University of BRISTOL

HANDLING QUALITIES

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Bristol and Gloucestershire Gliding Club

Tug Aircraft: 141hp EuroFox 2K

Handling Qualities

Airbus A350-1000

https://www.britishairways.com

Flight Dynamics Principles – Book References

- Chapter 5: The Solution of the Equations of Motion
  - *Section 5.1 – Methods of solution*
  - *Section 5.6 – The state space method*
  - *Section 5.7 – State space model augmentation*
- Chapter 6: Longitudinal Dynamics
  - *Section 6.1 – Response to controls*
  - *Section 6.2 – The dynamic stability modes*
  - *Section 6.5 – Flying and handling qualities*
  - *Section 6.6 – Mode excitation*
- Chapter 7: Lateral-Directional Dynamics
  - *Section 7.1 – Response to controls*
  - *Section 7.2 – The dynamic stability modes*
  - *Section 7.5 – Flying and handling qualities*
  - *Section 7.6 – Mode excitation*

- *This session*

Note that references are suggested starting points. Other sections might also be helpful!

Flight Dynamics Principles: A Linear Systems Approach to Aircraft Stability and Control (Elsevier Aerospace Engineering) Hardcover – 9 Aug 2007

The story so far….

- Nonlinear equations of motion (FD01 – FD07)
- Trimming the aircraft, static & manoeuvre stability (FD08 – FD11)
    - Find the required control inputs to balance forces and moments
- Linearisation (FD12)
    - Numerical linearisation to form state-space model
- Find the eigenvalues and eigenvectors of the ***A*** matrix (FD11 – FD13)
    - These represent the dynamic modes of motion which describe the response of the aircraft
    - Assume for conventional aircraft that longitudinal and lateral-directional response is de-coupled
    - Five characteristic modes of motion, two longitudinal and three lateral-directional
- Aircraft flying and handling qualities (FD14)
- Flight test (FD15 – FD16)
- Control

Trimming & Linearisation

$$\dot{x} = f(x, \delta)$$

Numerical Trimming

e.g. Matlab 'trim' function

$\dot{x} = ?$ e.g. find the control inputs required for a specified trim condition

Simplify Analytically

Numerical Linearisation – e.g.

$$\begin{bmatrix} \dot{u} \\ \dot{w} \\ \dot{q} \\ \dot{\theta} \end{bmatrix} = \begin{bmatrix} -0.068 & -0.011 & -0.049 & -9.81 \\ 0.023 & -2.10 & 366.0 & 0 \\ 0.011 & -0.160 & -9.52 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} u \\ w \\ q \\ \theta \end{bmatrix} + \begin{bmatrix} -0.41 \\ -77.0 \\ -61.0 \\ 0 \end{bmatrix} \eta$$

Small Perturbation Equations – e.g.

$$\begin{bmatrix} ms - X_u & -X_w & mg - X_q s \\ -Z_u & ms - Z_w & -mUs - Z_q s \\ -M_u & -M_{\dot{w}} s - M_w & I_{yy} s^2 - M_q s \end{bmatrix} \begin{bmatrix} u \\ w \\ \theta \end{bmatrix} = \begin{bmatrix} X_\eta & X_\delta \\ Z_\eta & Z_\delta \\ M_\eta & M_\delta \end{bmatrix} \begin{bmatrix} \eta \\ \delta \end{bmatrix} - w_g \begin{bmatrix} X_w \\ Z_w \\ M_w \end{bmatrix}$$

Analysis of Aircraft Modes and Handling Qualities

e.g. Eigenvalues & Eigenvectors

- Aircraft Modes – Longitudinal
  - Phugoid & Short-period
- Aircraft Modes – Lateral-directional
  - Roll Subsidence, Dutch Roll and Spiral

- Douglas DC-8 Aircraft

$$[\cancel{U}, V, \cancel{W}, p, \cancel{q}, r, \phi, \cancel{\theta}, \cancel{\psi}, \cancel{x_E}, \cancel{y_E}, \cancel{z_E}]$$

$$\boxed{\begin{bmatrix} \dot{v} \\ \dot{p} \\ \dot{r} \\ \dot{\phi} \end{bmatrix}} = \boxed{\begin{bmatrix} -0.1008 & 0 & -468.2 & 32.2 \\ -0.00579 & -1.232 & 0.397 & 0 \\ 0.00278 & -0.0346 & -0.257 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}} \boxed{\begin{bmatrix} v \\ p \\ r \\ \phi \end{bmatrix}}$$

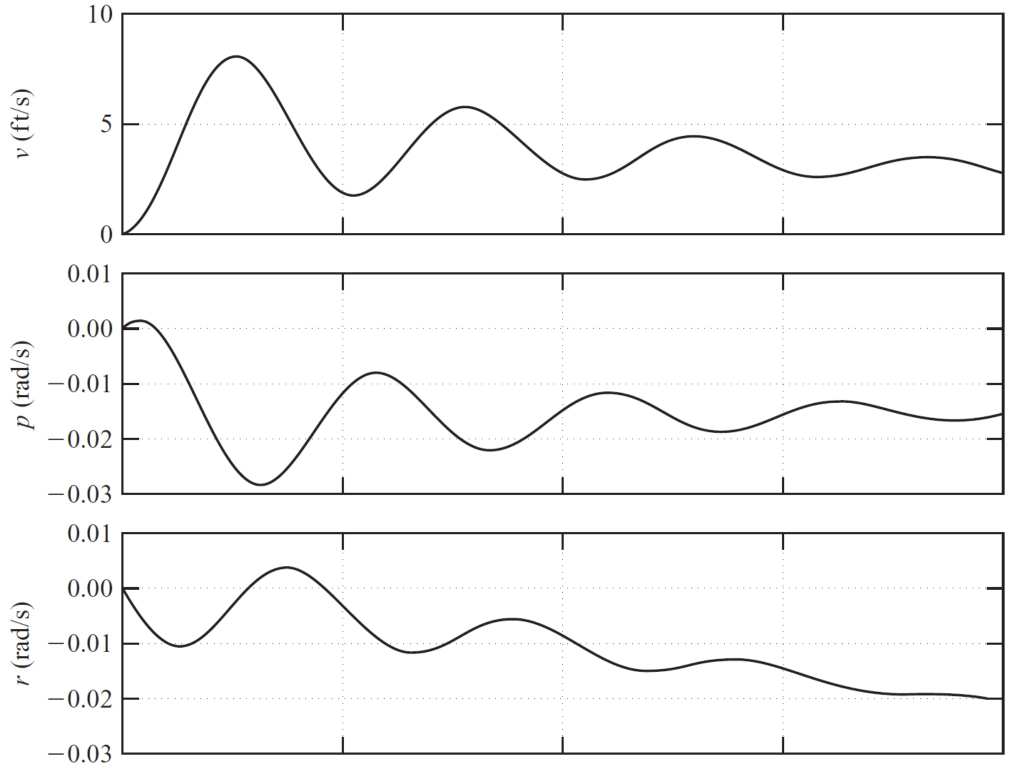
$$+ \begin{bmatrix} 0 & 13.48416 \\ -1.62 & 0.392 \\ -0.01875 & -0.864 \\ 0 & 0 \end{bmatrix} \boxed{\begin{bmatrix} \xi \\ \zeta \end{bmatrix}}$$

Wikipedia

Cook, M.V. Flight Dynamics Principles

- # Douglas DC-8 Aircraft

Cook, M.V. Flight Dynamics Principles. Arnold, London, 2012.



