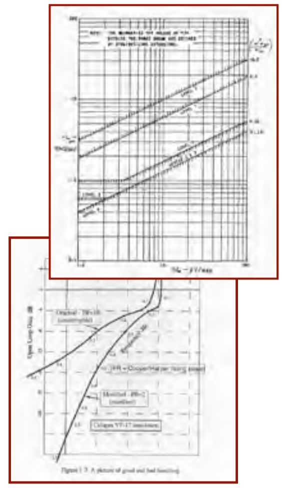
Flying Qualities Criteria

Robert Stengel, Aircraft Flight Dynamics
MAE 331, 2014



Learning Objectives

- **MIL-F-8785C criteria**
- ***CAP*, *C**, and other longitudinal criteria**
- **$\varphi/\beta, \omega_\varphi/\omega_d$, and other lateral-directional criteria**
- **Pilot-vehicle interactions**
- **Flight control system design**

Flight Dynamics
419-428, 525-533, 624-629
Airplane Stability and Control
Chapter 21

http://www.princeton.edu/~stengel/MAE331.html
http://www.princeton.edu/~stengel/FlightDynamics.html

Flying Qualities Research Moves with the Times

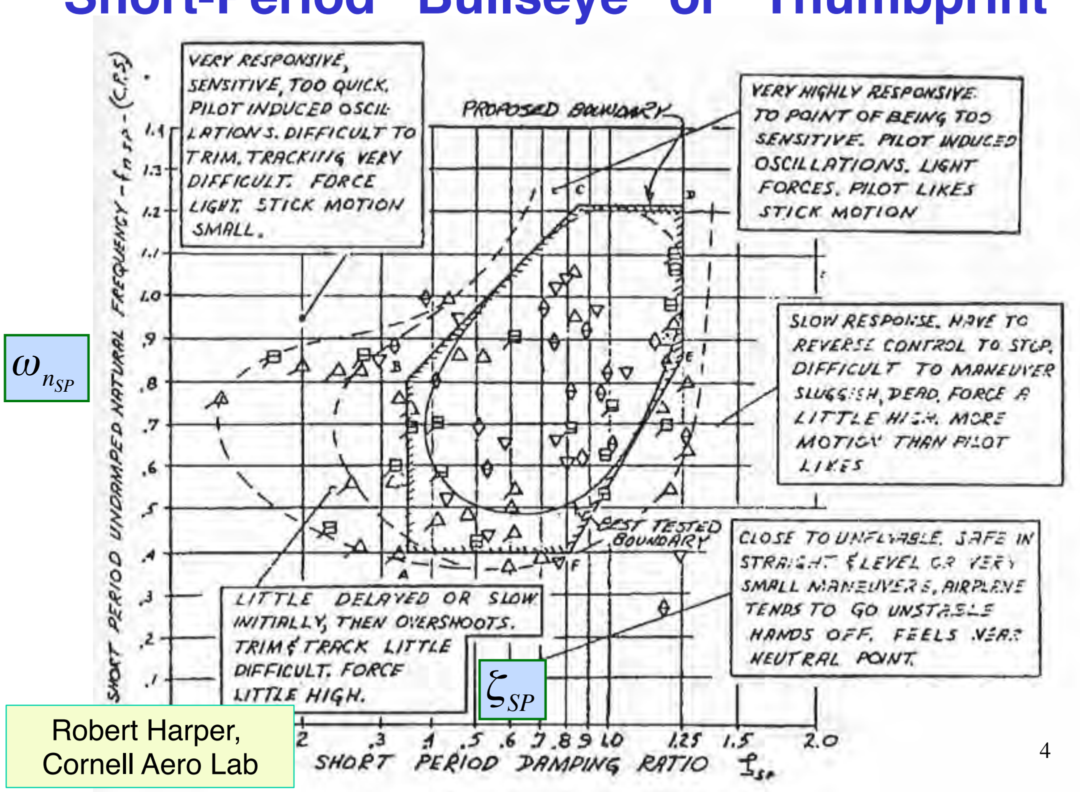
Chapter 21, *Airplane Stability and Control*, Abzug and Larrabee

- What are the principal subject and scope of the chapter?
- What technical ideas are needed to understand the chapter?
- During what time period did the events covered in the chapter take place?
- What are the three main "takeaway" points or conclusions from the reading?
- What are the three most surprising or remarkable facts that you found in the reading?

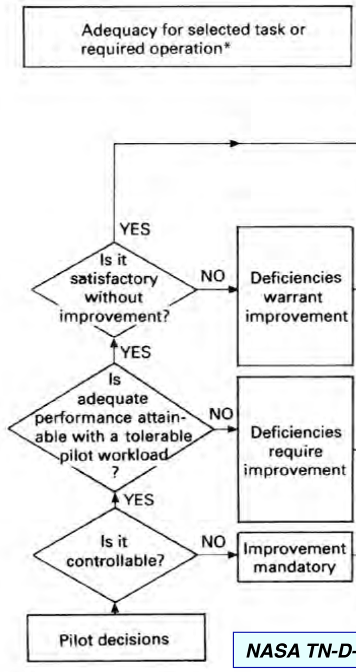
Design for Satisfactory Flying Qualities

- **Satisfy procurement requirement (e.g., Mil Standard)**
- **Satisfy test pilots (e.g., *Cooper-Harper ratings*)**
- **Avoid pilot-induced oscillations (PIO)**
- **Minimize time-delay effects**
- **Time- and frequency-domain criteria**

Short-Period "Bullseye" or "Thumbprint"



Cooper-Harper Handling Qualities Rating Scale



Aircraft characteristics	Demands on the pilot in selected task or required operation*	Pilot rating
Excellent Highly desirable	Pilot compensation not a factor for desired performance	1
Good Negligible deficiencies	Pilot compensation not a factor for desired performance	2
Fair – some mildly unpleasant deficiencies	Minimal pilot compensation required for desired performance	3
Minor but annoying deficiencies	Desired performance requires moderate pilot compensation	4
Moderately objectionable deficiencies	Adequate performance requires considerable pilot compensation	5
Very objectionable but tolerable deficiencies	Adequate performance requires extensive pilot compensation	6
Major deficiencies	Adequate performance not attainable with maximum tolerable pilot compensation. Controllability not in question	7
Major deficiencies	Considerable pilot compensation is required for control	8
Major deficiencies	Intense pilot compensation is required to retain control	9
Major deficiencies	Control will be lost during some portion of required operation	10

