FLIGHT TEST

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https://www.x-plane.com/

Airbus A350-1000

https://www.britishairways.com

Introduction to Flight Test

1. Introduction
2. Performance
3. Static Stability
4. Dynamic Response
5. Conclusions

For accreditation by the Royal Aeronautical Society: '… the Society believes all students on accredited programmes in aerospace engineering and related topics should experience elements of practical flight test…'

What is Flight Testing?

Flight testing covers a spectrum of airborne data gathering activities from Research and Development flying through to verification and validation that an air vehicle and its systems are safe to operate and fit for purpose.

Note: this lecture is only an introduction to the topic…

https://www.aerosociety.com/

What do we want to know from Flight Test?

Can I control the aircraft?

Is the aircraft stable?

How far and high can I fly?

What is the dynamic response?

How does the response change with altitude / airspeed?

Etc.…

Flight Test: Further Reading

- https://apps.dtic.mil/sti/pdfs/ADA444990.pdf
- *‘Introduction to Flight Test Engineering’*

Flight test is at the core of what organizations must do in order to validate the operation and systems on an aircraft. …. this volume pulls it all together as an introduction to the process required to do effective flight test engineering.

- Published July 2005 / Copyright © RTO/NATO 2005
- This is the Introductory Volume to the Flight Test Techniques Series. It is a general introduction to the various activities and aspects of Flight Test Engineering that must be considered when planning, conducting, and reporting a flight test program. Its main intent is to provide a broad overview to the novice engineer or to other people who have a need to interface with specialists within the flight test community.
- 456 pages….

'Introduction to Flight Test Engineering' Chapters (loosely grouped):

1. Introduction
2. Historical Perspective, One Hundred Years of Flight Testing
3. Background Considerations
4. Establishing the Test Team
5. Logistics Support Considerations
6. Flight Test Instrumentation
7. Data Processing
8. Preparation of the Flight Test Plan
9. Pre-Flight Tests
10. Safety Aspects

'Introduction to Flight Test Engineering' Chapters (loosely grouped):

11. Airdata Measurement and Calibration
12. Flight Envelope & Rotorcraft Flight Envelope Unique Considerations
13. Performance
14. Aeroelasticity
15. Handling Qualities
16. Aircraft External Noise
17. Airframe Tests
18. Testing under Environmental Extremes
19. Radar Cross Section & Antenna Radiation Patterns
20. Human Factors

Primary Lecture Focus

'Introduction to Flight Test Engineering' Chapters (loosely grouped):

21. Avionics
22. Reliability and Maintainability
23. Logistics Test and Evaluation
24. Propulsion
25. Armament Testing and Stores Separation
26. Software Test and Evaluation
27. Electromagnetic Interference/Electromagnetic Compatibility
28. Post Flight Operations
29. Post-Test Operations
30. Future Trends


MACE: BVLOS, Kenya, 2025, 2-hour test flight

A3: Flight Test and Data Analysis

Assignment Question

Figure A3: X-Plane 12 Cessna 172

A3.1:
- Choice of aircraft is up to you.
- Some will be more predictable than others!
- Collecting good data can be challenging, instructions will be given in Week 7.
- Data collection can be done within a group, figures and assignments must be individual.
- Flight Simulators available from Monday.

Nominally 3-pages including figures

Weeks 7 & 8

A3.1: Figure A3 shows a Cessna 172 from X-Plane 12. Using the flight simulators located in M.003 (or otherwise), collect data for an aircraft of your choice. Using this data, you are to provide a short flight test report on your selected aircraft. Within this report you are to include data and discussion on the aircraft:

a. performance including range and endurance
b. control authority
c. static and dynamic stability

15 marks

PLEASE DO NOT ALTER THE
FLIGHT SIMULATOR SETTINGS!

