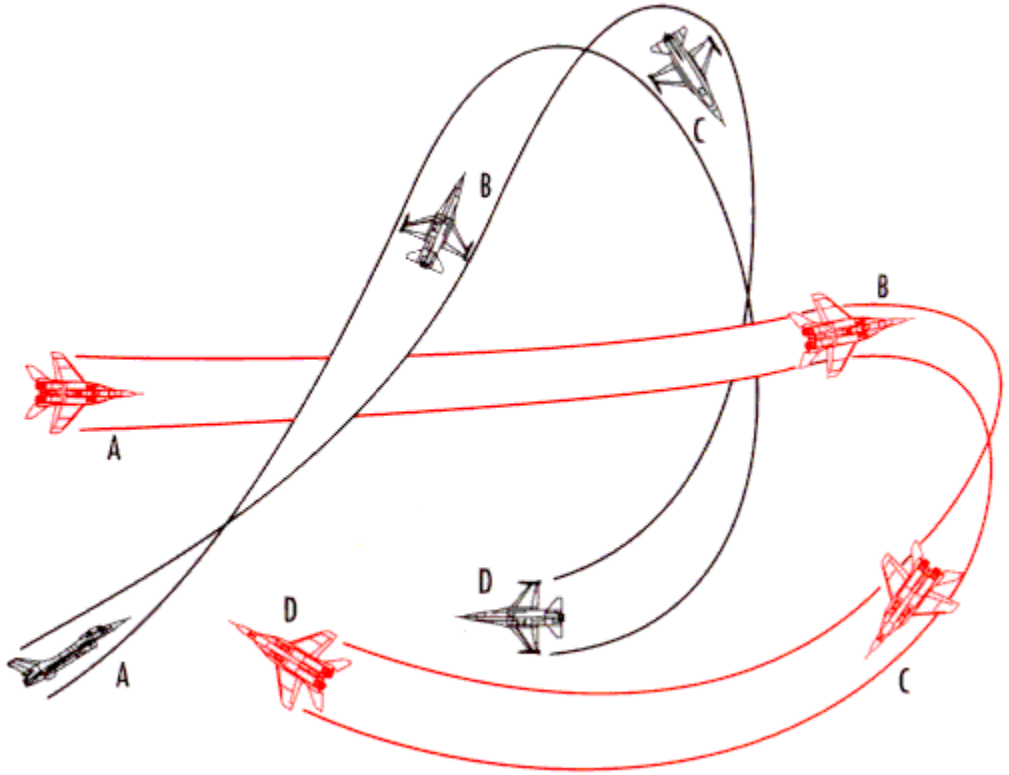
AERONAUTICS

**LESSON FQ2**




# Maneuvering Stability

# Why Maneuvering Stability?

- Aircraft that don't maneuver are called balloons
- Aircraft that aren't stable during maneuver can't be controlled without a Computer (feedback control system)
  - *Feedback control systems seek to mimic stable acft*
- Any unstable aircraft can be controlled with
  - Fast enough computer
  - Fast enough servos
  - Large enough control surfaces (control power)
- Large control power requires large structural loads

(Loads = weight)

# Test Objective 2

- **Evaluate Maneuver Stability**
  - **MOP 2-1 :** *Stick-Fixed Maneuver Point*

| | |
|---|---|
| **Description** | The C.G. location where the change in *elevator deflection* required to stabilize at a new load factor is zero. |
| **Test Methodology** | *Constant G Method FTT* (Appendix C).<br>Vary C.G. between flights to determine the maneuver point.<br>Yoke forces will be measured using a handheld force gauge.<br>Yoke deflection will be measured from the firewall using a ruler.<br>Load factor will be set using the T-41D onboard g-meter. |
| **Success Criteria** | Four C.G. datasets spanning at least 3.0 inches.<br>Efforts will be made to gather data at the following C.G.s: 40, 41, 42, 43 inches.<br>Each dataset must contain at least 3 load factors above 1 g. |
| **Evaluation Criteria** | Maneuver Margin (MM): distance between maneuver point & FM C.G. limit |

| **Criteria --** inches aft of FM limit | **Rating** |
|---|---|
| > 2” | Satisfactory |
| 1 – 2" | Marginal |
| < 1” | Unsatisfactory |

  - **MOP 2-2 :** *Stick-Free Maneuver Point(s)*

| | |
|---|---|
| **Description** | The C.G. location where the change in *stick force* required to stabilize at a new load factor is zero. |
| **Test Methodology, etc.** | *Same as MOP 2-1* |

  - **MOP 2-3 :** *MIL-STD-1797 Compliance*

| | |
|---|---|
| **Description** | Select MIL-STD-1797 criteria have been selected for evaluation. |
| **Test Method. Success Crit.** | *Same as MOP 2-1* |
| **Evaluation Criteria** | The following MIL-STD-1797 paragraph(s) will be used:<br>5.2.2.1.8.1 Steady-state control force and deflection per g (Wheel)<br>5.2.2.1.8.4 Control force versus control deflection (Wheel) |

*Refer to the Test Plan*

## OUTLINE

- Maneuvering Stability (Man-Flt)
  - Definitions
  - Criteria
  - Maneuver Point
    - Stick Fixed
    - Stick Free
  - Flight Test Techniques
  - C.G. Limiters
  - MIL-STD-1797 Requirements



# Definitions

- Maneuvering Stability (Man Flt)
  - Study of longitudinal static stability at load factors other than 1

- Stick-Force/g ($F_e/n$)
  - High
    - Large aircraft
    - Transports
    - Light aircraft (normal category)

  } Small g envelope

  - Low
    - Aerobatic aircraft
    - Fighters

  } Large g envelope

# Definitions

- Acceleration Sensitivity ($n/\alpha$)
  - Incremental change in load factor for an incremental change in angle of attack caused by an incremental movement of the pitch controller
  - Impacts stick force gradients
- Free Elevator Factor (F)
  - Accounts for stability change when the elevator is allowed to float
  - Affects stick forces

# Differences: Static & Maneuver

- Maneuvering Stability is a ***subset*** of Longitudinal Stability

  - Long-Stat parameter of interest

$$\frac{\partial C_m}{\partial C_L} \text{ or } \frac{\partial C_m}{\partial \alpha} \qquad C_L = \frac{2nW}{\rho_{sl} V_e^2 S}$$



  - Long Stat FTT: Vary $C_L$ by changing ***Velocity (V)***
  - Man Flt FTT : Vary $C_L$ by changing ***Normal Acceleration*** (n)

# Stick-Fixed Maneuver Point

- Stick-Fixed Maneuver Point ($h_m$)

$$\frac{\partial \delta_e}{\partial n} = 0$$

- With the C.G. at $h_m$:
  - Any elevator deflection away from the equilibrium position will cause the load factor to continue increasing until the elevator is returned to the equilibrium position.
  - With the elevator in the equilibrium position, the aircraft will maintain the current load factor.