*Definition of required operation involves designation of flight phase and/or subphases with accompanying conditions

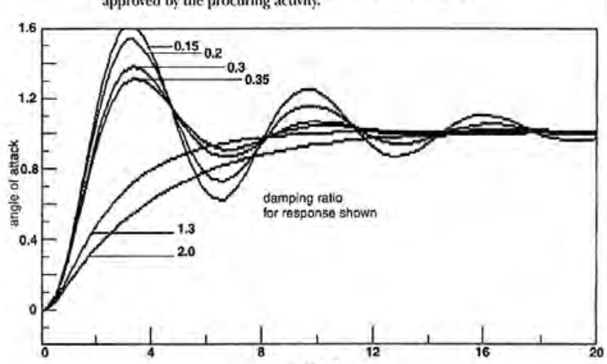
NASA TN-D-5153,1969

MIL-F-8785C Identifies Satisfactory, Acceptable, and Unacceptable Response Characteristics

Damping Ratio

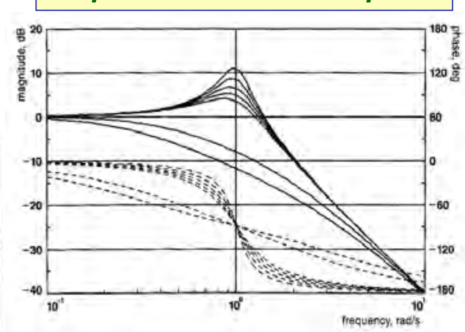
	Category A and C Flight Phases		Category B Flight Phases	
Level	Minimum	Maximum	Minimum	Maximum
1	0.35	1.30	0.30	2.00
2	0.25	2.00	0.20	2.00
3	0.15*	-	0.15	-

* May be reduced at altitudes above 20 000 feet if approved by the procuring activity.



Step Response

Short-period angle-of-attack response to elevator input



Frequency Response

Military Flying Qualities Specifications, MIL-F-8785C

- Specifications established during WWII
- US Air Force and Navy coordinated efforts beginning in 1945
- First version appeared in 1948, last in 1980
- Distinctions by flight phase, mission, and aircraft type
- Replaced by Military Flying Qualities Standard, MIL-STD-1797A, with procurement-specific criteria

MIL-F-8785C Aircraft Types

I. Small, light airplanes, e.g., utility aircraft and primary trainers
II. Medium-weight, low-to-medium maneuverability airplanes, e.g., small transports or tactical bombers
III. Large, heavy, low-to-medium maneuverability airplanes, e.g., heavy transports, tankers, or bombers
IV. Highly maneuverable aircraft, e.g., fighter and attack airplanes

MIL-F-8785C Flight Phase

A. Non-terminal flight requiring rapid maneuvering precise tracking, or precise flight path control
   - air-to-air combat
   - ground attack
   - in-flight refueling (receiver)
   - close reconnaissance
   - terrain following
   - close formation flying

B. Non-terminal flight requiring gradual maneuvering
   - climb, cruise
   - in-flight refueling (tanker)
   - descent

C. Terminal flight
   - takeoff (normal and catapult)
   - approach
   - wave-off/go-around
   - landing

MIL-F-8785C Levels of Performance

1. Flying qualities clearly adequate for the mission flight phase
2. Flying qualities adequate to accomplish the mission flight phase, with some increase in pilot workload or degradation of mission effectiveness
3. Flying qualities such that the aircraft can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate

Principal MIL-F-8785C Metrics

- **Longitudinal flying qualities**
  - static speed stability
  - phugoid stability
  - flight path stability
  - short period frequency and its relationship to command acceleration sensitivity
  - short period damping
  - control-force gradients
- **Lateral-directional flying qualities**
  - natural frequency and damping of the Dutch roll mode
  - time constants of the roll and spiral modes
  - rolling response to commands and Dutch roll oscillation
  - sideslip excursions
  - maximum stick and pedal forces
  - turn coordination

Longitudinal Criteria

Long-Period Flying Qualities Criteria
(MIL-F-8785C)

Flight Phase	*Level of Performance*
A. Non-terminal flight requiring rapid maneuvering B. Non-terminal flight requiring gradual maneuvering C. Terminal flight	1. Clearly adequate for the mission 2. Adequate to accomplish the mission, with some increase in workload 3. Aircraft can be controlled safely, but workload is excessive

- **Static speed stability**
  - No tendency for aperiodic divergence
    - Phugoid oscillation -> 2 real roots, 1 that is unstable
  - Stable control stick position and force gradients
    - e.g., Increasing "pull" position and force with decreasing speed

Long-Period Flying Qualities Criteria
(MIL-F-8785C)

- **Flight path stability [Phase C]**
  1. $(\Delta\gamma/\Delta V)_{SS} < 0.06$ deg/kt
  2. $(\Delta\gamma/\Delta V)_{SS} < 0.15$ deg/kt
  3. $(\Delta\gamma/\Delta V)_{SS} < 0.24$ deg/kt

Steady-State Response to Elevator

$$\boxed{\begin{aligned}\Delta V_{SS} &= a\Delta\delta E_{SS}\\ \Delta\gamma_{SS} &= c\Delta\delta E_{SS}\end{aligned}}$$

Ratio

$$\boxed{\frac{\Delta\gamma_{SS}}{\Delta V_{SS}} = \frac{c}{a} \quad \text{(with appropriate scaling)}}$$

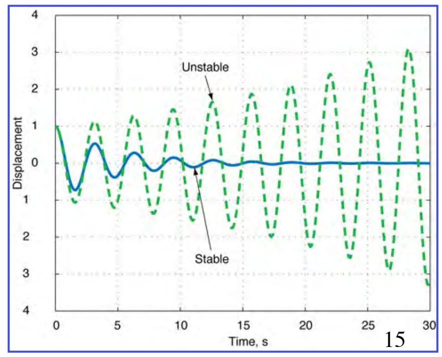
Long-Period Flying Qualities Criteria

(MIL-F-8785C)

