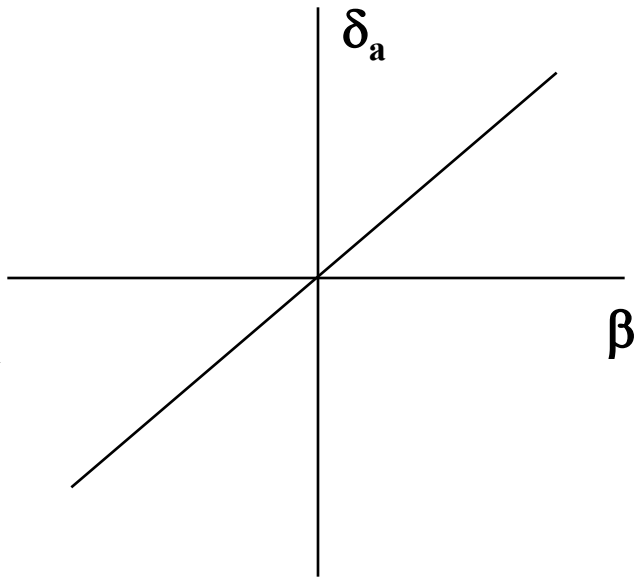
Aileron-Fixed Stability

- Solve for δ_a and differentiate with respect to β

$$C_\ell = C_{\ell_\beta}\beta + C_{\ell_{\dot\beta}}\dot\beta + C_{\ell_p}p + C_{\ell_r}r + C_{\ell_{\delta_a}}\delta_a + C_{\ell_{\delta_r}}\delta_r$$

$$\frac{\partial \delta_a}{\partial \beta} = -\frac{C_{\ell_\beta}}{C_{\ell_{\delta_a}}}$$ (-) (+)

Laterally Stable Airplane

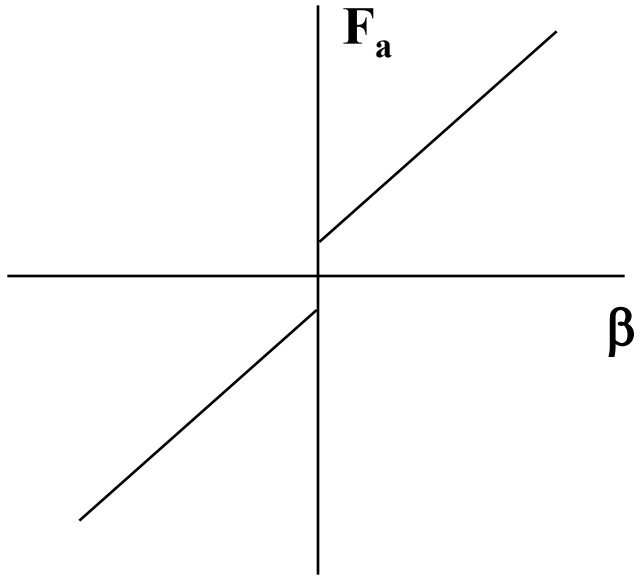


Aileron-Free Stability

- Similarly, we can find stick force variation with β

$$\frac{\partial F_a}{\partial \beta} = G q_a S_a c_a \frac{C_{h_{\delta_a}}}{C_{\ell_{\delta_a}}} C_{\ell_\beta}$$

Laterally Stable Airplane



Flight Test Techniques

Flight Test Techniques (FTTs)

1. Steady Heading Side-Slip (SHSS)





1. Steady Heading Side-Slip (SHSS)

Procedure:

- Perform Trim Shot
- Input target rudder deflection
- Use aileron to counter heading change
  - Turn needle centered ▫ no yaw rate
- Use elevators to keep airspeed constant
- Repeat at ¼,1/2,3/4,Full rudder, left and right
- Record:
  - H_i, V_i, δ_{yoke}, , F_a, F_r, F_e, δ_a, δ_r, δ_e, $\Delta\psi \approx \Delta\beta$

Assumptions/Constraints:

- No yaw rate
- SLUF

Data Reduction:

$$\delta_e = f(\delta_{yoke})$$

$$\Delta\psi \approx \Delta\beta \sim \beta$$

Watch out!

- T-38 in PA configuration will flip on its back with excessive sideslip (rudder authority increases with gear down)
- Hard rudder kicks will cause a C-130 to fin stall