- Compare this to the definition of the stick-fixed neutral point:

$$\frac{\partial \delta_e}{\partial C_L} = 0$$

# Stick-Free Maneuver Point

- Stick-Free Maneuver Point ($h_m$')

$$\frac{\partial F_e}{\partial n} = 0$$

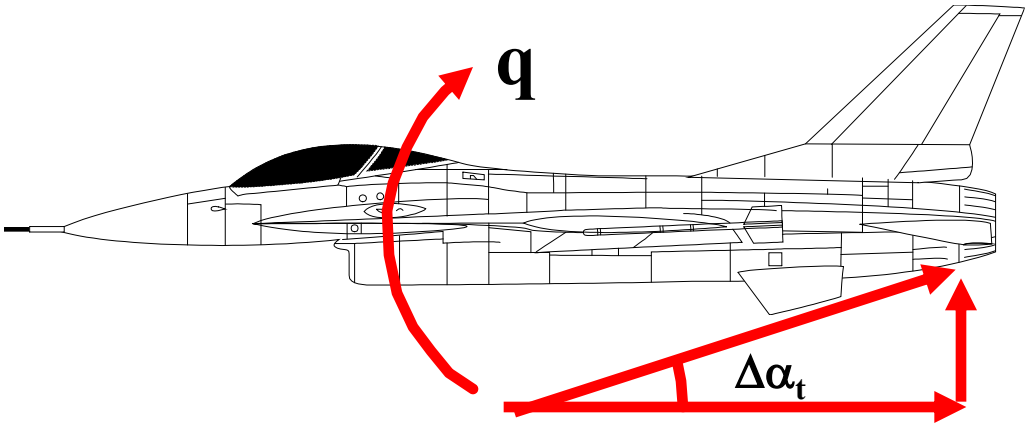
- With the C.G. at $h_m$'
  - Any stick force away from the equilibrium force will cause the load factor to continue increasing until the stick force is returned to the equilibrium value.
  - With the stick force at the equilibrium force, the aircraft will maintain the current load factor.

- Compare this to the definition of the stick-free neutral point:

$$\frac{\partial\left(\frac{F_e}{q}\right)}{\partial C_L} = 0$$

# Pitch Rate Damping

- Pitch Rate Damping ($C_{m_q}$)
  - Due to effects of pitch rate on the angle of attack of the tail
  - Causes the difference between maneuver points & neutral points
  - Effect of $C_{m_q}$ is to increase stability
    - Therefore maneuver points are farther aft than neutral points



# Maneuver Margin

- **Stick-fixed maneuver margin**
  - $h_m$ - h
- **Stick-free maneuver margin**
  - $h_m$' - h

- **Analogous to the static margin, but with maneuver point instead of neutral point**

# Flight Test Relationship Stick-Fixed

- **Elevator deflections affect load factor** (duh)
- **Considering the Push-Over/Pull-Up FTT, we get the relationships**

$$\frac{\partial \delta_e}{\partial n} = \frac{aC_{L_{trim}}}{C_{m_\alpha} C_{L_{\delta_e}} - C_{m_{\delta_e}}} \left[ (h - h_n) + \frac{\rho S c C_{m_q}}{4m} \right]$$

Measure of stick fixed stability

$$h_m = h_n - \frac{\rho S c C_{m_q}}{4m}$$

***So what can we gather from these relationships?***

# Stick-Fixed Maneuver Stability

Rearranging the first equation:

$$\frac{\partial \delta_e}{\partial n} = \frac{-aC_{L_{trim}}}{C_{m_\alpha} C_{L_{\delta_e}} - C_{m_{\delta_e}}} \left[ \underbrace{h_n - \frac{\rho S c C_{m_q}}{4m}}_{h_m} - h \right]$$

(-)

Maneuver Margin

- $\frac{\partial \delta_e}{\partial n}$ varies directly with the maneuver margin
- As $C_{L_{trim}}$ increases (low speed), more elevator deflection is required to produce the same load factor
- $\frac{\partial \delta_e}{\partial n}$ should be linear with respect to C.G. at a constant $C_{L_{trim}}$

# Stick-Fixed Maneuver Stability

$$h_m = h_n - \frac{\rho S c C_{m_q}}{4m}$$

- Maneuver point is behind the neutral point ($C_{m_q}$ is negative)
- Aircraft geometry affects position of maneuver point
- At high altitude, the maneuver point moves toward the neutral point
- For lower aircraft mass, the maneuver point moves farther aft from neutral point
- Largest difference in maneuver point and neutral point happens in a light aircraft at sea level

# Maneuver Point FTTs Stick-Fixed

## Flight Test Techniques (FTTs)

1. Wings level push-over/pull-up
2. Constant g
   **(we'll do this one in the T-41D)**
3. Wind-up turns (slowly varying g)




- **Different equations are used for each method**
  - **Difference arises from different pitch rate**

# 1. Push-Over/Pull-Up

## Procedure:

- Perform Trim Shot
- Start above/slower than data band (PU)
- Start below/faster than data band (PO)
- Climb/descend with power, then reset trim power
- Climb/dive towards data band
- Push/pull to hit target g on altitude/airspeed
- Repeat at different load factors and C.G.s (and airspeeds and altitudes)
- Record:
  - $H_i$, $V_i$, $\delta_{e/yoke}$, $n$

## Assumptions/Constraints:

- Must hit altitude/airspeed/g simultaneously*

  * w/in tolerance of data band

## Data Reduction:

Plot for $\delta_e$ *vs* $n$ for different $n$ and C.G.s

Get slope ($\Delta\delta_e/\Delta n$) for each line at each C.G. to get $\frac{\partial \delta_e}{\partial n}$ as a function of C.G.

# 1. Push-Over/Pull-Up

- Advantages
  - Direct measurement of $\delta_e$ and $n$
  - Simple data reduction
  - Only good way to get less than 1 g
  - Can get data for negative $P_s$ points
- Disadvantages
  - Requires practice to hit altitude/airspeed/g simultaneously
  - Potential to over-shoot test point or over-g

# Constant g Stick-Fixed

- For a level turn we get the relationships

$$\frac{\partial \delta_e}{\partial n} = \frac{aC_{L_{trim}}}{C_{m_\alpha} C_{L_{\delta_e}} - C_{m_{\delta_e}}} \left[ (h - h_n) + \frac{\rho S c C_{m_q}}{4m} \right] \left( 1 + \frac{1}{n^2} \right)$$