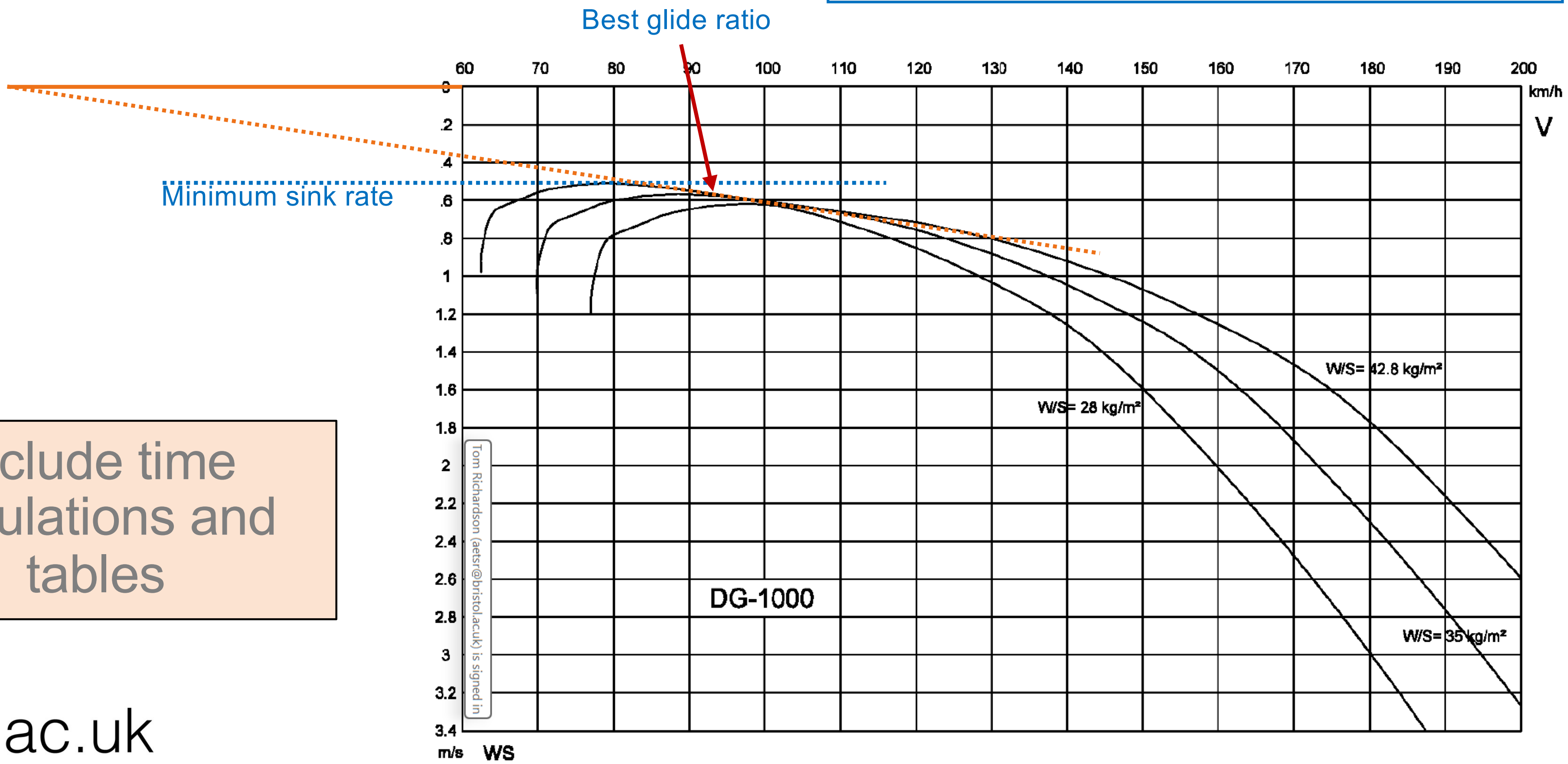
Aircraft Performance

Flight Test: Performance

- Minimum sink rate
- Best glide ratio
- Etc…

Flight manual DG-1000S

5.3.3 Flight polar with 20 m wing span



Include time simulations and tables

Flight Test: Performance

5.3.2 Gliding performance

Performance data with **20 m** span (S = 17,53 m²)

wing loading	kg/m²	28	35	42
minimum sink	m/s	0,51	0,56	0,62
at	V [km/h]	79	88	98
best glide ratio	/	45,9	46,3	46,6
at	V [km/h]	93	104	120

Performance data with **18 m** span (S = 16,72 m²)

wing loading	kg/m²	30	36	45
minimum sink	m/s	0,60	0,65	0,72
at	V [km/h]	84	90	100
best glide ratio	/	41,5	41,7	42
at	V [km/h]	100	110	123

With winglets on the 18 m wing tips (optional) the best glide ratio is increased by 0,5 points.

With **17,2 m** span (S = 16,30 m²) the best glide ratio decreases by 1,5 glide points, compared to 18 m span without winglets.

A variation in speed by ± 10 km/h (5 kts.) from the above will decrease the best glide angle by 0.5 glide points and increase the min. sink rate by 1 cm/sec. (2 ft/min).

The polar curves can be seen on the next page.