Aircraft response to 1° rudder step input.

Wikipedia

Cook, M.V. Flight Dynamics Principles

- ## Douglas DC-8 Aircraft

```
>> damp(DC8)
```

Pole	Damping	Frequency (rad/TimeUnit)	Time Constant (TimeUnit)
-1.27e-01 + 1.19e+00i	1.06e-01	1.20e+00	7.87e+00
-1.27e-01 - 1.19e+00i	1.06e-01	1.20e+00	7.87e+00
-1.33e+00	1.00e+00	1.33e+00	7.52e-01
-6.49e-03	1.00e+00	6.49e-03	1.54e+02

The first real root describes the *spiral mode* with time constant

$$T_s = \frac{1}{0.0065} \cong 154\,\mathrm{s}$$

the second real root describes the *roll subsidence mode* with time constant

$$T_r = \frac{1}{1.329} = 0.75\,\mathrm{s}$$

and the pair of complex roots describe the oscillatory *dutch roll mode* with characteristics

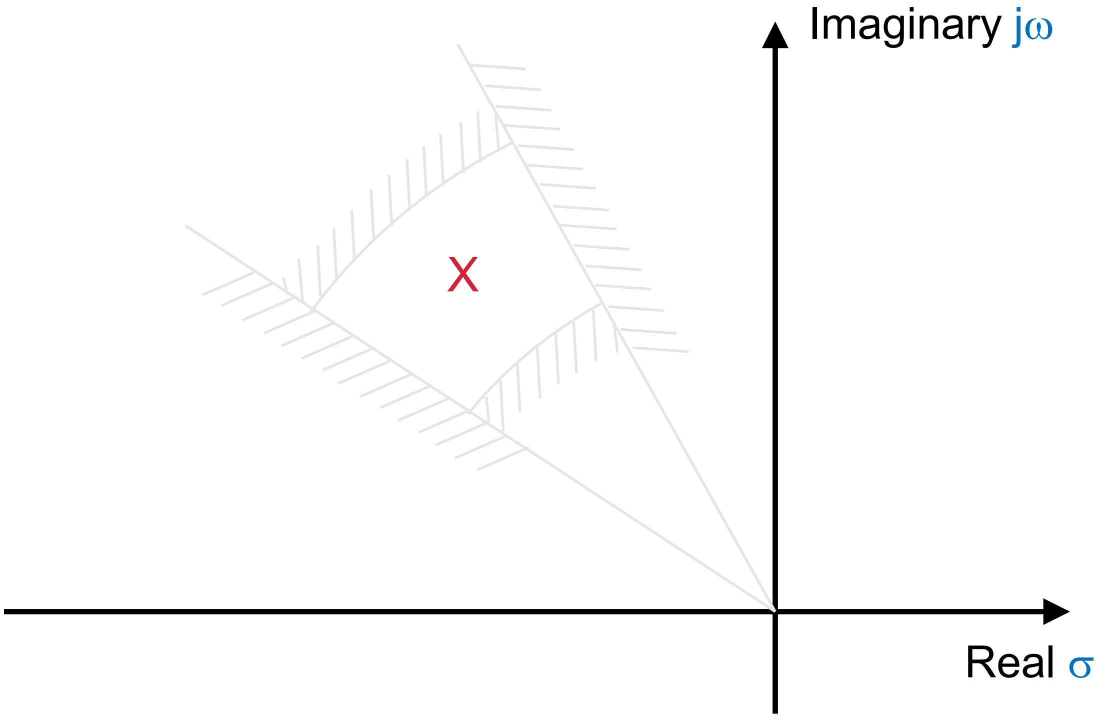
$$\text{Damping ratio } \zeta_d = 0.11$$

$$\text{Undamped natural frequency } \omega_d = 1.2\,\mathrm{rad/s}$$

Wikipedia

Cook, M.V. Flight Dynamics Principles

Desired region?



Flying and Handling Qualities

- The pilot's judgement of the flying qualities of an aircraft is based on the feel of the stick (and rudder pedals) and on the aircraft's response to commands like these. Ideally, the aircraft should feel the same throughout the flight envelope.

- There are established criteria for assessment of handling qualities, longitudinal and lateral, derived from tests using *variable-stability aircraft* and *ground-based simulators*.

Flight Dynamics Principles
Michael V. Cook
Second Edition

sensory feedback information to the pilot. The author's interpretation distinguishes between *flying qualities* and *handling qualities* as indicated. The pilot's perception of flying qualities is considered to comprise a qualitative description of how well the aeroplane carries out the commanded task. On the other hand, the pilot's perception of handling qualities is considered a qualitative description of the adequacy of the short term dynamic response to controls in the execution of the flight task. The two *qualities* are therefore very much interdependent and in practice are probably inseparable. Thus to summarise, the flying qualities may be regarded as being task related, whereas the handling qualities may be regarded as being response related. When the

Flying and Handling Qualities

- There are many others which are less amenable to simple measurement:

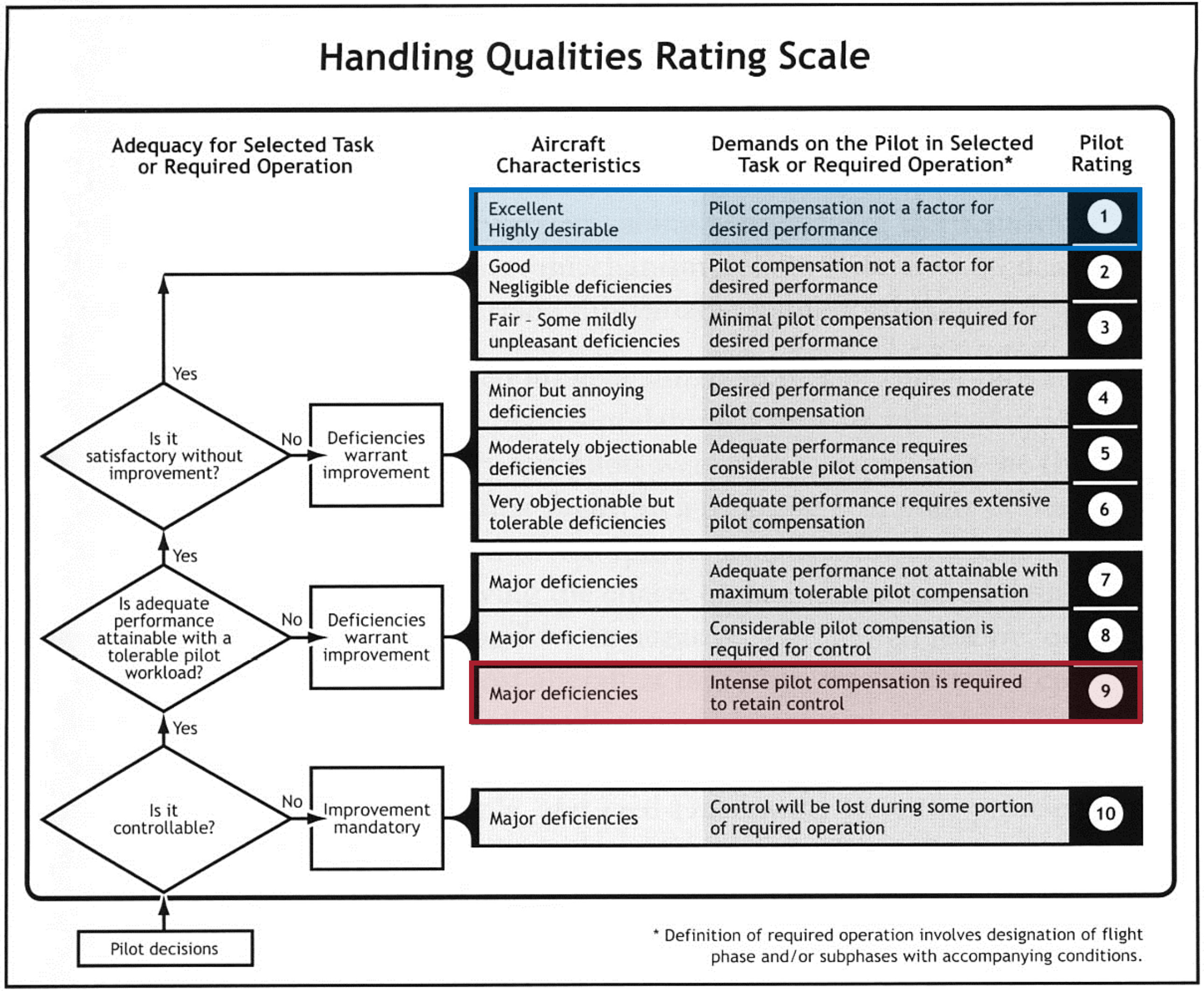
  - pilot's workload
  - pilot's view/visibility
  - control linearity
  - instrument layout
  - ride quality in gusts
  - response while flying at high α.

- Such studies of HQ are a large specialist field, and we look here at only one small range of HQ criteria - those for short period and phugoid roots.

The Cooper-Harper Rating Scheme

- The Cooper-Harper rating scale is a set of criteria used by test pilots and flight test engineers to evaluate the handling qualities of aircraft during flight tests.
- The scale ranges from 1 to 10, with 1 indicating the best handling characteristics and 10 the worst.
- Note: Pilot Opinion sometimes difficult to evaluate.

The Cooper-Harper Rating Scheme



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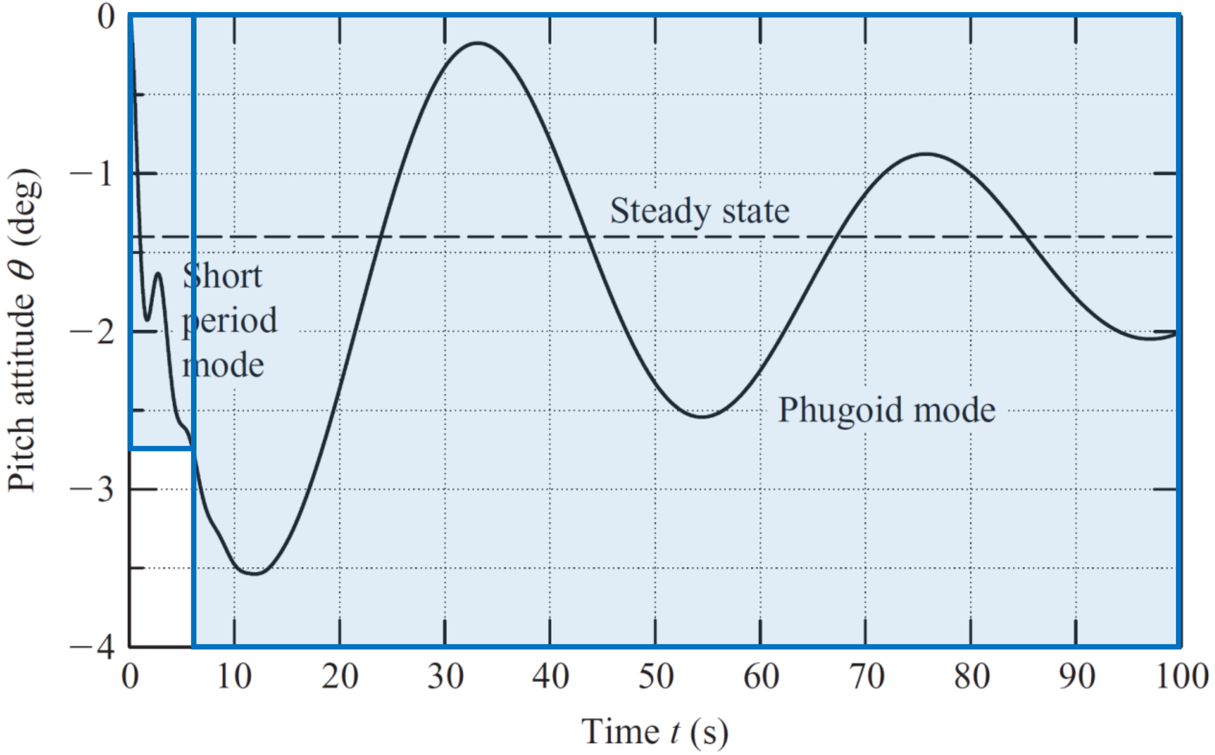

Pitch attitude response of the F-104 to a 1° step of elevator.