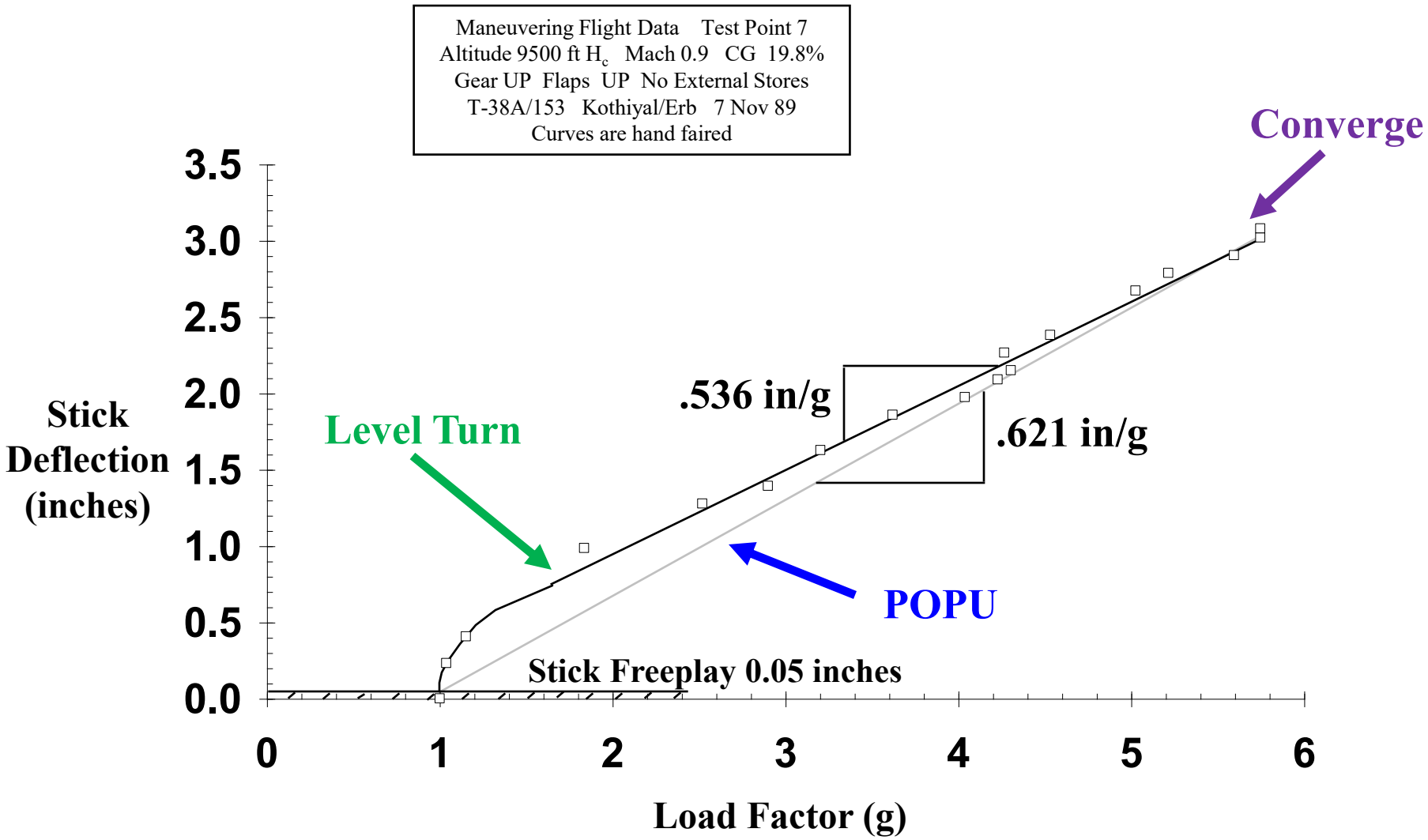
$$h_m = h_n - \frac{\rho S c C_{m_q}}{4m} \left( 1 + \frac{1}{n^2} \right)$$

*Difference from POPU (caused by pitch rate)*

**As load factor increases, $h_{m_{pull\text{-}up}}$ and $h_{m_{turn}}$ move closer together**

$$\left( 1 + \frac{1}{n^2} \right) \Rightarrow 1$$

# Example Data - POPU vs Level Turn






We'll do this in the T-41D!

# 2. Constant g

## Procedure:

- Perform Trim Shot
- Stabilize in a turn at target bank or load factor
- Dive as required to maintain airspeed
- Repeat at different load factors and C.G.s (and airspeeds and altitudes)

- Record:
  - $H_i$, $V_i$, $\delta_{e/yoke}$, $n$

## Assumptions/Constraints:

- Stabilized conditions

## Data Reduction:

Plot for $\delta_e$ *vs* $n$ for different $n$ and C.G.s

Get slope ($\Delta\delta_e / \Delta n$) for each line at each C.G. to get $\frac{\partial \delta_e}{\partial n}$ as a function of C.G.

# 2. Constant g

- Advantages
  - Direct measurement of $\delta_e$ and $n$
  - Simple data reduction
  - Simple to fly

- Disadvantages
  - Can't achieve less than 1 g
  - Can't stabilize at (very) negative $P_s$ points (fly through data band)




# 3. Wind-up Turn (slowly varying g)

## Procedure:

*Continuous version of stabilized g*

- Perform Trim Shot
- Gradually increase g until reaching ultimate target load factor
- Use pitch to maintain airspeed
- Repeat at different load factors and C.G.s (and airspeeds and altitudes)

- Record:
  - $H_i$, $V_i$, $\delta_{e/yoke}$, $n$
  - *DAS required*

## Assumptions/Constraints:

- Maintain airspeed
- Altitude changes have little effect

## Data Reduction:

Plot for $\delta_e$ *vs* $n$ for different $n$ and C.G.s

Get slope ($\Delta\delta_e / \Delta n$) for each line at each C.G. to get $\frac{\partial \delta_e}{\partial n}$ as a function of C.G.

# 3. Wind-up Turn (slowly varying g)

- Advantages
  - Efficient (captures all load factors in one maneuver
- Disadvantages
  - Requires a DAS
  - Can achieve less than 1 g (Wind-up push)
  - Can achieve negative $P_s$ points (descending turn)
  - Requires some practice for highly negative $P_s$ points

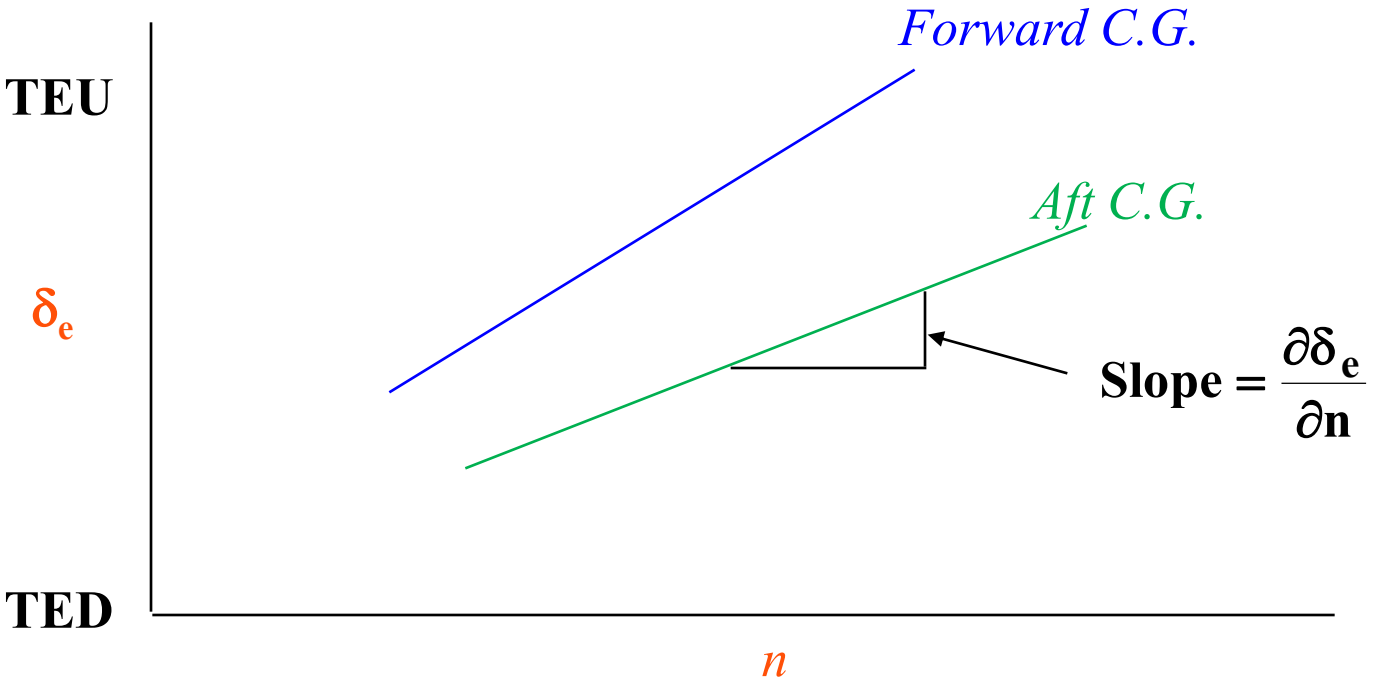
# Most Common Approach

- **Combination of flight test techniques**
  - **Constant g method up to 2 g**
  - **Wind-up turn method above 2 g**
  - **Push-Overs below 1 g**