Next Time

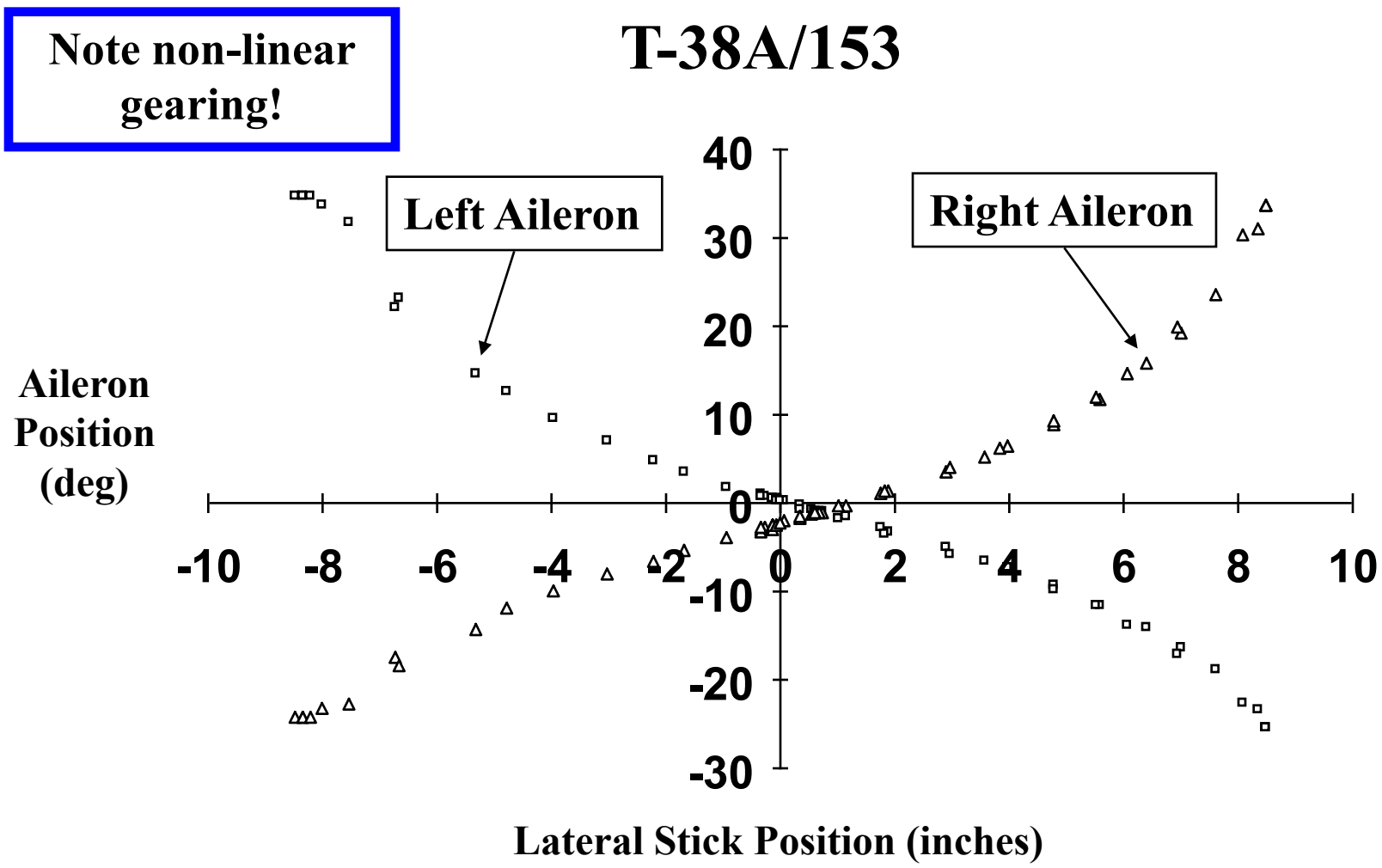
Flight-3

In Class Exercise

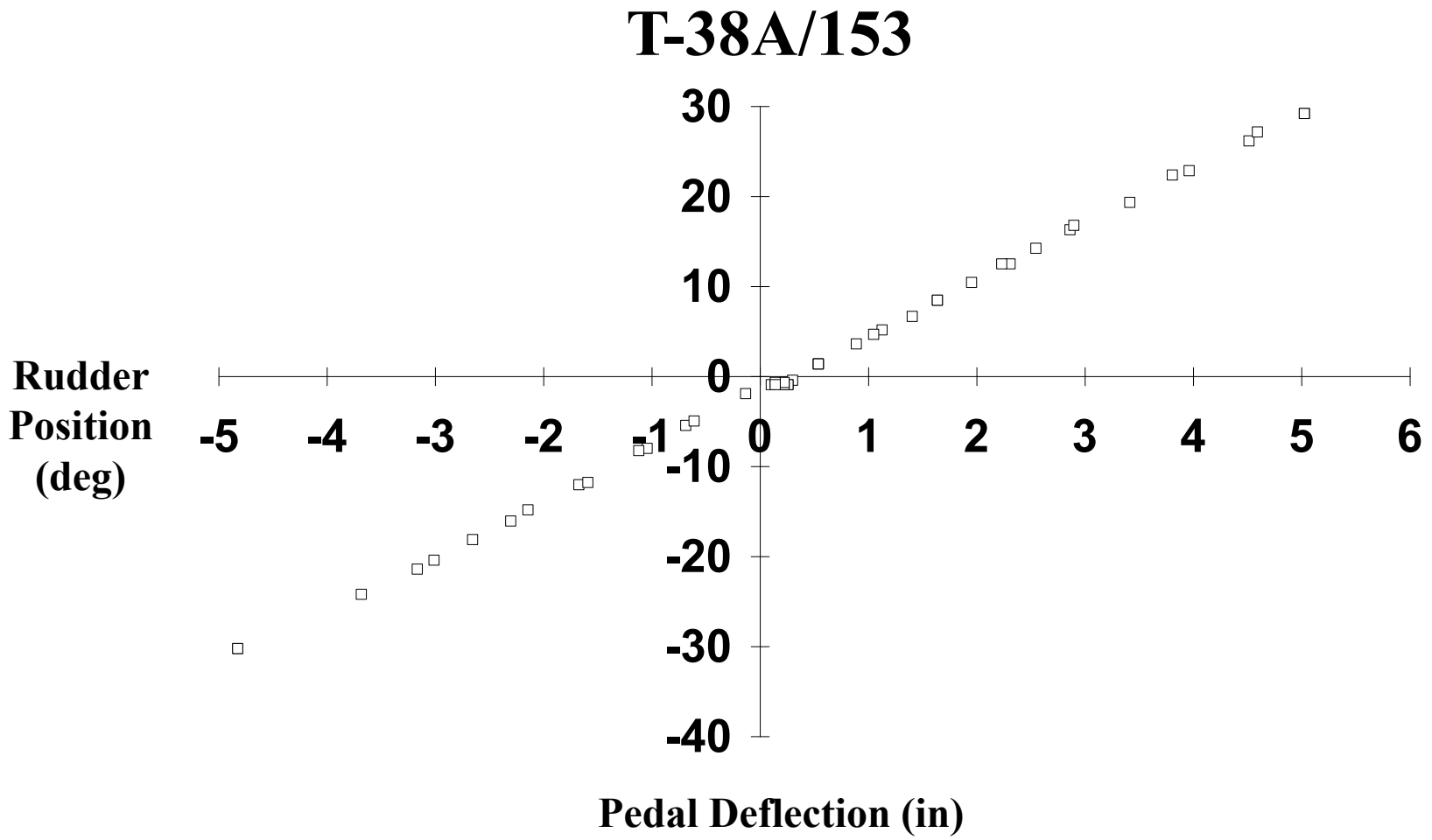
- Given T-38 example data in slides FQ3-27 through FQ3-35, determine PASS/FAIL for these MIL-F-8785C paragraphs:
  - 3.3.6.1
  - 3.3.6.2
  - 3.3.6.3
  - 3.2.3.7
  - 3.5.2.1
- Be prepared to explain your ratings.

Example Data

Note non-linear gearing!