Short Period

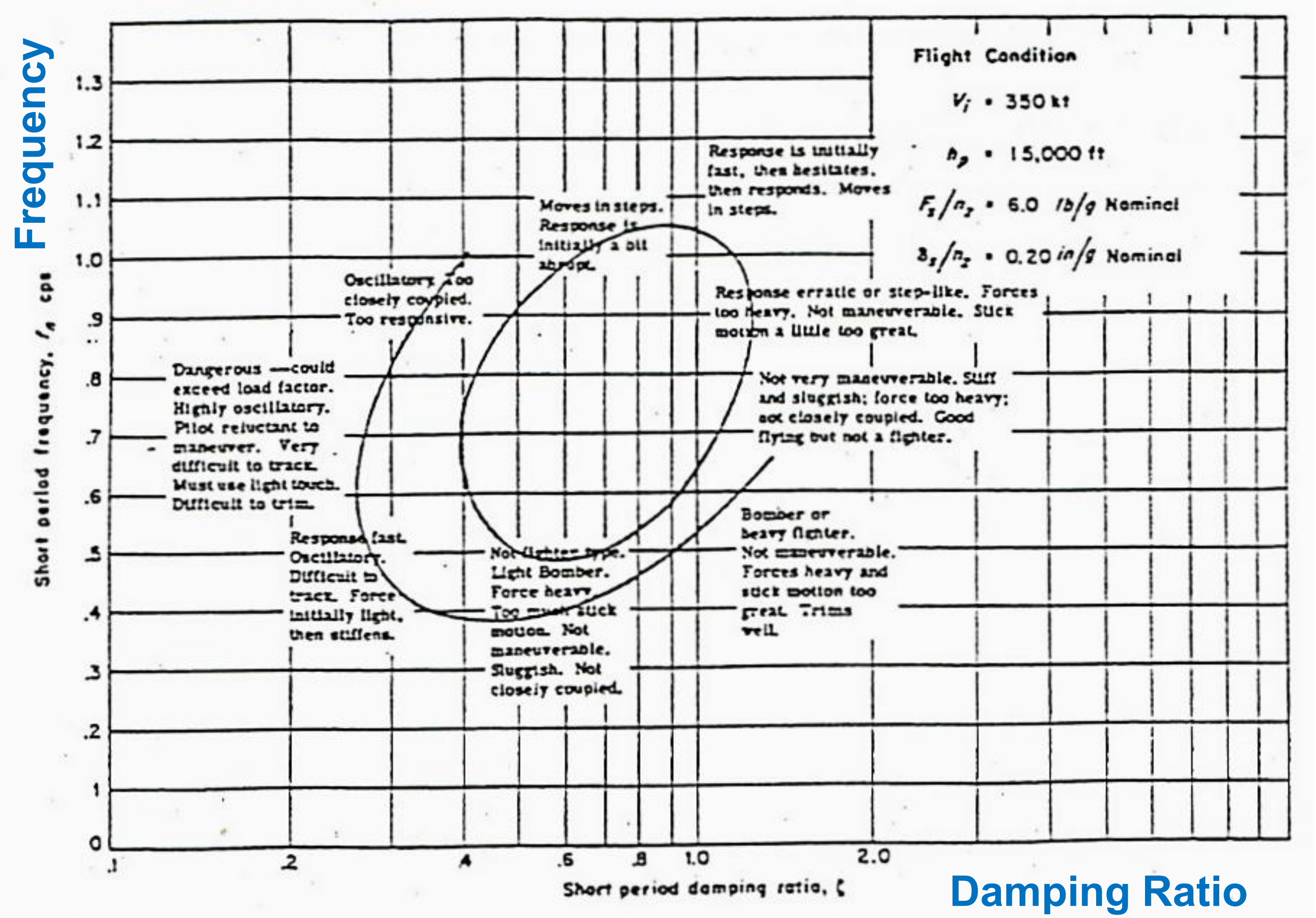

Fig. 4a Pilots' attitudes to dynamic response factors

Plot taken from Kolk, Prentice-Hall 1961, shows flight test results from late 1950's.