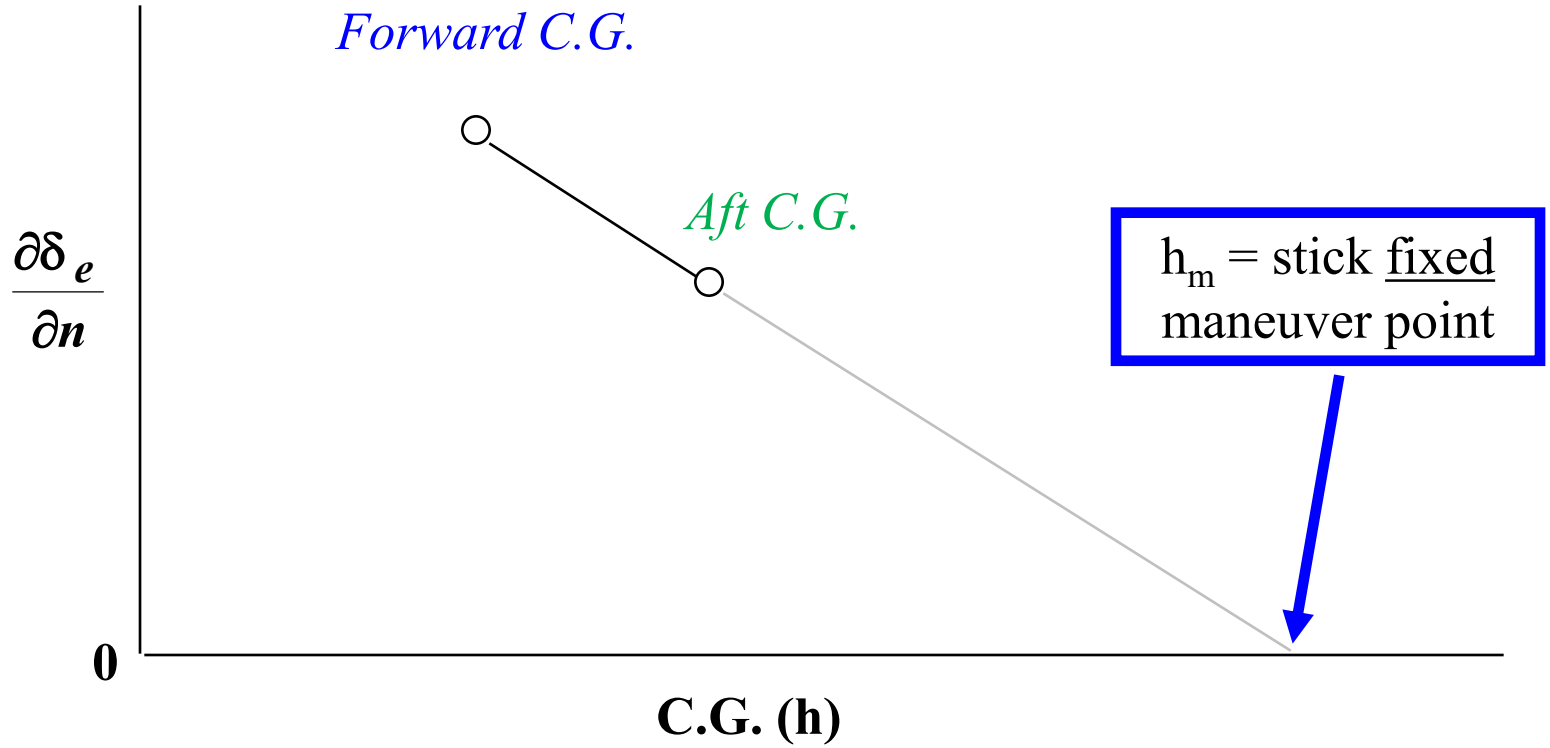
# Finding Stick-Fixed Maneuvering Stability

- Measure $\delta_e$ and $n$ at a given altitude, weight, airspeed ($C_L$) and C.G.



# Finding Stick-Fixed Maneuvering Stability

- Now plot the slopes vs C.G. locations



# Flight Test Relationship Stick-Free

- **Yoke forces affect load factor** (duh)
- **Considering the Push-Over/Pull-Up FTT, we get the relationships**

$$\frac{\partial F_e}{\partial n} = GqS_e c_e \frac{C_{h_{\delta_e}} C_{L_{trim}}}{C_{m_{\delta_e}}} \left[ \left( h - h_n' \right) + \frac{\rho S c C_{m_q}}{4m} F \right]$$

Measure of stick free stability

$$h_m' = h_n' - \frac{\rho S c C_{m_q}}{4m} F$$

***So what can we gather from these relationships?***

# Stick-Free Maneuver Stability

**Rearranging the first equation:**

$$\frac{\partial F_e}{\partial n} = GqS_e c_e \frac{C_{h_{\delta_e}} C_{L_{trim}}}{C_{m_{\delta_e}}} \left[ \left( h - h_n' \right) + \frac{\rho S c C_{m_q}}{4m} F \right]$$

$h - h_m'$ — Maneuver Margin

- $\frac{\partial F_e}{\partial n}$ varies directly with the maneuver margin
- $\frac{\partial F_e}{\partial n}$ varies directly with gear ratio ($G$)
- As $C_{L_{trim}}$ increases (low speed), more elevator deflection is required to produce the same load factor
- $\frac{\partial F_e}{\partial n}$ should be linear with respect to C.G. at a constant $C_{L_{trim}}$

# Stick-Free Maneuver Stability

$$h'_m = h'_n - \frac{\rho S c C_{m_q}}{4m} F$$

- Maneuver point is behind the neutral point ($C_{m_q}$ is negative)
- Aircraft geometry affects position of maneuver point
- At high altitude, the maneuver point moves toward the neutral point
- For lower aircraft mass, the maneuver point moves farther aft from neutral point
- Largest difference in maneuver point and neutral point happens in a light aircraft at sea level

**Same as Stick-Fixed… Except**

- **Only difference is yoke force:**
  - Large yoke forces increase maneuver stability