- **Phugoid stability**
  1. Damping ratio ≥ 0.04
  2. Damping ratio ≥ 0
  3. "Time to double", $T_2 \geq 55$ sec

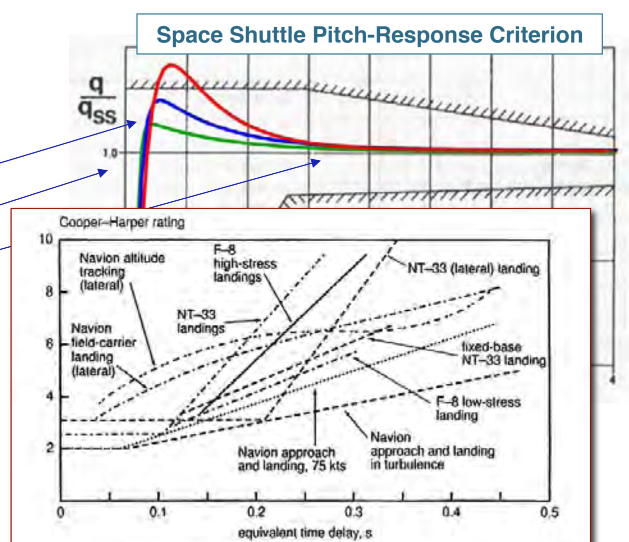
Time to Double

$$T_{2_{Ph}} = -0.693/\zeta_{Ph}\omega_{n_{Ph}}$$



Short Period Criteria

- **Important parameters**
  - Short-period natural frequency
  - Damping ratio
  - Lift slope
  - Step response
    - Over-/under-shoot
    - Rise time
    - Settling time
    - Pure time delay
  - Pitch angle response
  - Normal load factor response
  - Flight path angle response (landing)

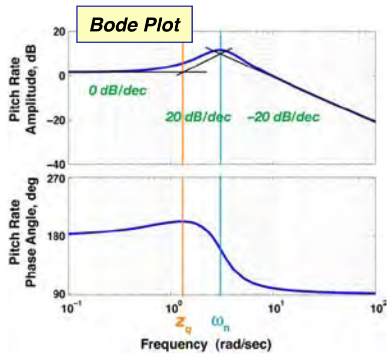


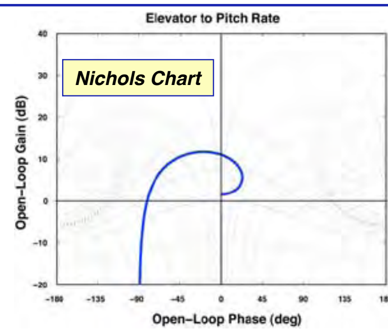
Rate of degradation of Cooper–Harper pilot ratings increases with difficulty of task

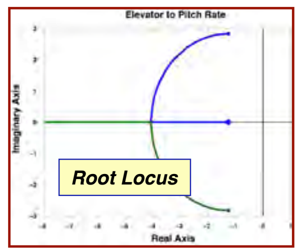
Short-Period Approximation Transfer Functions

- Elevator to pitch rate

$$\frac{\Delta q(s)}{\Delta \delta E(s)} = \frac{k_q\left(s - z_q\right)}{s^2 + 2\zeta_{SP}\omega_{n_{SP}} s + \omega_{n_{SP}}^2} \equiv \frac{k_q\left(s + \frac{1}{T_{\theta_2}}\right)}{s^2 + 2\zeta_{SP}\omega_{n_{SP}} s + \omega_{n_{SP}}^2}$$





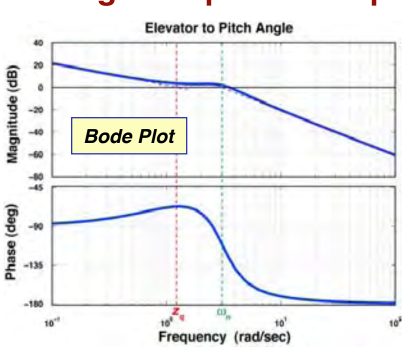


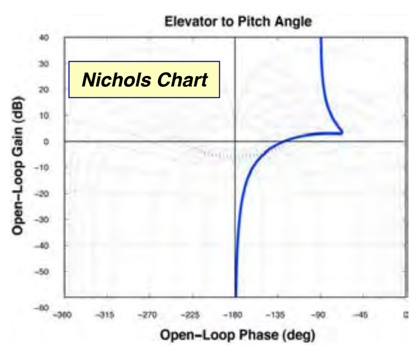
- Pure gain or phase change (< 90°) in feedback control cannot produce instability

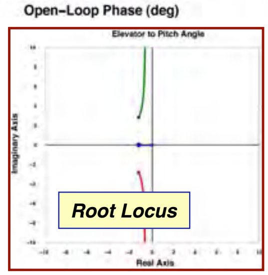
Short-Period Approximation Transfer Functions

- Elevator to pitch angle
- Integral of prior example

$$\frac{\Delta \theta(s)}{\Delta \delta E(s)} = \frac{k_q\left(s - z_q\right)}{s\left(s^2 + 2\zeta_{SP}\omega_{n_{SP}} s + \omega_{n_{SP}}^2\right)}$$







- Pure gain or phase change (< 45°) in feedback control cannot produce instability

Normal Load Factor

$$\Delta n_z = \frac{V_N}{g}\left(\Delta\dot{\alpha} - \Delta q\right) = -\frac{V_N}{g}\left(\frac{L_\alpha}{V_N}\Delta\alpha + \frac{L_{\delta E}}{V_N}\Delta\delta E\right)$$

positive down

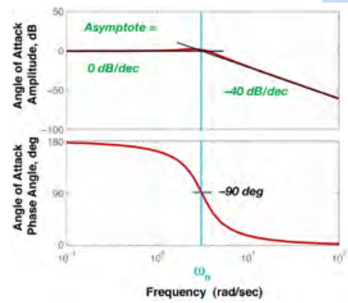
- **Therefore, with negligible $L_{\delta E}$ (aft tail/canard effect)**

$$\frac{\partial\Delta n_z(s)}{\partial\Delta\delta E(s)} = \frac{1}{g}\left(L_\alpha\frac{\partial\Delta\alpha(s)}{\partial\Delta\delta E(s)} + L_{\delta E}\right) \approx \left(\frac{L_\alpha}{g}\right)\frac{\partial\Delta\alpha(s)}{\partial\Delta\delta E(s)}$$