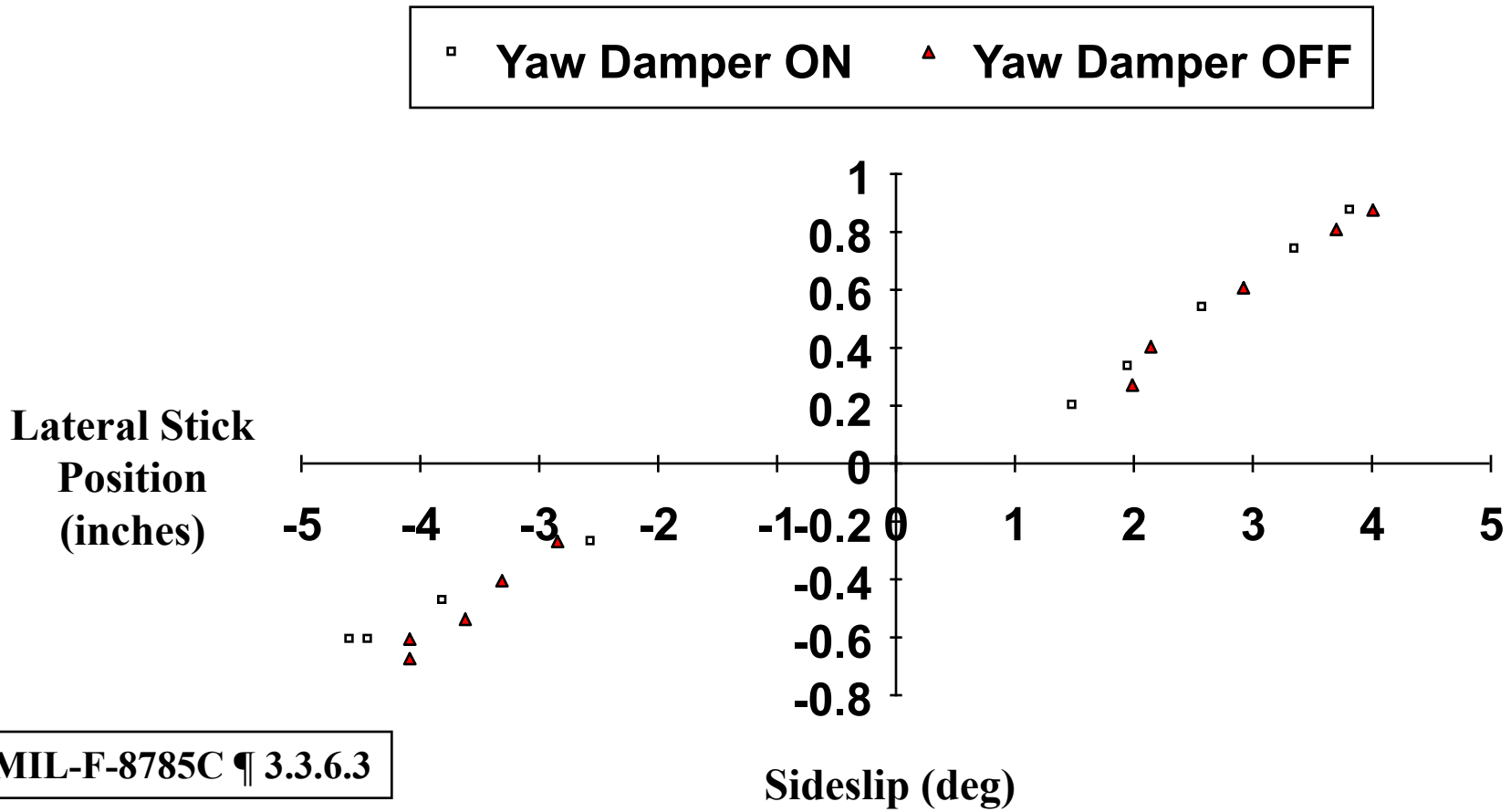


Example Data



Example Data

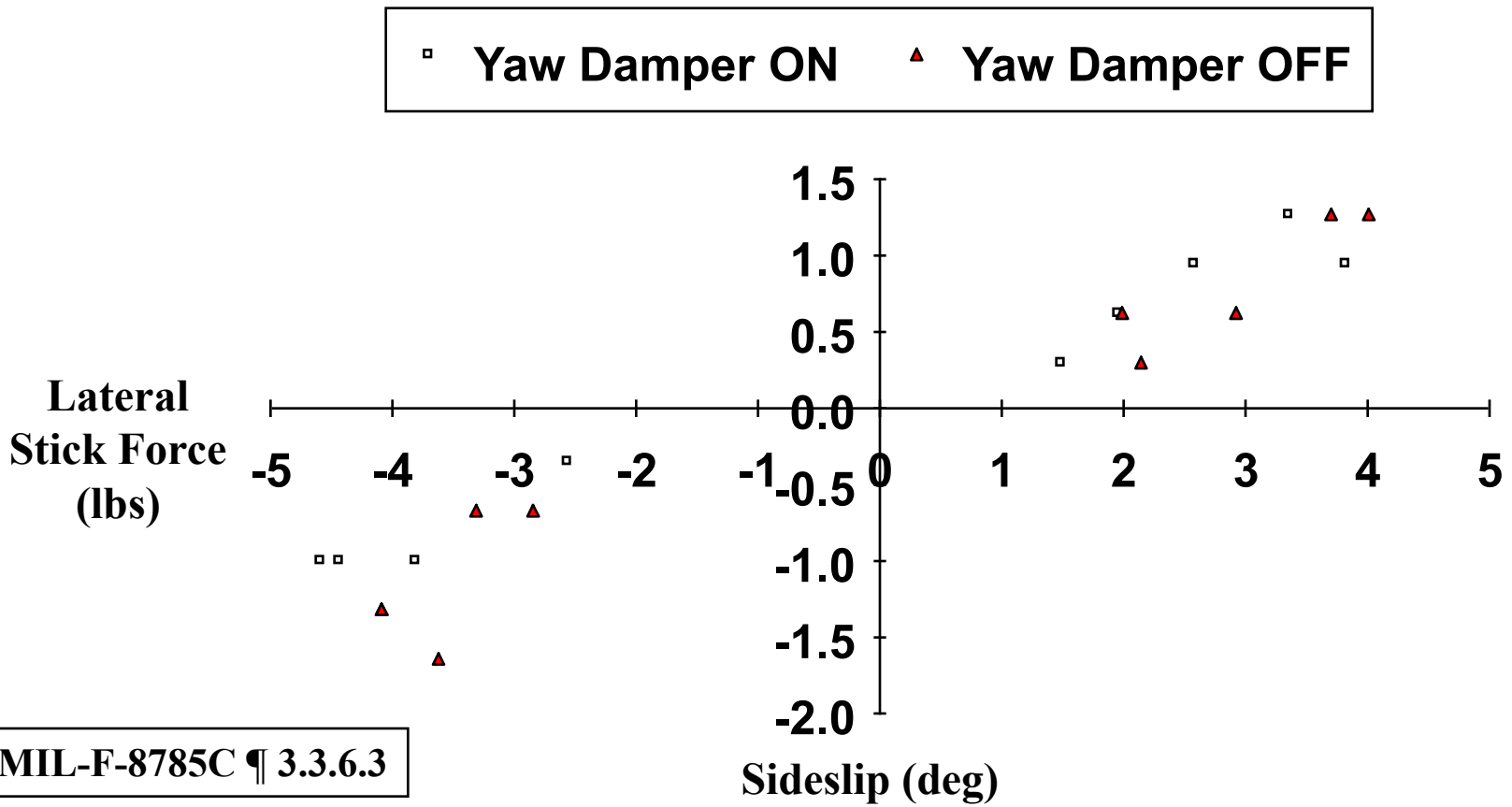
Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.3.6.3