# Level Turn (Stabilized G) Stick-Free

- For a level turn we get the relationships

$$\frac{\partial F_e}{\partial n} = GqS_e c_e \frac{C_{h_{\delta_e}} C_{L trim}}{C_{m_{\delta_e}}} \left[ \left( h - h_n' \right) + \frac{\rho S c C_{m_q}}{4m} F \right] \left( 1 + \frac{1}{n^2} \right)$$

$$h_m' = h_n' - \frac{\rho S c C_{m_q}}{4m} F \left( 1 + \frac{1}{n^2} \right)$$

**Difference from POPU (caused by pitch rate)**

**As load factor increases, $h_m'_{\text{pull-up}}$ and $h_m'_{\text{turn}}$ move closer together**

$$\left( 1 + \frac{1}{n^2} \right) \Rightarrow 1$$

# Maneuver Point FTTs Stick-Free

## Flight Test Techniques (FTTs)

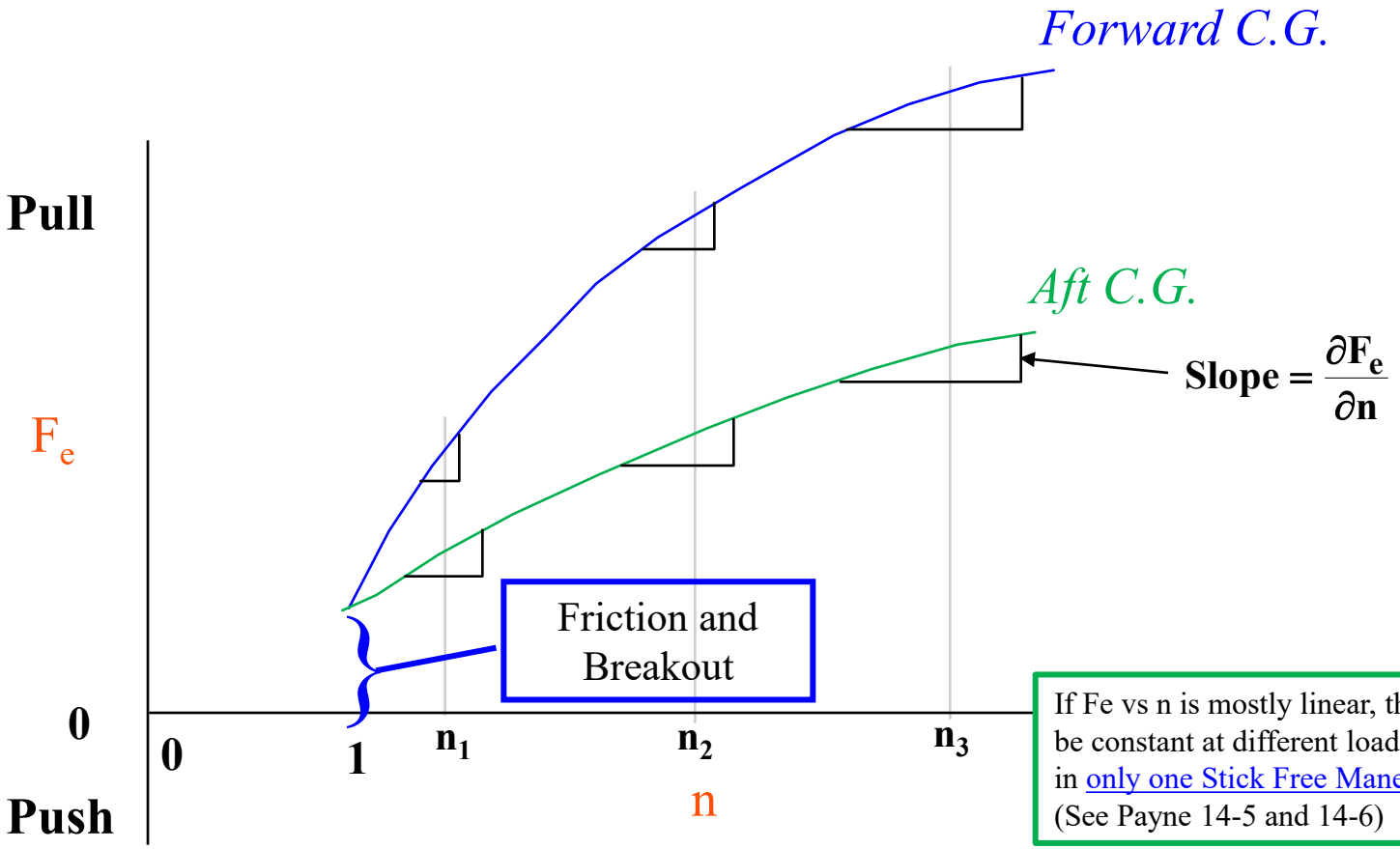
1. Wings level push-over/pull-up
2. Constant g
   **(we'll do this one in the T-41D)**
3. Wind-up turns (slowly varying g)




**Same as Stick Fixed except we measure yoke forces**

# Finding Stick-Free Maneuvering Stability

- Measure $F_e$ and $n$ at a given altitude, weight, and airspeed at different **C.G.**