Desired HQ: $\zeta = 0.7$, $\omega_n = 0.5$ Hz

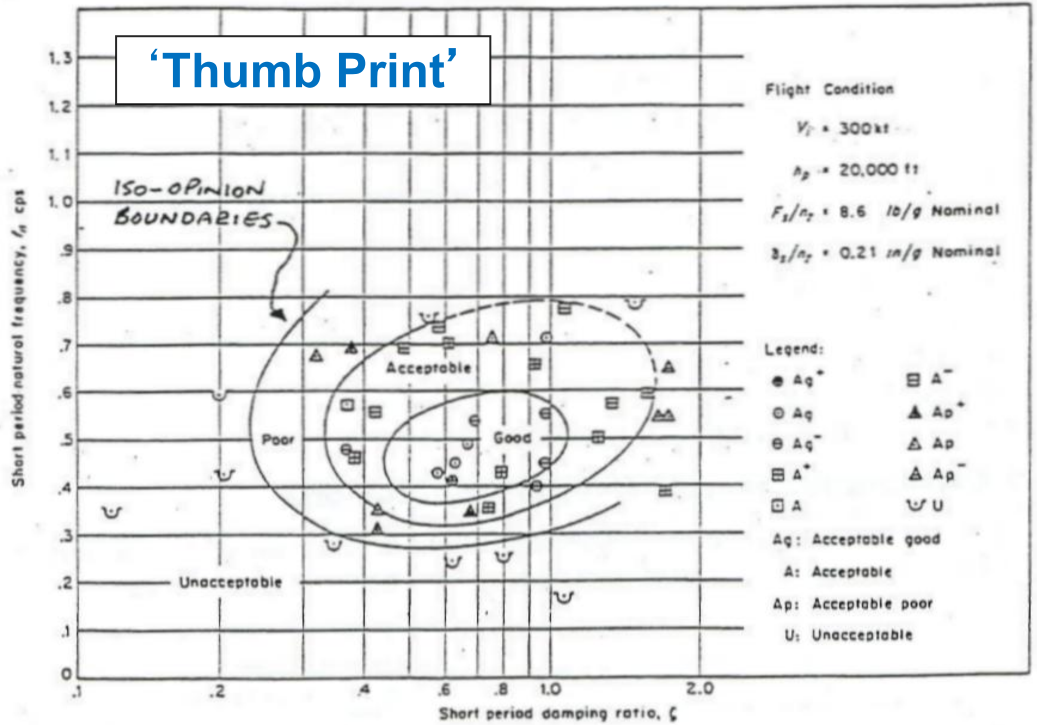

Fig. 4b The infuence of Short-Period roots on Handling Qualities

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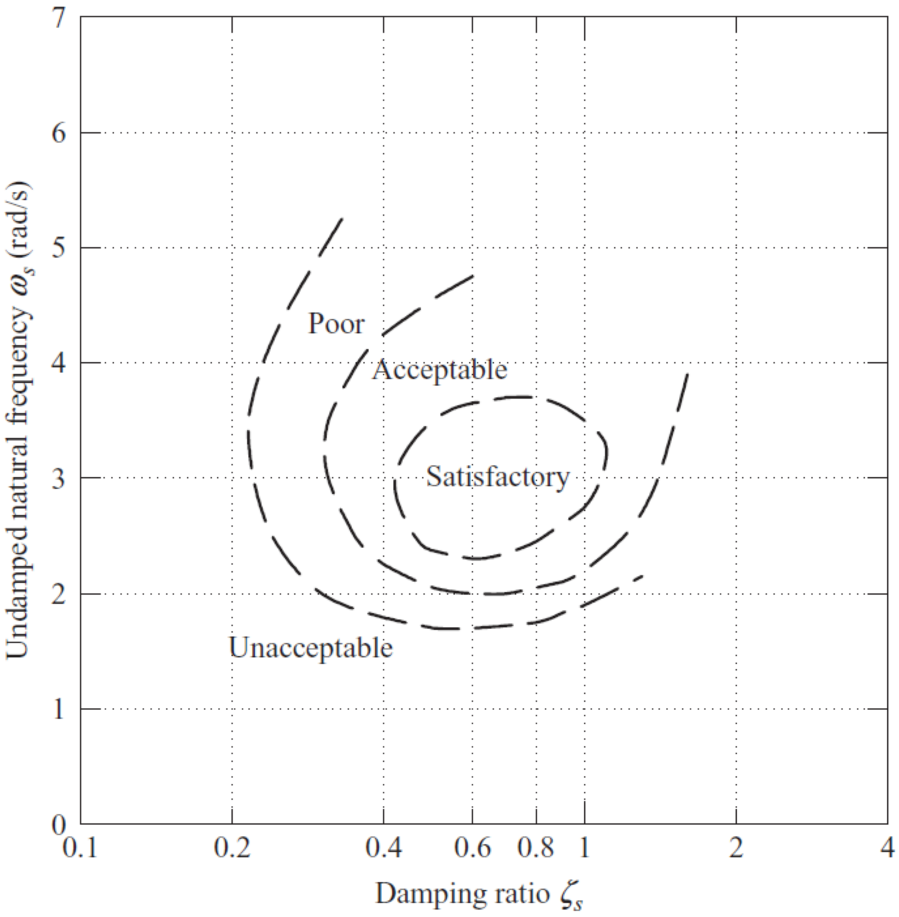
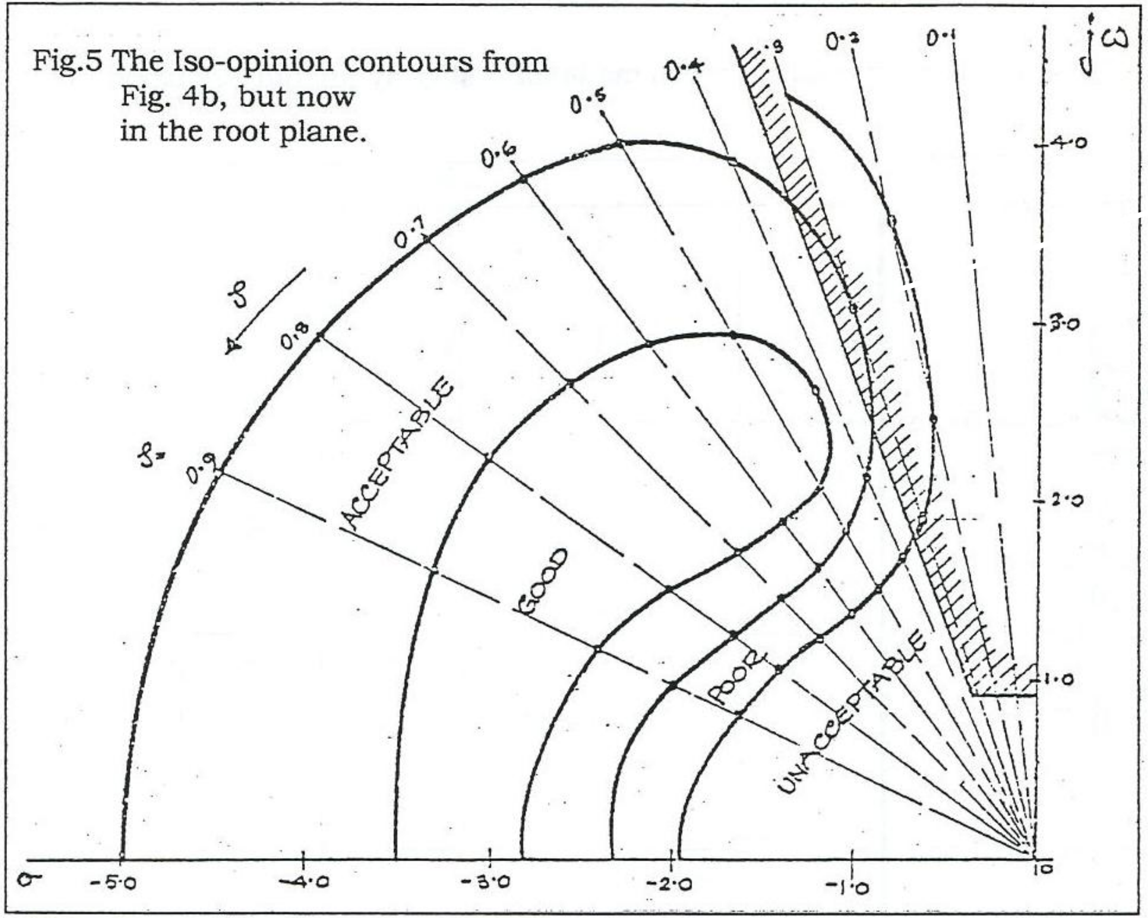


Longitudinal short period pilot opinion contours – the thumb print

Short Period Handling Qualities



Note the boundary defined by a constant damping ratio $\zeta = 0.35$ is marked (above a minimum frequency), as this is part of a U.S. Mil. Spec.

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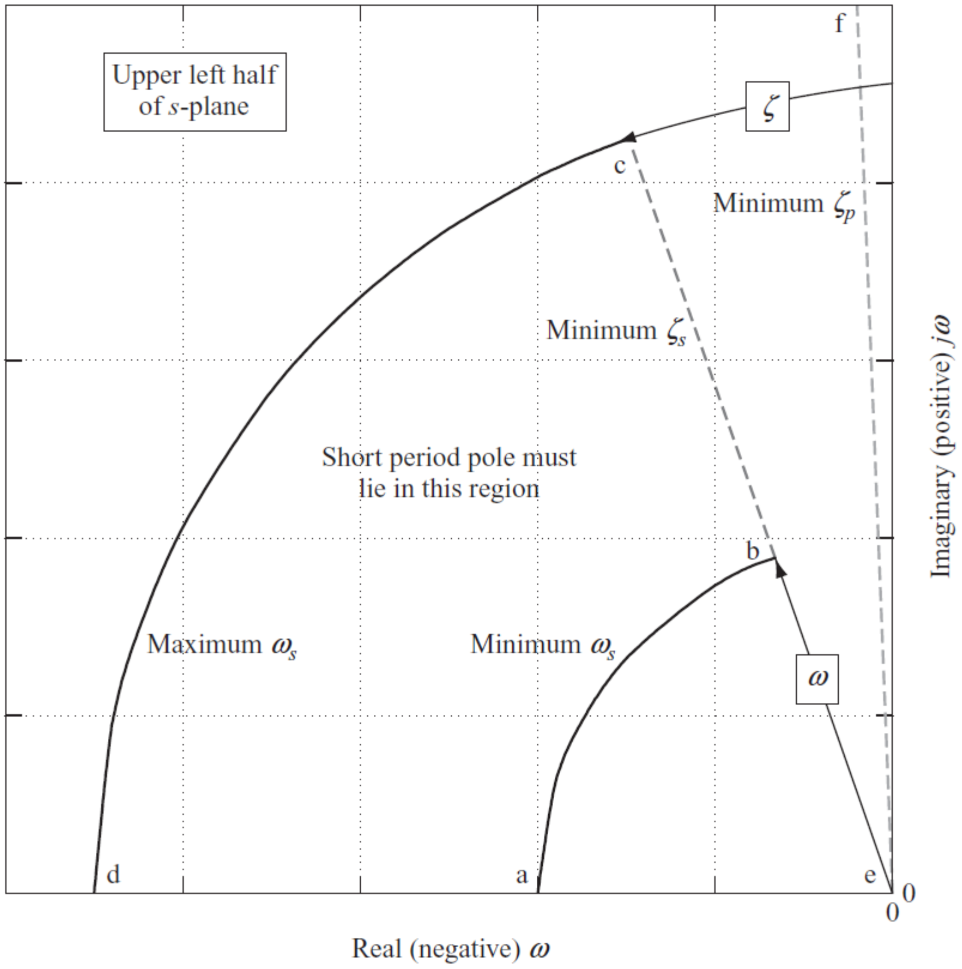

Longitudinal flying qualities requirements on the s-plane.