Example Data

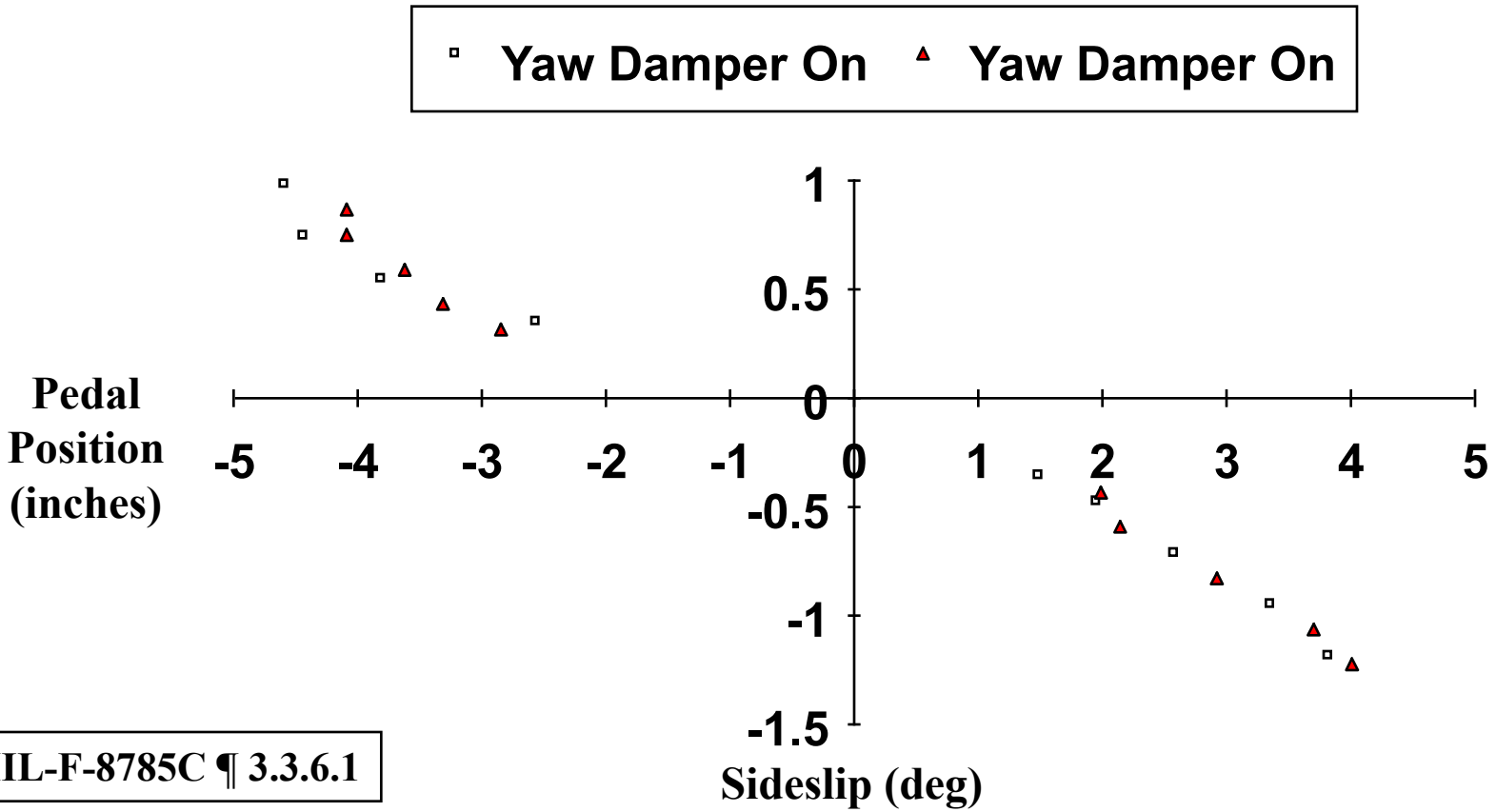
Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.3.6.3