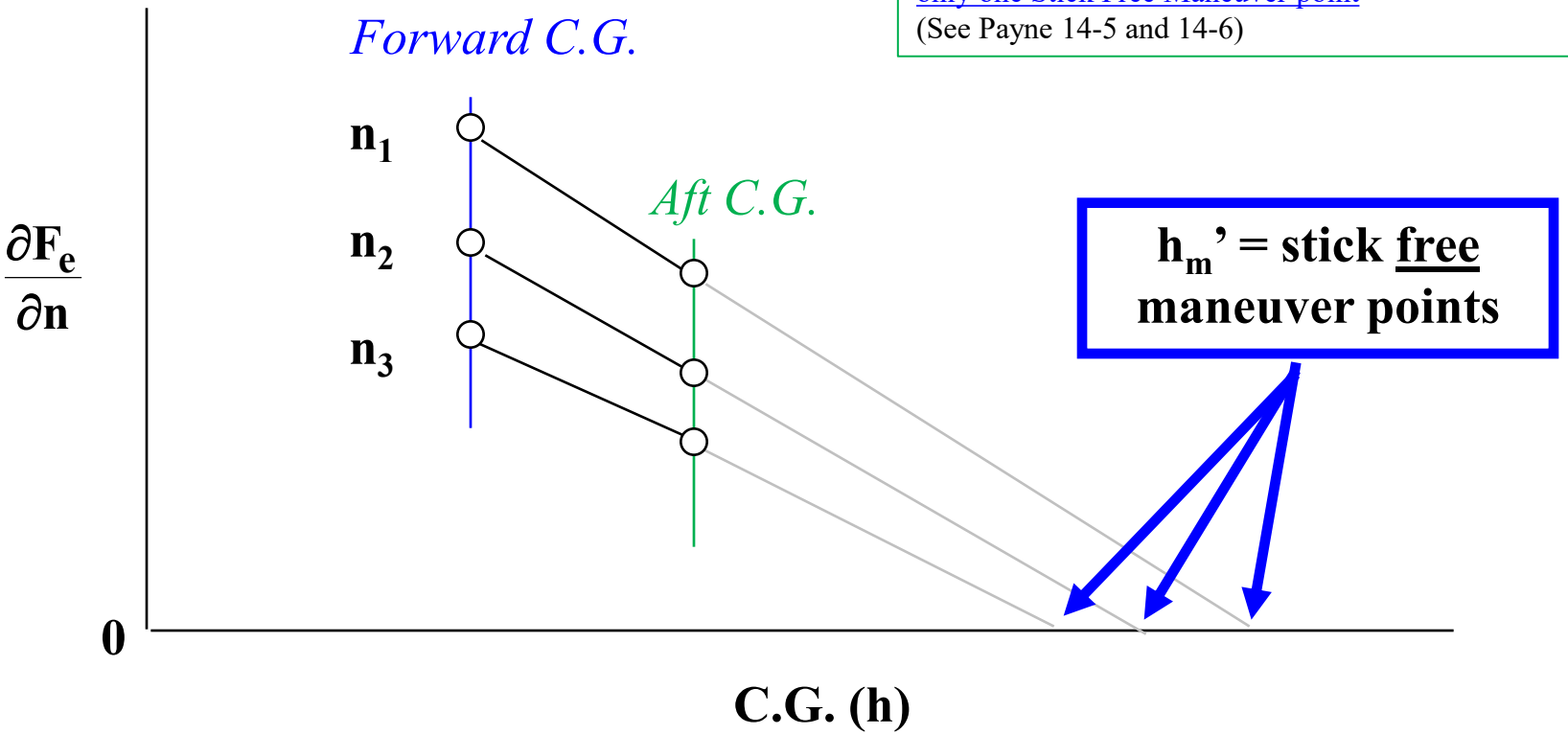



If Fe vs n is mostly linear, then the slope will be constant at different load factors resulting in only one Stick Free Maneuver point
(See Payne 14-5 and 14-6)

# Finding Stick-Free Maneuvering Stability

- Now plot the slopes vs cg locations at selected load factors

Realize that if the $F_e$ vs *n* relationship is mostly linear, slope will be constant at different load factors resulting in only one Stick Free Maneuver point
(See Payne 14-5 and 14-6)



# Factors Affecting Maneuvering Stability

- It can be shown (ICBS)

$$\frac{\partial F_e}{\partial n} = GH_e\left(\frac{W}{S}\right)\left(\frac{1}{C_{m_{\delta_e}}}\right)\left(h - h_m'\right)$$

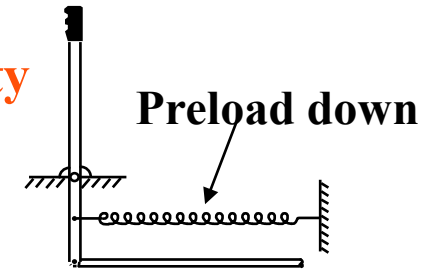


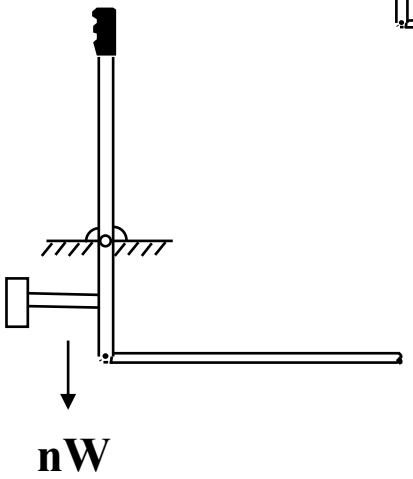
- Stick force per g is a function of
  - Hinge moment
  - Wing loading (not directly - also in $h_m$')
  - Elevator power (inversely)
  - Negative of stick free maneuver margin

- It is not a function of **airspeed** !
  - Assuming no Mach or $R_e$ effects

# Modifying Maneuvering Stability

- Centering Spring
  - Artificial feel Creates artificial stick force/g (really it is stick force/displacement)
    Stick force/g diminishes as A/S increases (less deflection needed)
- Downspring
  - Increases overall Stick force gradient
    Does not improve Maneuver Stability
    Destabilizes Phugoid
- Bobweight
  - Increases Stick force/g
    Improves Maneuver Stability
    Dampens Phugoid
    Adds weight and inertia

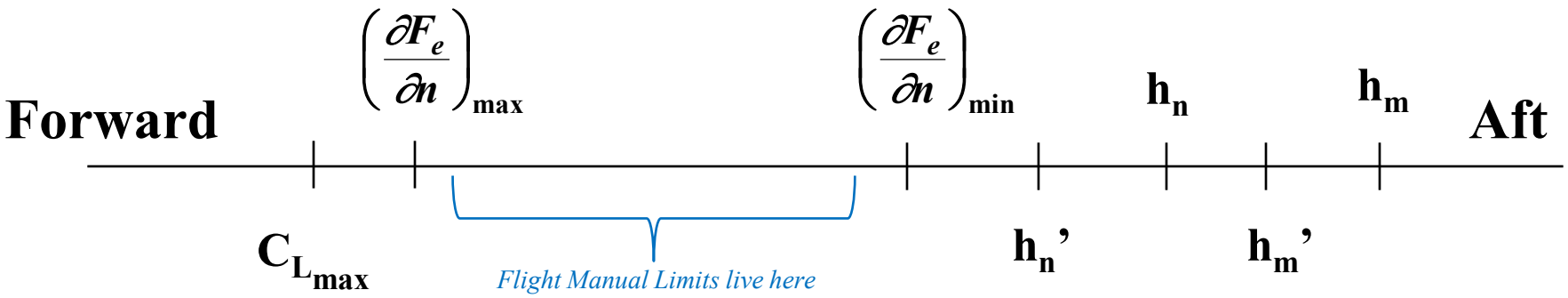



*Combos can greatly improve stability*

# C.G. Limiters

- Forward C.G. limit
  - Maximum stick force/g gradient
  - Landing flare or takeoff rotation
- Aft C.G. limit
  - Minimum stick force/g gradient
  - Stick free neutral point with power on