Phugoid Handling Qualities

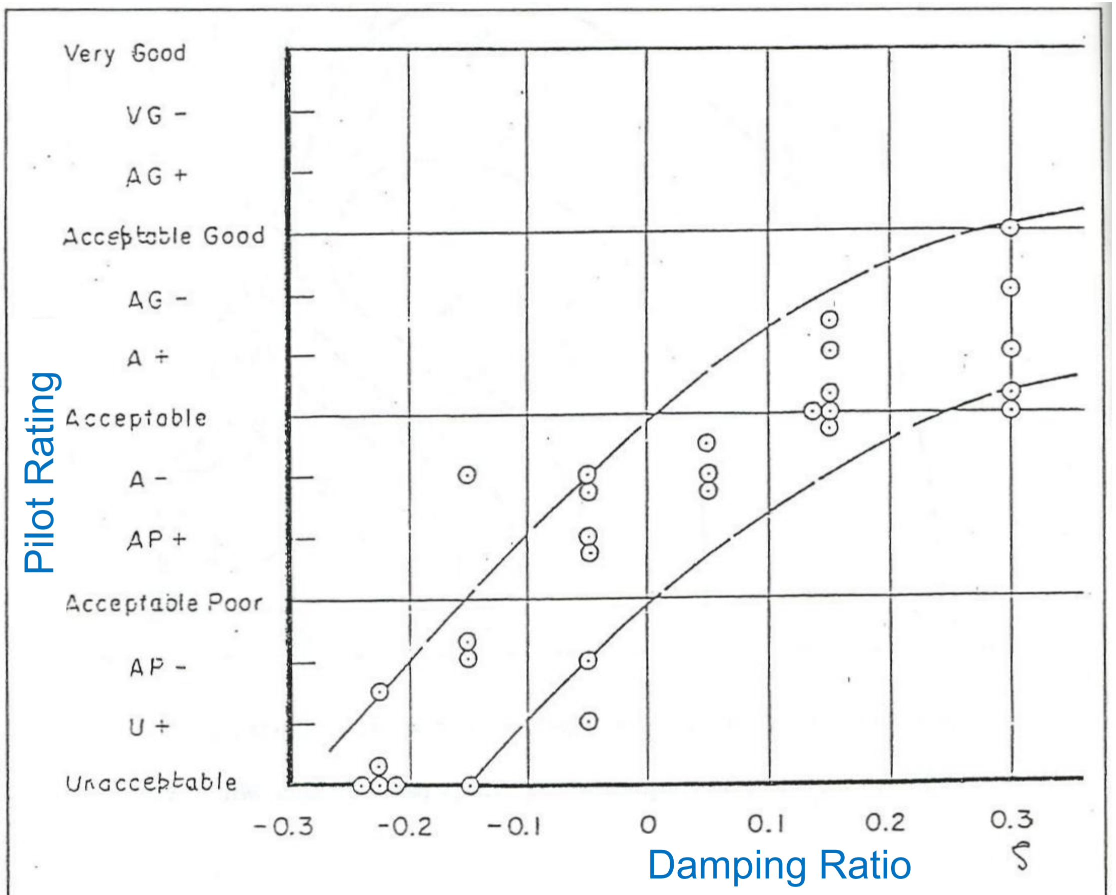

Fig. 6 The influence of Phugoid Roots on pilot opinion

- More difficult to quantify
- Generally pilot rating improves with phugoid damping
- Small negative damping of the phugoid is tolerable

10.4.1 Aircraft classification

Aeroplane types are classified broadly according to size and weight as follows:

Class I	Small light aeroplanes.
Class II	Medium weight, low to medium manoeuvrability aeroplanes.
Class III	Large, heavy, low to medium manoeuvrability aeroplanes.
Class IV	High manoeuvrability aeroplanes.

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10.4.2 Flight phase

A sortie or mission may be completely defined as a sequence of piloting tasks. Alternatively, a mission may be described as a succession of flight phases. Flight phases are grouped into three *categories* and each category comprises a variety of tasks requiring similar flying qualities for their successful execution. The tasks are separately defined in terms of *flight envelopes*. The flight phase categories are defined:

Category A	Non-terminal flight phases that require rapid manoeuvring, precision tracking, or precise flight path control.
Category B	Non-terminal flight phases that require gradual manoeuvring, less precise tracking and accurate flight path control.
Category C	Terminal flight phases that require gradual manoeuvring and precision flight path control.

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Level 1 Flying qualities clearly adequate for the mission flight phase.

Level 2 Flying qualities adequate to accomplish the mission flight phase, but with an increase in pilot workload and, or, degradation in mission effectiveness.

Level 3 Degraded flying qualities, but such that the aeroplane can be controlled, inadequate mission effectiveness and high, or, limiting, pilot workload.

Level 1 flying qualities implies a fully functional aeroplane which is 100% capable of achieving its mission with acceptable pilot workload at all times. Therefore, it follows that any fault or failure occurring in airframe, engines or systems may well degrade the level of flying qualities. Consequently the *probability* of such a situation arising during a mission becomes an important issue. Thus the levels of flying qualities are very much dependent on the *aircraft failure state* which, in turn, is dependent on the reliability of the critical functional components of the aeroplane. The development of this aspect of flying qualities assessment is a subject in its own right and is beyond the scope of the present book.