Example Data

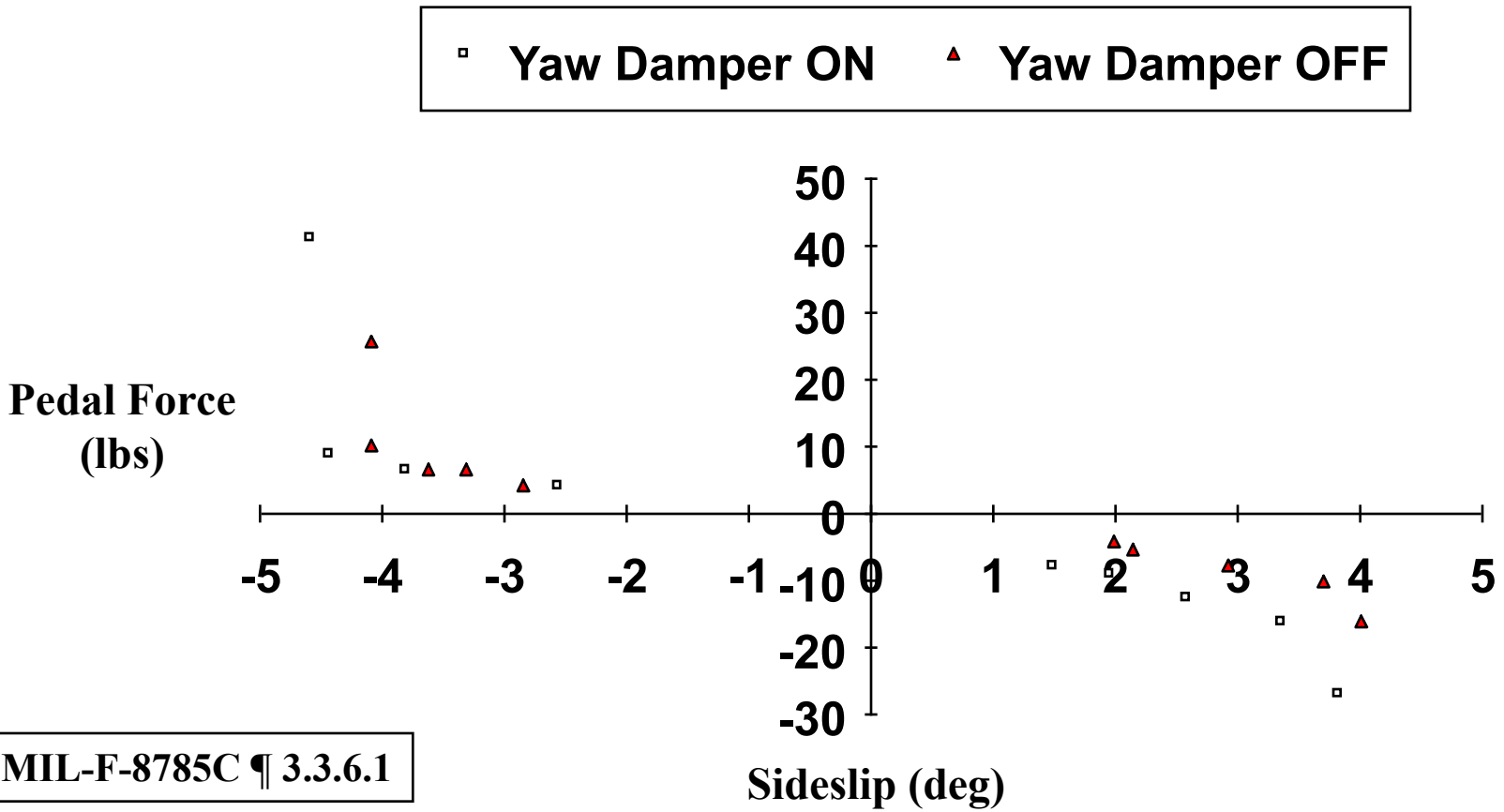
Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.3.6.1