**Note: Some relative positions may vary**

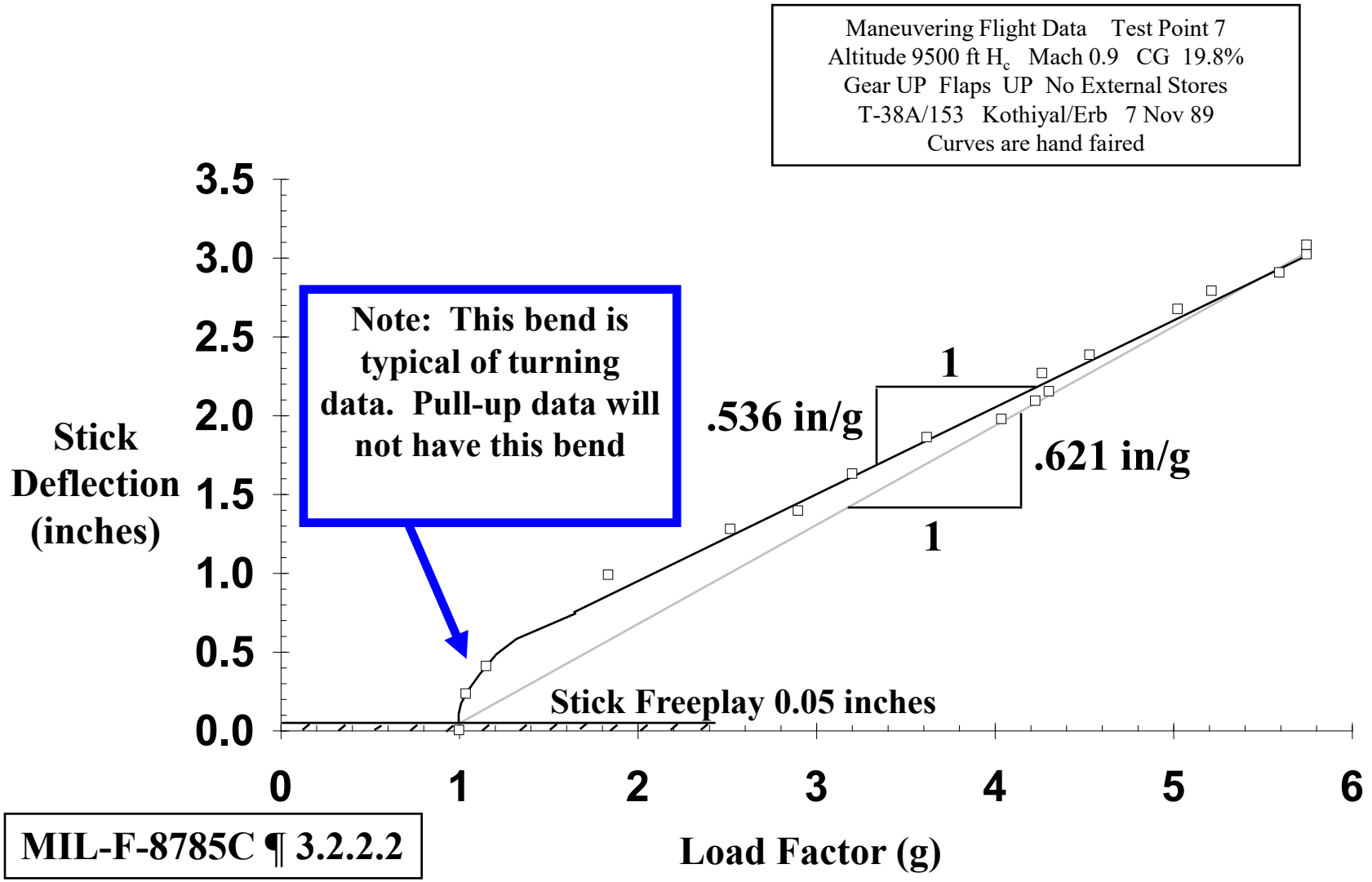
# Next Time

## FQ-3:
## Lateral-Directional Stability

# In Class Exercise

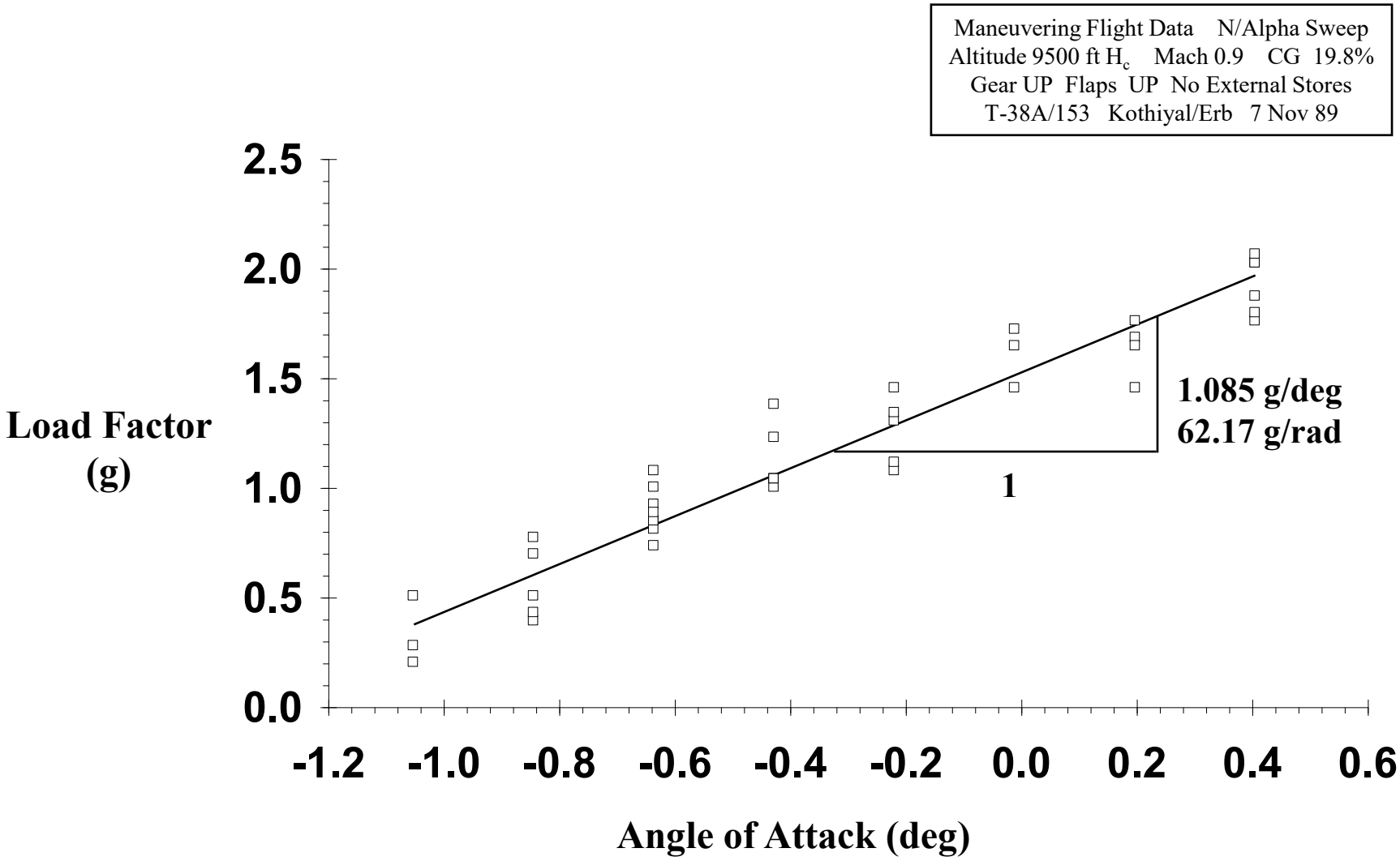
- Given T-38 example data in slides FQ2-42 through FQ2-45, determine PASS/FAIL for these MIL-F-8785C paragraphs:
  - 3.2.2.2
  - 3.2.2.2.1
  - 3.2.2.2.2
- Be prepared to explain your ratings.
  - Include in your discussion a description of how to determine n/$\alpha$