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Table 10.4 *Short period mode damping*

	Level 1		Level 2		Level 3
Flight phase	ζ_s *min*	ζ_s *max*	ζ_s *min*	ζ_s *max*	ζ_s *min*
CAT A	0.35	1.30	0.25	2.00	0.10
CAT B	0.30	2.00	0.20	2.00	0.10
CAT C	0.50	1.30	0.35	2.00	0.25

Table 10.5 *Phugoid damping ratio*

Level of flying qualities	*Minimum* ζ_p
1	0.04
2	0
3	Unstable, period $T_p > 55$ s

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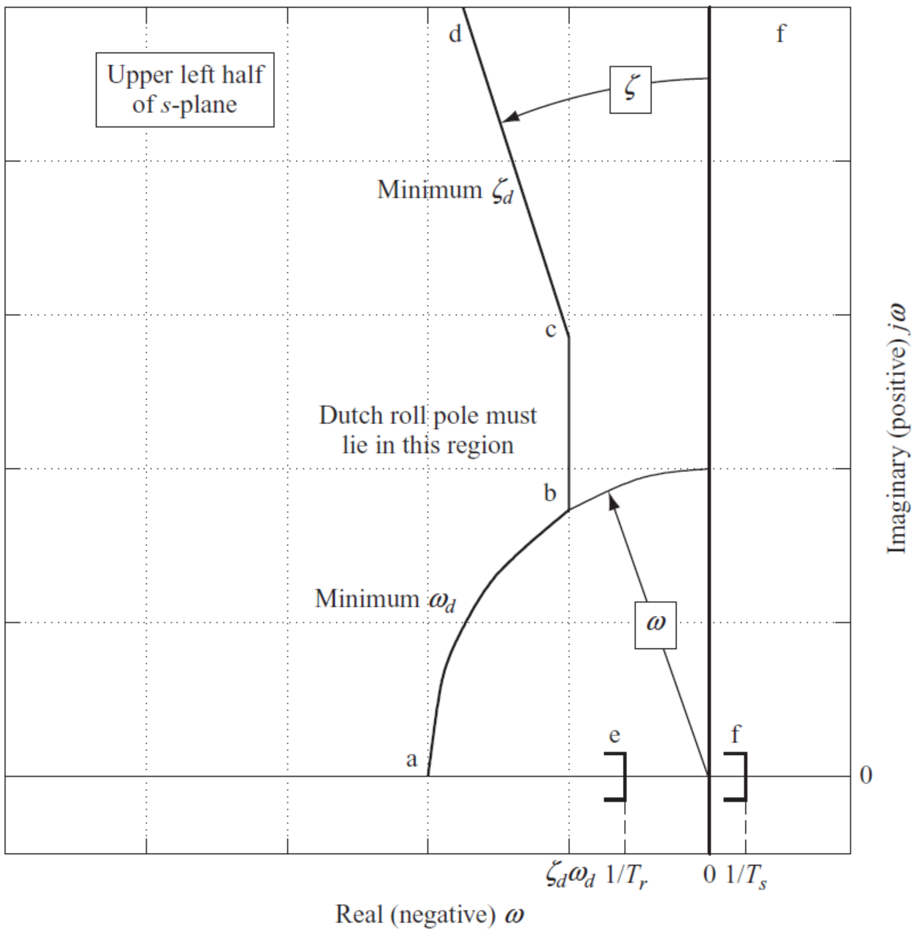

Lateral–directional flying qualities requirements on the s-plane.

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Table 10.6 *Roll subsidence mode time constant*

Aircraft class	Flight phase category	Maximum value of T_r (seconds) Level 1	Level 2	Level 3
I, IV	A, C	1.0	1.4	—
II, III	A, C	1.4	3.0	—
I, II, III, IV	B	1.4	3.0	—

Table 10.8 *Spiral mode time constant*

Flight phase category	*Minimum value of T_s (seconds)*		
	Level 1	*Level 2*	*Level 3*
A, C	17.3	11.5	7.2
B	28.9	11.5	7.2

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Table 10.9 *Dutch roll frequency and damping*

		Minimum values							
		Level 1			*Level 2*			*Level 3*	
Aircraft class	*Flight phase*	ζ_d	$\zeta_d\omega_d$	ω_d	ζ_d	$\zeta_d\omega_d$	ω_d	ζ_d	ω_d
I, IV	CAT A	0.19	0.35	1.0	0.02	0.05	0.5	0	0.4
II, III	CAT A	0.19	0.35	0.5	0.02	0.05	0.5	0	0.4
All	CAT B	0.08	0.15	0.5	0.02	0.05	0.5	0	0.4
I, IV	CAT C	0.08	0.15	1.0	0.02	0.05	0.5	0	0.4
II, III	CAT C	0.08	0.10	0.5	0.02	0.05	0.5	0	0.4

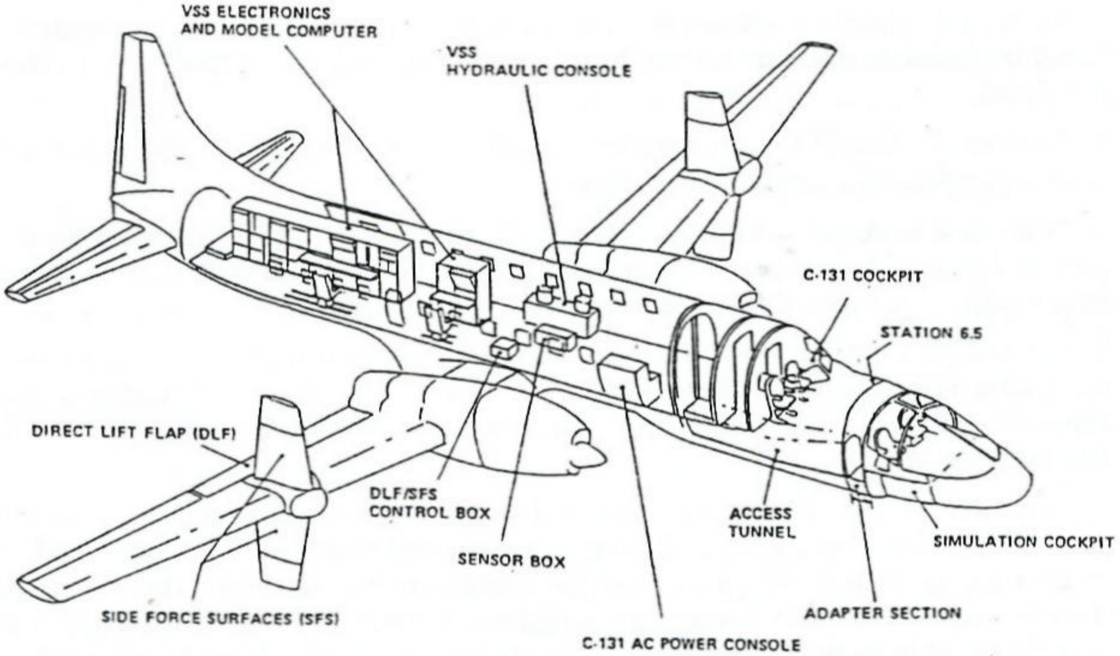
HANDLING QUALITIES REQUIREMENTS DOCUMENTS

- Main specification for handling qualities for most modern western military aircraft: US specification MIL-STD-8785C “Flying Qualities for Piloted Airplanes” produced in 1969.
- This remained in existence during the development of the F/A-18. Following problems with the F/A-18 much work was completed on revised criteria which resulted in the publication of MIL-STD-1797 “Flying Qualities of Piloted Vehicles” in 1987.
- This contained extensive guidelines but avoided precise numerical criteria in many key areas. It has since been reissued and it remains to be seen if important problems have finally been resolved especially in light of recent well publicised crashes of development aircraft.
- In the case of rotorcraft, Aeronautical Design Standard (ADS) 33C – Handling qualities for Military Helicopters (1989) is used.