Example Data

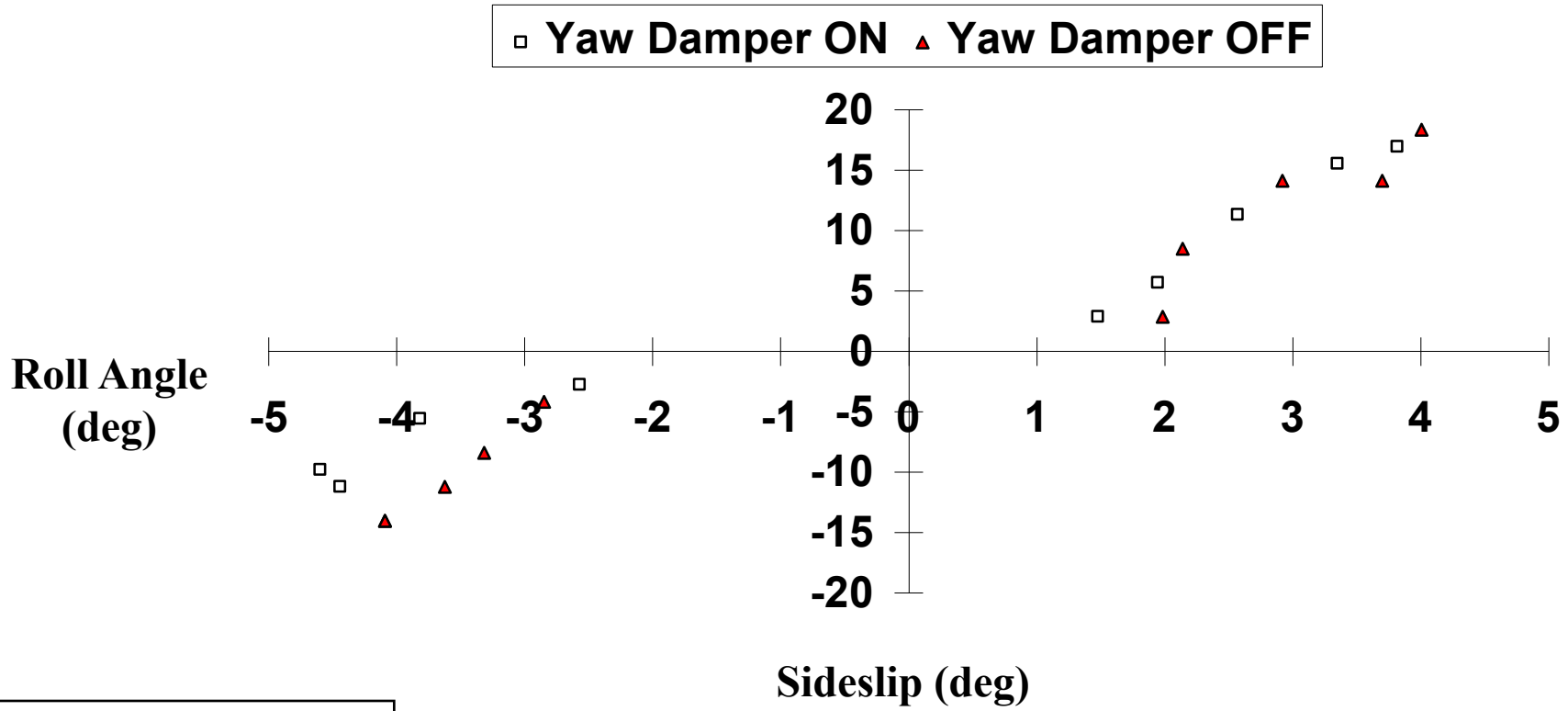
Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.3.6.1

Example Data

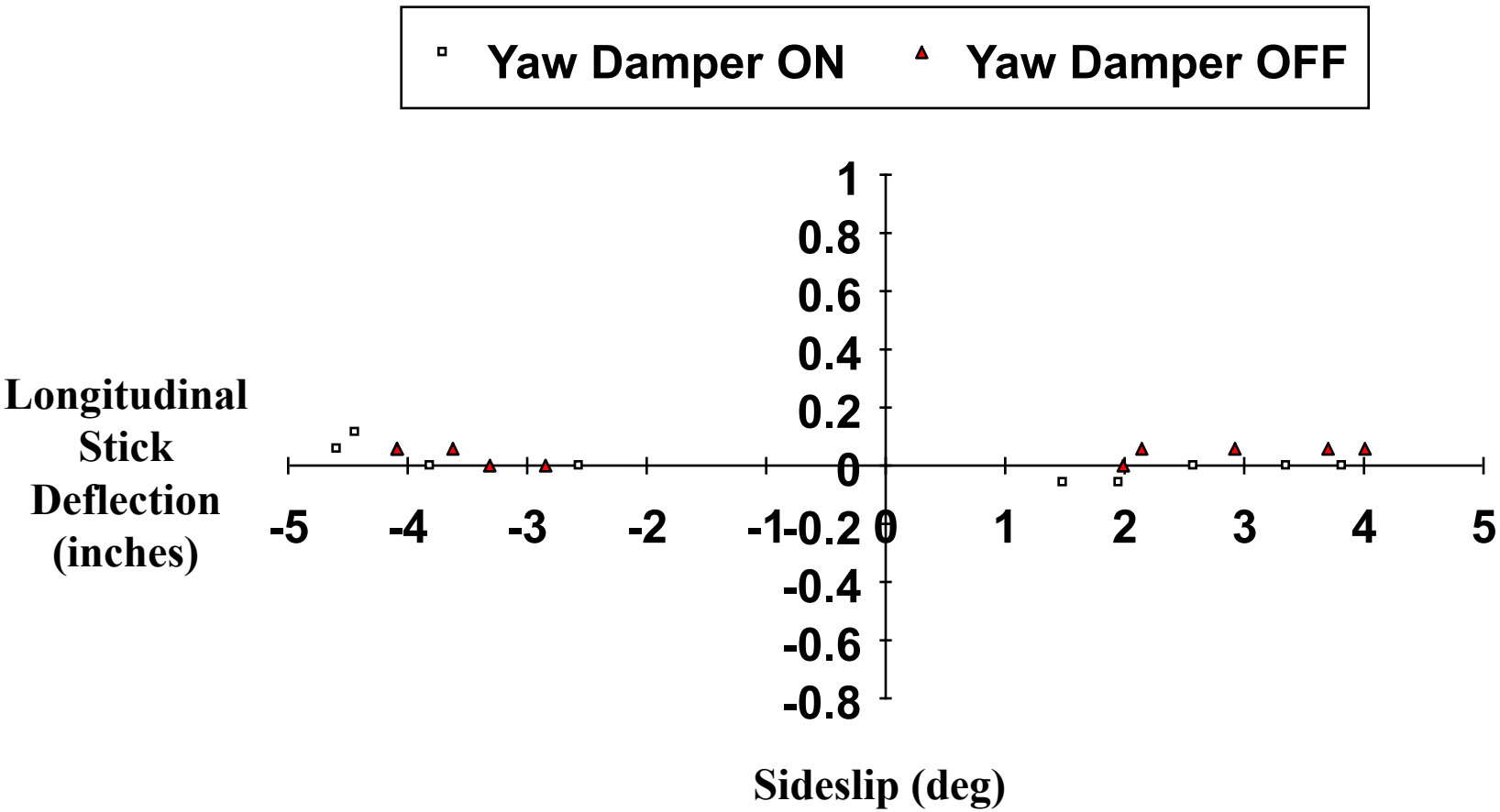
Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.3.6.2