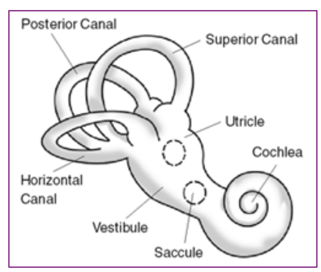
positive up

- **Elevator to angle of attack ($L_{\delta E}$ = 0)**

$$\frac{\Delta\alpha(s)}{\Delta\delta E(s)} \approx \frac{k_\alpha}{s^2 + 2\zeta_{SP}\omega_{n_{SP}}s + \omega_{n_{SP}}^2}$$



Control Anticipation Parameter, *CAP*



Inner ear senses angular acceleration about 3 axes

Initial Angular Acceleration

$$\Delta\dot{q}(0) = \left(M_{\delta E} - \frac{M_\alpha}{V_N + L_\alpha}L_{\delta E}\right)\Delta\delta E_{SS}$$

Desired Normal Load Factor

$$\Delta n_{SS} = \frac{V_N}{g}\Delta q_{SS} = -\left(\frac{V_N}{g}\right)\frac{\left(M_{\delta E}\,{}^{L_\alpha}\!/_{V_N} - M_\alpha\,{}^{L_{\delta E}}\!/_{V_N}\right)}{\left(M_q\,{}^{L_\alpha}\!/_{V_N} + M_\alpha\right)}\Delta\delta E_{SS}$$

Control Anticipation Parameter, *CAP*

Inner ear cue should aid pilot in <u>anticipating commanded normal acceleration</u>

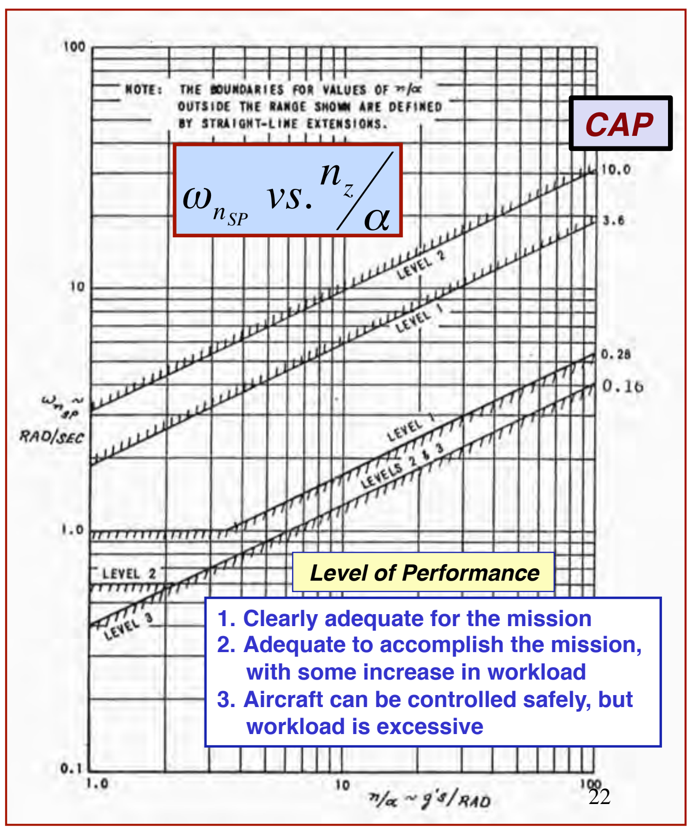
$$\color{red}{CAP} = \frac{\Delta\dot{q}(0)}{\Delta n_{SS}} = \frac{-\left(M_{\delta E} - \dfrac{M_\alpha}{V_N + L_\alpha} L_{\delta E}\right)\left(M_q \, {L_\alpha}/{V_N} + M_\alpha\right)}{\left(L_\alpha M_{\delta E} - L_{\delta E} M_\alpha\right)/g}$$

with $L_{\delta E} = 0$

$$\color{red}{CAP} = \frac{-\left(M_q \, {L_\alpha}/{V_N} + M_\alpha\right)}{L_\alpha / g} \approx \frac{\omega_{n_{SP}}^{\;2}}{n_z / \alpha}$$

MIL-F-8785C Short-Period Flying Qualities Criterion

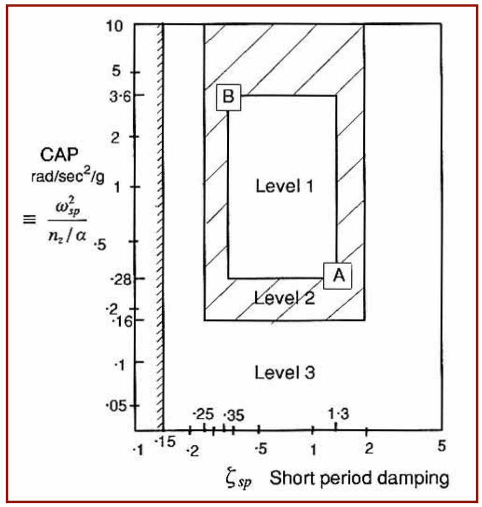
***CAP* = constant along <u>Level Boundaries</u>**



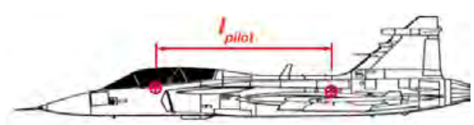
Control Anticipation Parameter vs. Short-Period Damping Ratio

(MIL-F-8785C, Category A)

$$CAP = \frac{-\left(M_q \frac{L_\alpha}{V_N} + M_\alpha\right)}{L_\alpha / g} \approx \frac{\omega_{n_{SP}}^{\;2}}{n_z / \alpha}$$