# Example Data

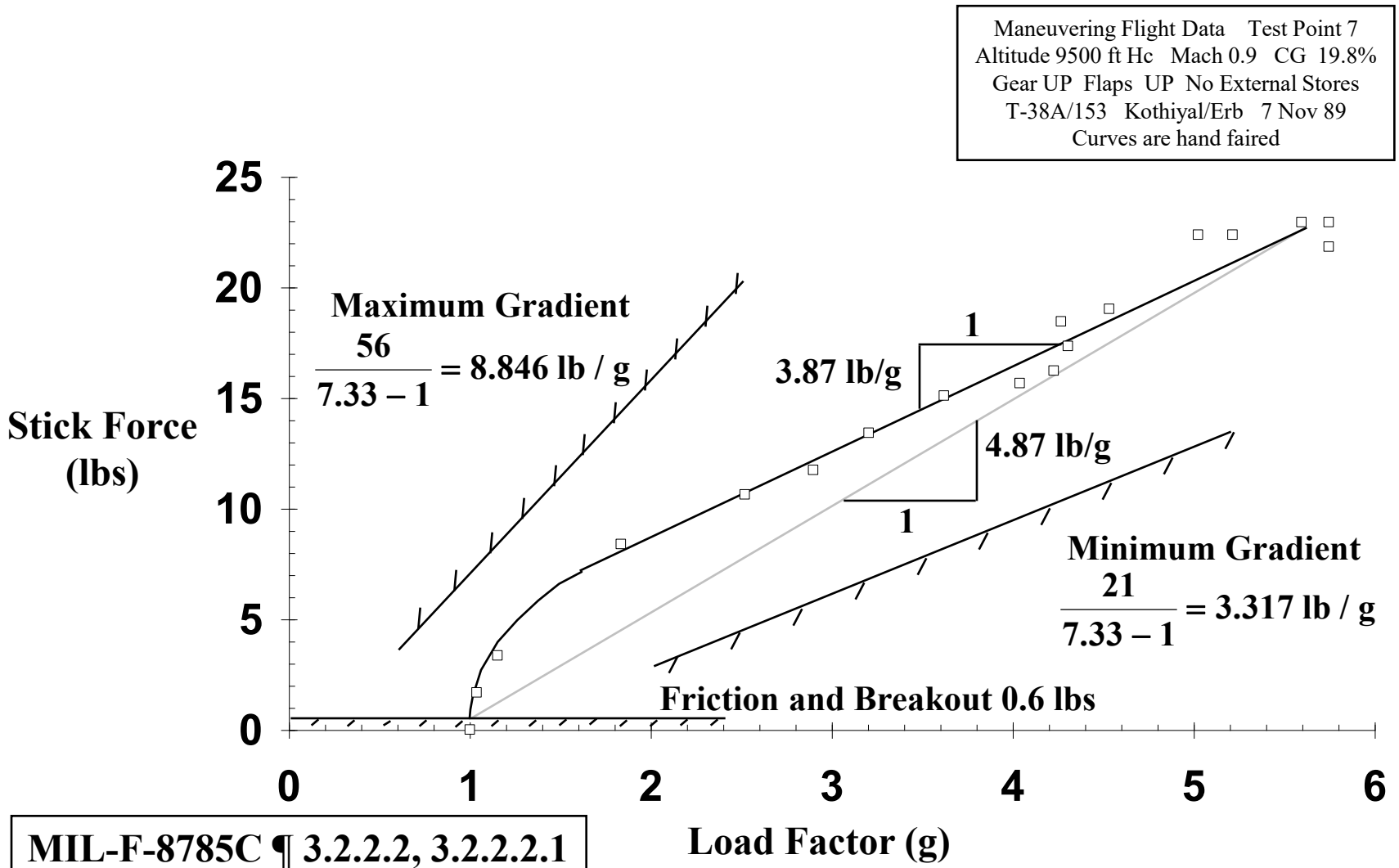



MIL-F-8785C ¶ 3.2.2.2

# Example Data

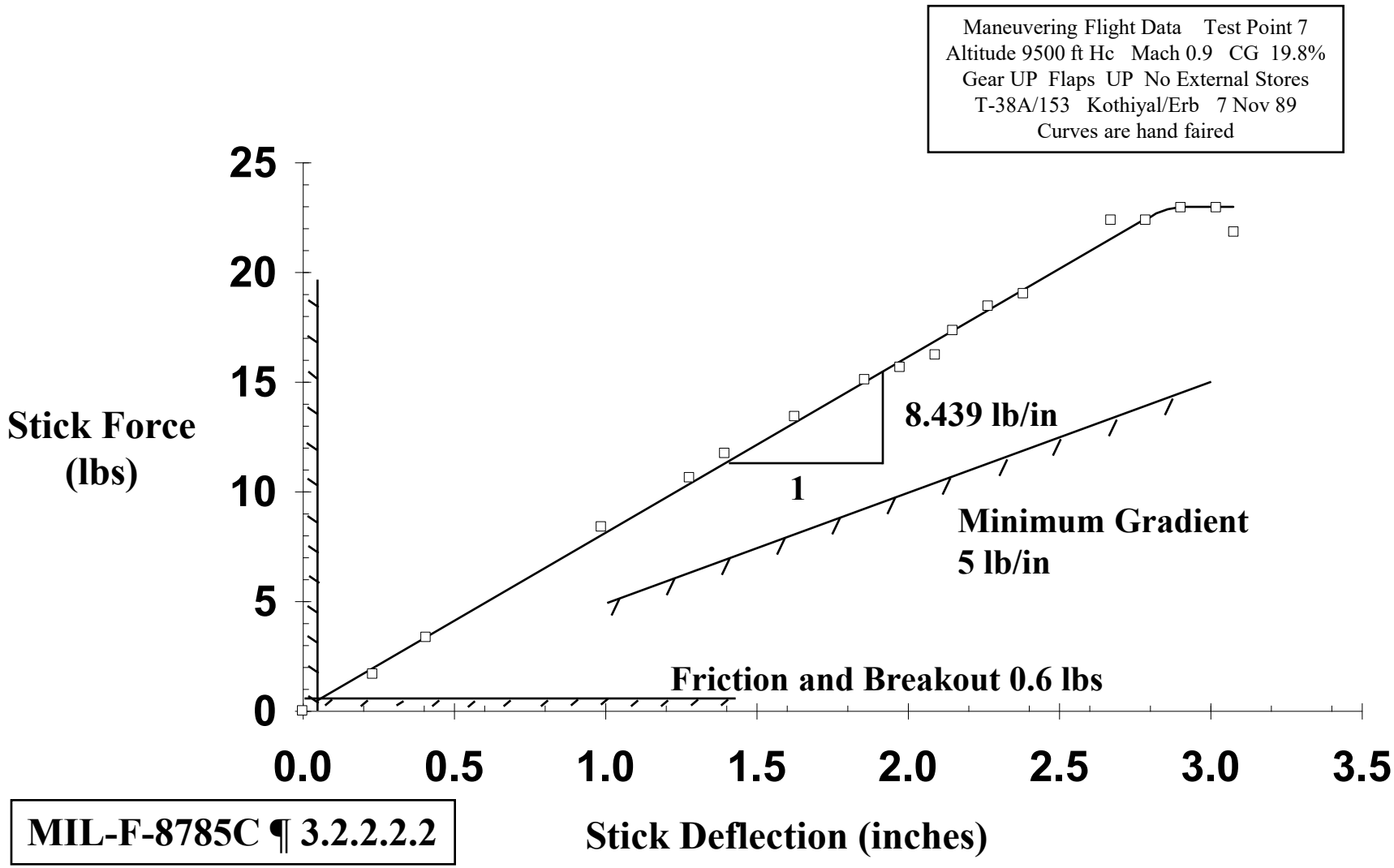


# Example Data




MIL-F-8785C ¶ 3.2.2.2, 3.2.2.2.1

# Example Data




MIL-F-8785C ¶ 3.2.2.2.2