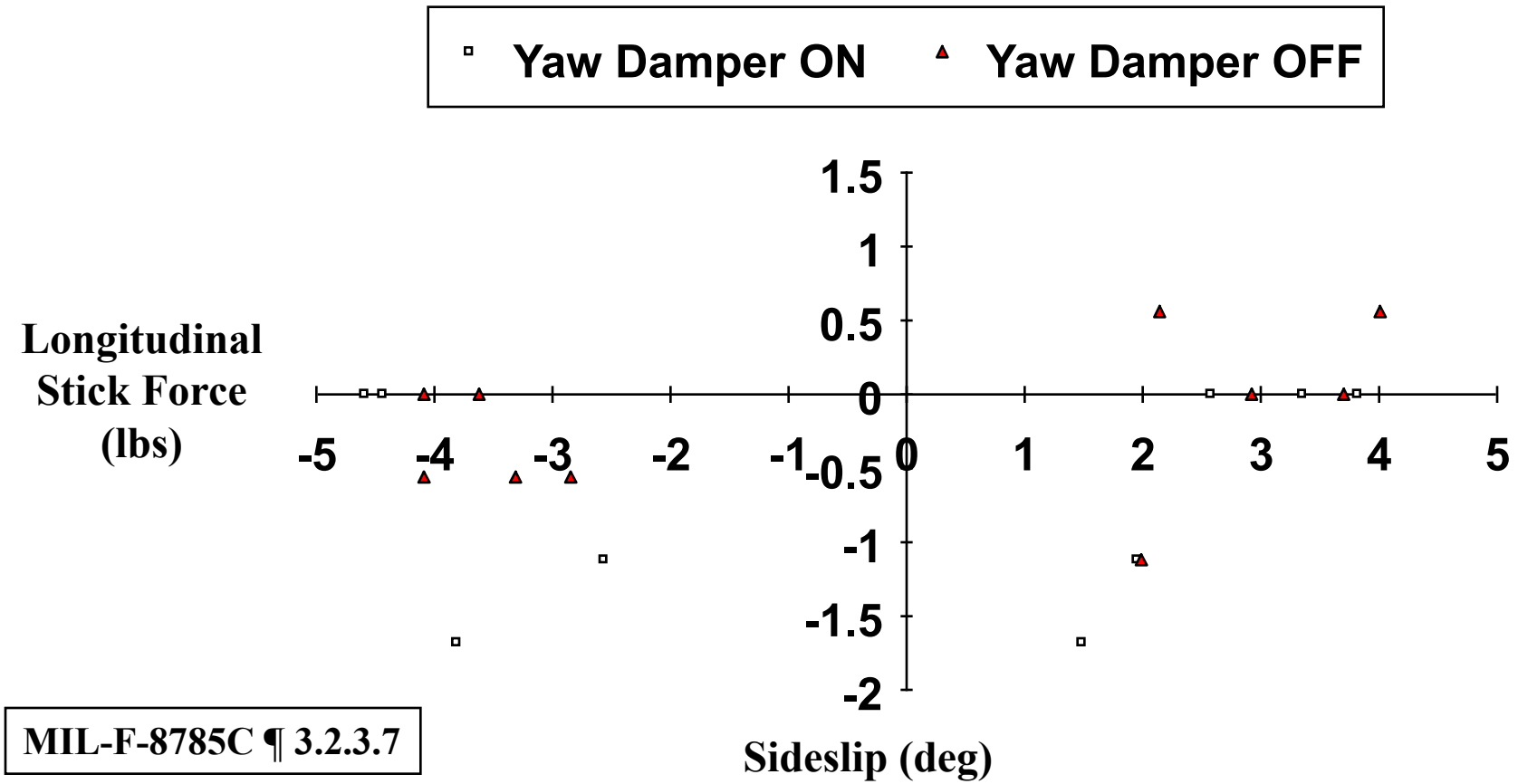
Example Data

Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



Example Data

Steady Heading Sideslip Data Test Point 42 Altitude 9500 ft H_c Mach 0.75
Gear UP Flaps UP No External Stores T-38A/153 Manton/Erb 13 Nov 89



MIL-F-8785C ¶ 3.2.3.7