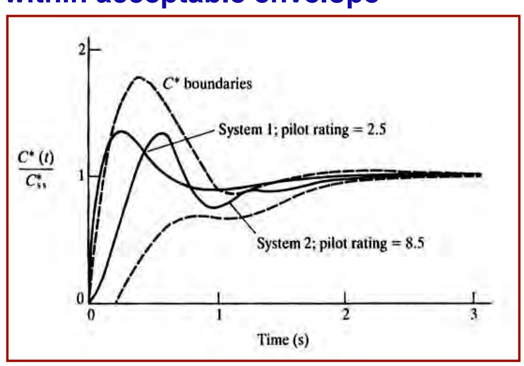


C* Criterion



- **Hypothesis**
  - ***C**** **blends** **normal load factor at pilot's location** **and pitch rate**
  - **Step response of *C**** **should lie within acceptable envelope**

$$
\begin{aligned}
C^* &= \Delta n_{pilot} + \frac{V_{crossover}}{g}\Delta q \\
&= \left(l_{pilot}\Delta\dot{q} + \Delta n_{cm}\right) + \frac{V_{crossover}}{g}\Delta q \\
&= \left[l_{pilot}\Delta\dot{q} + \frac{V_N}{g}\left(\Delta q - \Delta\dot{\alpha}\right)\right] + \frac{V_{crossover}}{g}\Delta q
\end{aligned}
$$



- **Below $V_{crossover}$, Δq is pilot's primary control objective**
- **Above $V_{crossover}$, Δn_{pilot} is the primary control objective**

Fighter Aircraft: $V_{crossover} \approx 125\ m/s$

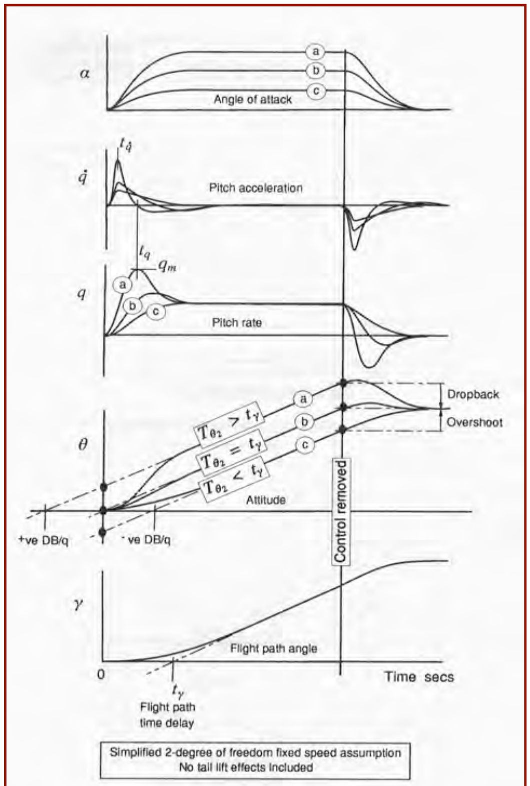
Gibson Dropback Criterion for Pitch Angle Control

- Step response of pitch rate should have overshoot for satisfactory pitch and flight path angle response

$$\frac{\Delta q(s)}{\Delta\delta E(s)} = \frac{k_q\left(s+\dfrac{1}{T_{\theta_2}}\right)}{s^2+2\zeta_{SP}\omega_{n_{SP}}s+\omega_{n_{SP}}^2} = \frac{k_q\left(s+\omega_{n_{SP}}/\zeta_{SP}\right)}{s^2+2\zeta_{SP}\omega_{n_{SP}}s+\omega_{n_{SP}}^2}$$

- Criterion is satisfied when

$$z_q \triangleq -\frac{1}{T_{\theta_2}} = -\left(\omega_{n_{SP}}/\zeta_{SP}\right)$$



Gibson, 1997

Figure 7-3 Generic short period pitch transient responses

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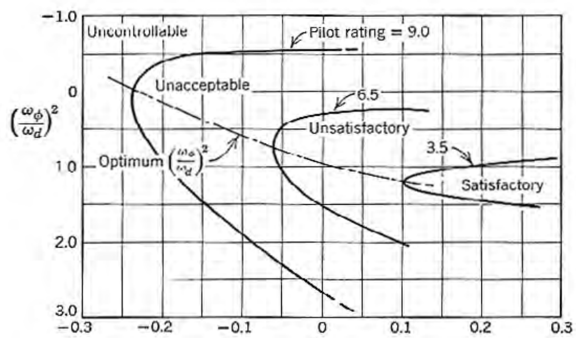
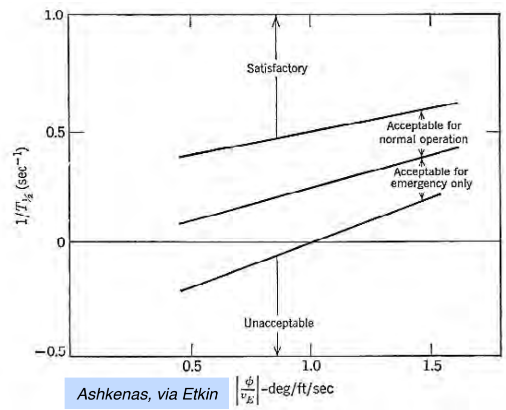
- ***Shift to Lecture on Advanced Problems in Lateral-Directional Dynamics***
- ***Return to Lateral-Directional Flying Qualities Criteria***

Early Lateral-Directional Flying Qualities Criteria



O'Hara, via Etkin



Ashkenas, via Etkin

$$T_{1/2} = 0.693 / \zeta\, \omega_n$$
$$v = V_N \beta$$

Time to Half

Lateral-Directional Flying Qualities Parameters

- Lateral Control Divergence Parameter, ***LCDP***
- φ/β Effect
- ω_φ/ω_d Effect

Lateral Control Divergence Parameter (*LCDP*)

- **Aileron deflection produces yawing as well as rolling moment**
  - "Favorable yaw" aids the turn command
  - "Adverse yaw" opposes it
- **Equilibrium response to constant aileron input**

$$\frac{\Delta\phi_S}{\Delta\delta A_S} = \frac{\left(N_\beta + N_r \frac{Y_\beta}{V_N}\right) L_{\delta A} - \left(L_\beta + L_r \frac{Y_\beta}{V_N}\right) N_{\delta A}}{\frac{g}{V_N}\left(L_\beta N_r - L_r N_\beta\right)}$$