- Note that there are many types of requirements/criteria, including in the *frequency domain* and in the *time domain*.

‘In Flight Simulator’

Computers force the real aircraft to follow a trajectory mapped out for a theoretical aircraft – e.g. Shuttle



TIFS : TOTAL IN-FLIGHT SIMULATOR.

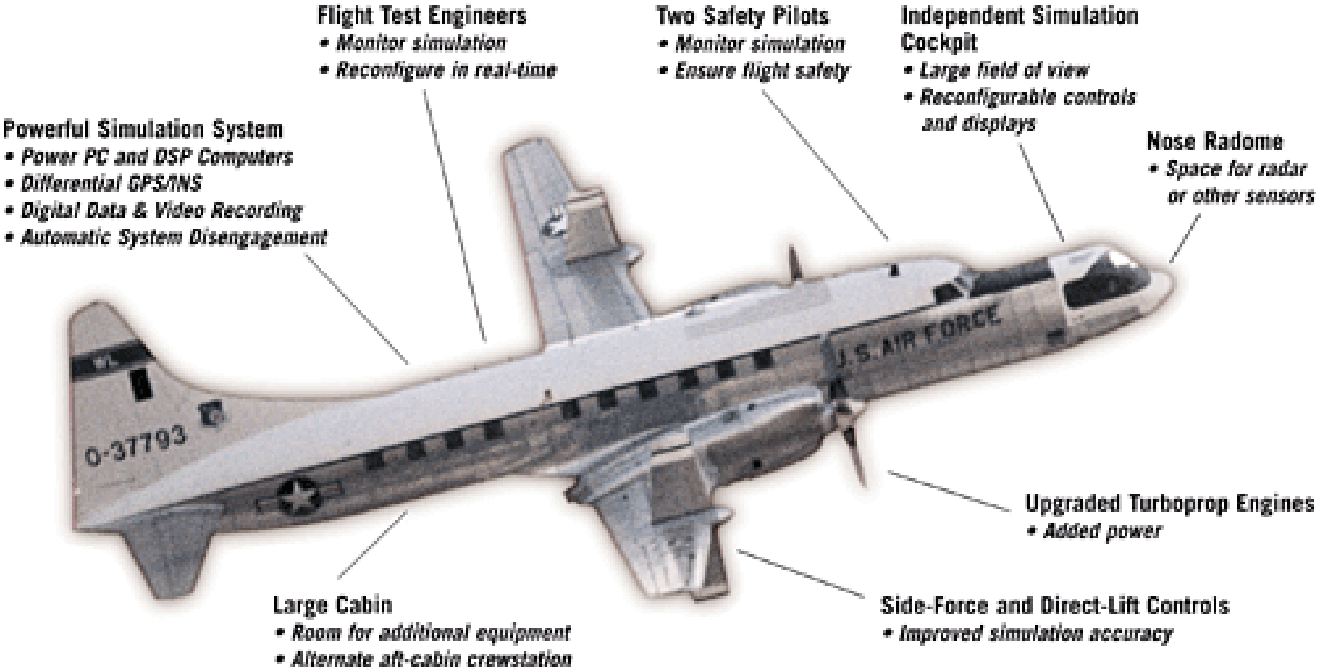
‘In Flight Simulator’

- The TIFS is the most capable in-flight simulator. It is operated by Calspan under a Cooperative Research and Development Agreement (CRADA) for the US Air Force Research Laboratory (AFRL).
- The TIFS is a highly modified Convair-580 (AF C-131) twin turboprop transport. Calspan finished the development of this IFS in 1970 and has operated it ever since on over 30 major aircraft development and research programs.
- The TIFS unique features include a separate two-place evaluation cockpit and control over all six rigid-body degrees-of-freedom.
- Special aerodynamic controls (including sideforce and direct lift surfaces) and a model-following control system permit the TIFS to produce motions at the simulation cockpit that completely duplicate the computed responses of the simulated aircraft.

TIFS - Reconfigurable Simulation Cockpit

The primary use has been in the development and evaluation of new aircraft flying qualities, flight controls, and cockpit displays, as well as general flight research in these areas.

‘In Flight Simulator’



Variable-Stability In-Flight Simulator Aircraft

Variable Stability Learjet 24

Variable Stability Learjet 25

Variable-Stability In-Flight Simulator Aircraft

- The Learjet Model 24 and 25 aircraft provide three degree-of-freedom (3-DOF) airborne simulation capabilities for advanced stability, control and flying qualities demonstrations and research. They are also used to test/demonstrate advanced flight control systems concepts.
- Learjet Model 24 first flew in its modified state in January of 1981.
- Learjet Model 25 began service in March of 1991.
- A third Learjet, Model 25, was purchased in 2005.

Variable-Stability In-Flight Simulator Test Aircraft

- The U.S. Air Force Test Pilot School Variable-Stability In-Flight Simulator Test Aircraft (VISTA) NF-16D
- It was delivered to the USAF in 1995. VISTA is used as a research and training tool by the USAF Test Pilot School and customers worldwide.
- VISTA's unique features include a front evaluation cockpit which allows the pilot to fly the aircraft through a separate simulation flight control computer which can be programmed to simulate the response characteristics of any aircraft.
- It has a five degree-of-freedom simulation system which reproduces the three rotational, and normal and axial force characteristics of the modelled aircraft.

Variable-Stability In-Flight Simulator Test Aircraft

Variable-Stability In-Flight Simulator Test Aircraft

‘VISTA flies over the Edwards Air Force Base, California, US. Credit: US Air Force, photo by Christian Turner/Defense Advanced Research Projects Agency.’

‘In addition to replacing the VISTA Simulation System (VSS) with a newer, upgraded version of the same system, a System for Autonomous Control of Simulation (SACS) will be added in order to operate X-62A as a Skyborg. One application is as autonomously piloted aircraft, perhaps as robotic wingman to a manned aircraft.’

https://en.wikipedia.org/wiki/General_Dynamics_X-62_VISTA

https://www.airforce-technology.com/news/darpa-vista-test-ai-software/


VAAC
QinetiQ
Active Control
Technology

Shuttle Training Aircraft

'To match the descent rate and drag profile of the real Shuttle at 37,000 feet (11,300 m), the main landing gear of the C-11A was lowered (the nose gear stayed retracted due to wind load constraints) and engine thrust was reversed. Its flaps could deflect upwards to decrease lift as well as downwards to increase lift.'

https://en.wikipedia.org/wiki/Shuttle_Training_Aircraft

Next Session
Flight Test

- ‘What's being called the world's largest aircraft, the 124.5-meter-long Pathfinder 1, took flight Tuesday morning over San Francisco's Golden Gate Bridge.’
- abc7news.com
- Tuesday, October 28, 2025

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ANY QUESTIONS

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