- **Large-enough $N_{\delta A}$ effect can reverse the sign of the response**
  - Can occur at high angle of attack
  - Can cause "departure from controlled flight"
- **Lateral Control Divergence Parameter provides simplified criterion**

$$\frac{\left(N_\beta\right) L_{\delta A} - \left(L_\beta\right) N_{\delta A}}{L_{\delta A}} = N_\beta - \frac{N_{\delta A}}{L_{\delta A}} L_\beta$$

$$LCDP \equiv C_{n_\beta} - \frac{C_{n_{\delta A}}}{C_{l_{\delta A}}} C_{l_\beta}$$

ω_φ/ω_d Effect

- **Aileron-to-roll-angle transfer function**

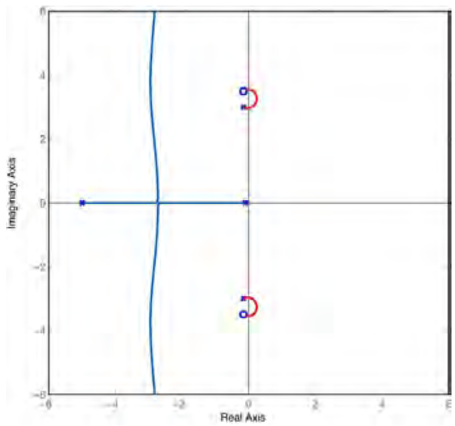
$$\frac{\Delta\phi(s)}{\Delta\delta A(s)} = \frac{k_\phi\left(s^2 + 2\zeta_\phi\omega_\phi s + \omega_\phi^2\right)}{\left(s-\lambda_S\right)\left(s-\lambda_R\right)\left(s^2 + 2\zeta_{DR}\omega_{n_{DR}} s + \omega_{n_{DR}}^2\right)}$$

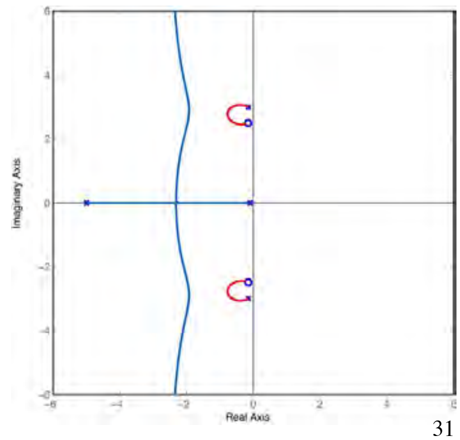
  - ω_φ is the "natural frequency" of the complex zeros
  - $\omega_d = \omega_{nDR}$ is the natural frequency of the Dutch roll mode
- **Conditional instability may occur with closed-loop control of roll angle, even with a perfect pilot**

ω_φ/ω_d Effect is Important in Roll Angle Control

$$\frac{\Delta\phi(s)}{\Delta\delta A(s)}=\frac{k_\phi\left(s^2+2\zeta_\phi\omega_\phi s+\omega_\phi^2\right)}{\left(s-\lambda_S\right)\left(s-\lambda_R\right)\left(s^2+2\zeta_{DR}\omega_{n_{DR}}s+\omega_{n_{DR}}^2\right)}$$

- As feedback gain increases, Dutch roll roots go to numerator zeros
- If zeros are over poles, conditional instability results





φ/β Effect

- φ/β measures the degree of rolling response in the Dutch roll mode
  – Large φ/β: Dutch roll is primarily a rolling motion
  – Small φ/β: Dutch roll is primarily a yawing motion
- Eigenvectors, $\mathbf{e}_i$, indicate the degree of participation of the state component in the i^{th} mode of motion

$$\det\left(s\mathbf{I}-\mathbf{F}\right)=\left(s-\lambda_1\right)\left(s-\lambda_2\right)\ldots\left(s-\lambda_n\right)$$
$$\left(\lambda_i\mathbf{I}-\mathbf{F}\right)\mathbf{e}_i=\mathbf{0}$$

Eigenvectors

- Eigenvectors, $\mathbf{e}_i$, are solutions to the equation

$$\boxed{\begin{aligned}&(\lambda_i \mathbf{I} - \mathbf{F})\mathbf{e}_i = \mathbf{0}, \quad i = 1,n \\ &or \\ &\lambda_i \mathbf{e}_i = \mathbf{F}\mathbf{e}_i, \quad i = 1,n\end{aligned}}$$

- For each eigenvalue, the corresponding eigenvector can be found (within an arbitrary constant) from

$$\boxed{Adj(\lambda_i \mathbf{I} - \mathbf{F}) = \begin{pmatrix} a_1\mathbf{e}_i & a_2\mathbf{e}_i & \ldots & a_n\mathbf{e}_i \end{pmatrix}, \quad i = 1,n}$$

MATLAB

$(\mathbf{V},\mathbf{D}) = eig(\mathbf{F})$

V: Modal Matrix (i.e., Matrix of Eigenvectors)

D: Diagonal Matrix of Corresponding Eigenvalues

φ/β Effect

- With λ_i chosen as a complex root of the Dutch roll mode, the corresponding eigenvector is

$$\mathbf{e}_{DR+} = \begin{bmatrix} e_r \\ e_\beta \\ e_p \\ e_\phi \end{bmatrix}_{DR+} = \begin{bmatrix} (\sigma + j\omega)_r \\ (\sigma + j\omega)_\beta \\ (\sigma + j\omega)_p \\ (\sigma + j\omega)_\phi \end{bmatrix}_{DR+} = \begin{bmatrix} (AR\, e^{j\phi})_r \\ (AR\, e^{j\phi})_\beta \\ (AR\, e^{j\phi})_p \\ (AR\, e^{j\phi})_\phi \end{bmatrix}_{DR+}$$

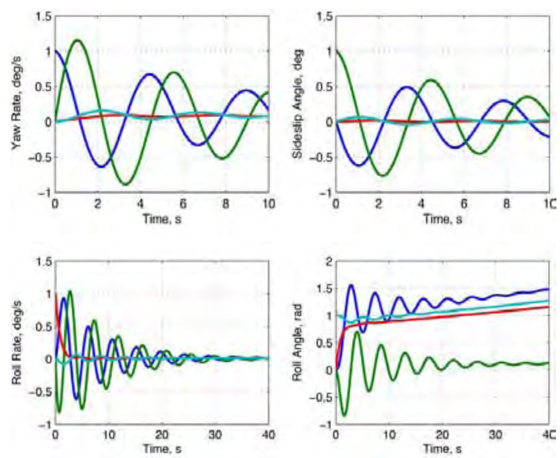
- φ/β is the magnitude of the ratio of the φ and β eigenvectors

$$\boxed{\phi/\beta = \left| \frac{(AR)_\phi}{(AR)_\beta} \right| = \left(\frac{V_N}{g}\right) \left[\left(\zeta_{DR}\omega_{n_{DR}} + \frac{Y_\beta}{V_N} + \frac{L_\beta}{L_r} \right)^2 + \left(\omega_{n_{DR}} \sqrt{1 - \zeta_{DR}^2} \right) \right]^{1/2}}$$

φ/β Effect for the Business Jet Example

$$\mathbf{e}_{DR+} = \begin{bmatrix} |e_r| \\ |e_\beta| \\ |e_p| \\ |e_\phi| \end{bmatrix}_{DR+} = \begin{bmatrix} 0.525 \\ \boxed{0.416} \\ 0.603 \\ \boxed{0.433} \end{bmatrix}_{DR+}$$

$$\boxed{\phi \big/ \beta = 1.04}$$



Roll/Sideslip Angle ratio in the Dutch roll mode

Criteria for Lateral-Directional Modes (MIL-F-8785C)

Maximum Roll-Mode Time Constant

TABLE VII. Maximum roll-mode time constant, seconds.

Flight Phase Category	Class	Level 1	Level 2	Level 3
A	I, IV	1.0	1.4	
	II, III	1.4	3.0	
B	All	1.4	3.0	10
C	I, II-C, IV	1.0	1.4	
	II-L, III	1.4	3.0	

Minimum Spiral-Mode Time to Double

TABLE VIII. Spiral stability - minimum time to double amplitude.

Flight Phase Category	Level 1	Level 2	Level 3
A & C	12 sec	8 sec	4 sec
B	20 sec	8 sec	4 sec

Minimum Dutch Roll Natural Frequency and Damping (MIL-F-8785C)

TABLE VI. Minimum Dutch roll frequency and damping.

Flight Phase Level	Category	Class	Min ζ_d *	Min $\zeta_d \omega_{n_d}$ * rad/sec.	Min ω_{n_d} rad/sec.
1	A (CO and GA)	IV	0.4	-	1.0
	A	I, IV	0.19	0.35	1.0
		II, III	0.19	0.35	0.4**
	B	All	0.08	0.15	0.4**
	C	I, II-C, IV	0.08	0.15	1.0
		II-L, III	0.08	0.10	0.4**
2	All	All	0.02	0.05	0.4**
3	All	All	0	-	0.4**

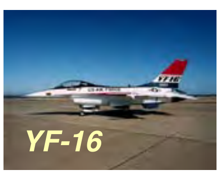
* The governing damping requirement is that yielding the larger value of ζ_d, except that a ζ_d of 0.7 is the maximum required for Class III.

** Class III airplanes may be excepted from the minimum ω_{n_d} requirement, subject to approval by the procuring activity, if the requirements of 3.3.2 through 3.3.2.4.1, 3.3.5 and 3.3.9.4 are met.

Pilot-Vehicle Interactions

YF-16 Test Flight Zero

- High-speed taxi test; no flight intended
- *Pilot-induced oscillations* from overly sensitive roll control
- Tail strike
- Pilot elected to go around rather than eject

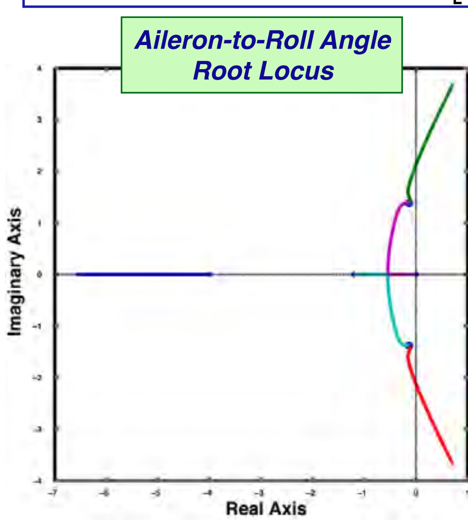


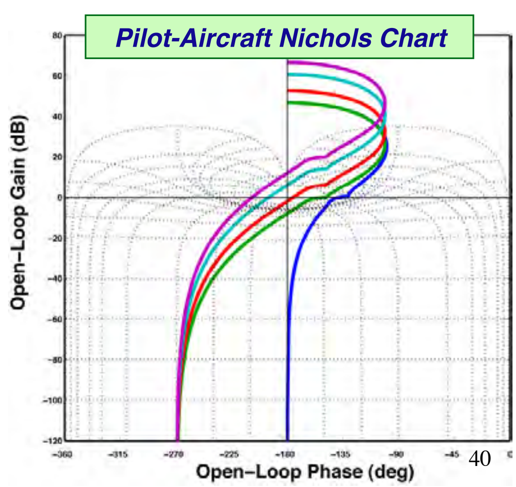
Pilot-Induced Roll Oscillation

Pilot Transfer Function

Aircraft Transfer Function

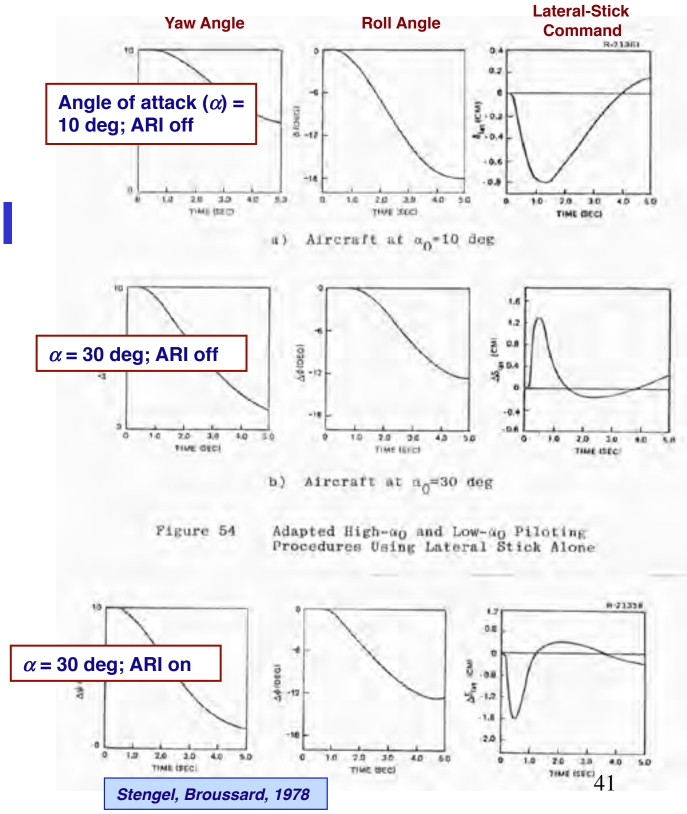
$$\left.\frac{\Delta\phi(s)}{\Delta\delta A(s)}\right|_{\text{pilot in loop}} = \left(\frac{K_p / T_p}{s + 1/T_p}\right)\left[\frac{k_\phi\left(s^2 + 2\zeta_\phi\omega_\phi s + \omega_\phi^2\right)}{\left(s-\lambda_S\right)\left(s-\lambda_R\right)\left(s^2 + 2\zeta_{DR}\omega_{n_{DR}} s + \omega_{n_{DR}}^2\right)}\right]$$





Inverse Problem of Lateral Control

- Given a flight path, what is the control history that generates it?
  - Necessary piloting actions
  - Control-law design
- Aileron-rudder interconnect (ARI) simplifies pilot input



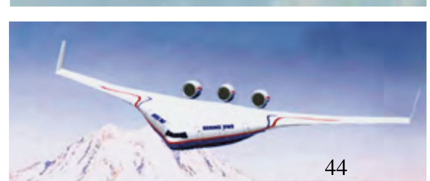
Next Time: Maneuvering at High Angles and Rates

Flight Dynamics
681-785
Airplane Stability and Control
Chapter 8

Supplemental Material

Large Aircraft Flying Qualities

- High wing loading, W/S
- Distance from pilot to rotational center
- Slosh susceptibility of large tanks
- High wing span -> short relative tail length
  - Higher trim drag
  - Increased yaw due to roll, need for rudder coordination
  - Reduced rudder effect
- Altitude response during approach
  - Increased non-minimum-phase delay in response to elevator
  - Potential improvement from canard
- Longitudinal dynamics
  - Phugoid/short-period resonance
- Rolling response (e.g., time to bank)
- Reduced static stability
- Off-axis passenger comfort in BWB turns



Criteria for Oscillations and Excursions

(MIL-F-8785C)

3.3.2.2 Roll rate oscillations. Following a yaw-control-free step roll control command, the roll rate at the first minimum following the first peak shall be of the same sign and not less than the following percentage of the roll rate at the first peak:

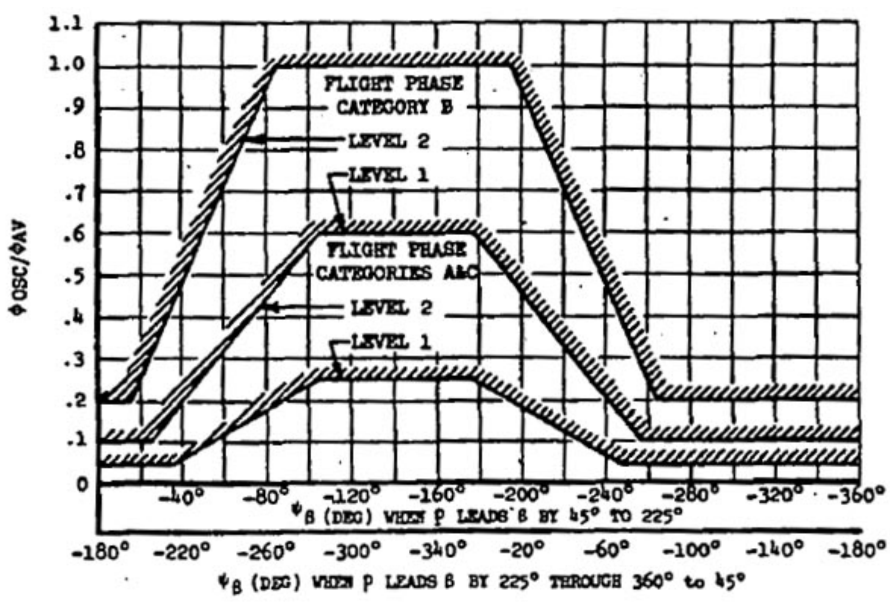
Level	Flight Phase Category	Percent
1	A & C	60
	B	25
2	A & C	25
	B	0

3.3.2.4 Sideslip excursions. Following a yaw-control-free step roll control command, the ratio of the sideslip increment, $\Delta\beta$, to the parameter k (6.2.6) shall be less than the values specified herein. The roll command shall be held fixed until the bank angle has changed at least 90 degrees.

Level	Flight Phase Category	Adverse Sideslip (Right roll command causes right sideslip	Proverse Sideslip (Right roll command causes left sideslip
1	A	6 degrees	2 degrees
	B & C	10 degrees	3 degrees
2	All	15 degrees	4 degrees

Criteria for Oscillations and Excursions

(MIL-F-8785C)



Flight Testing Videos

TSR2 Test Flight

http://www.youtube.com/watch?v=GXdJxjvQZW4

Neil Armstrong, Test Pilot

http://www.youtube.com/watch?v=t6DdlPoPOE4

NASA Dryden(now Armstrong) Flight Research Center

http://www.youtube.com/watch?v=j85jlc1Zfk4

Avro Arrow Revisited

https://www.youtube.com/watch?v=S74zf0YZX20