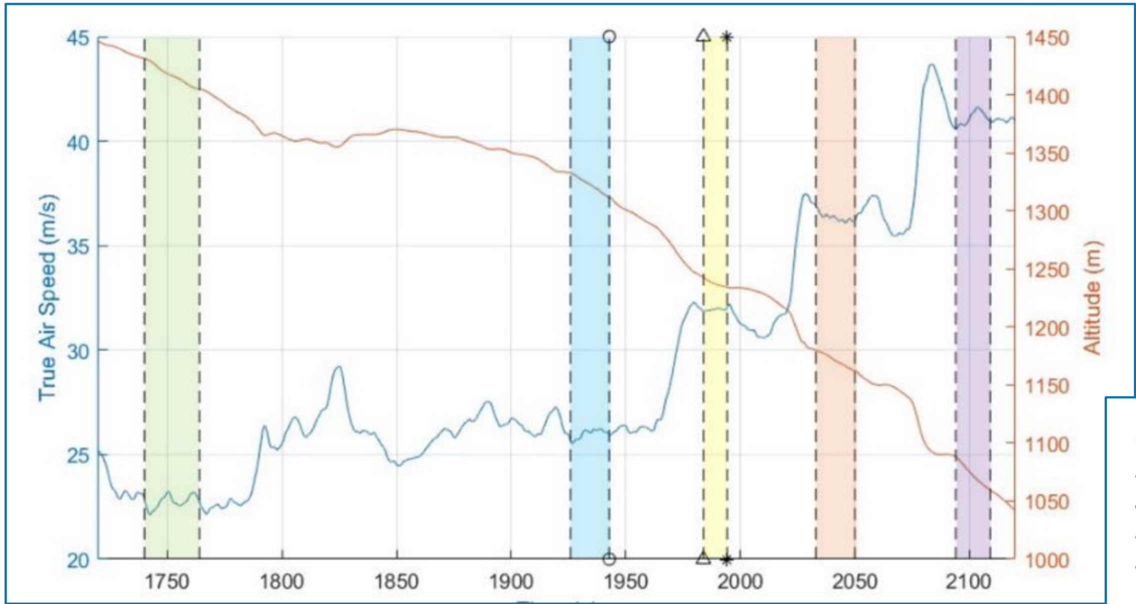
For optimum performance, the aircraft should be flown with a C.G. towards the rear of the allowable range. This especially improves thermalling performance. However the aircraft will be more pitch sensitive.

The wing fuselage joint, wing parting and the tail plane fin joint should be taped up and the aircraft thoroughly cleaned to obtain maximum performance.

The polars apply to a "clean" aircraft.
With dirty wings or flight in rain, the performance drops accordingly.

DG1000S Flight Manual

Aircraft Performance



Student Assignment: Actual Flight Data
(Prof. Lowenberg)

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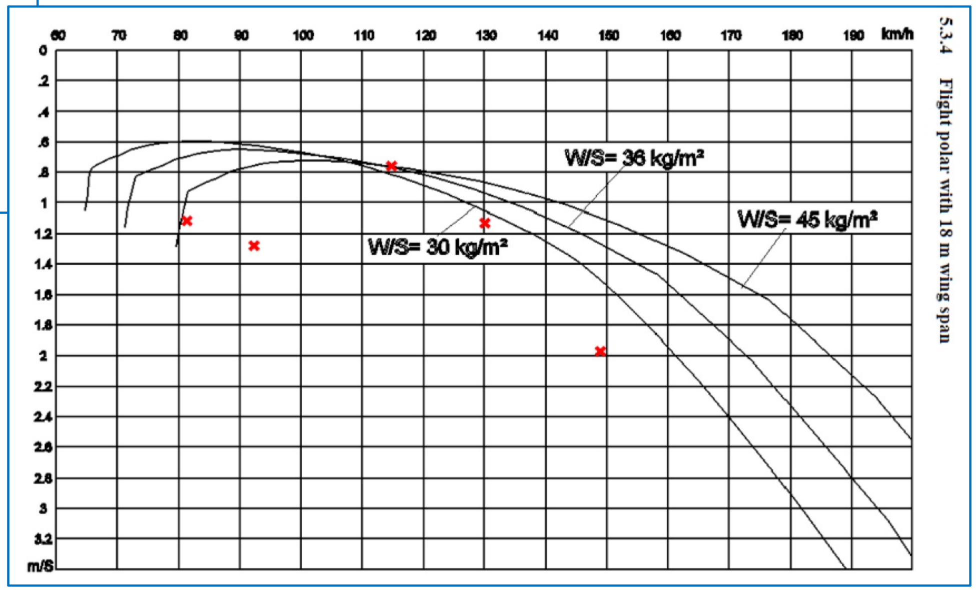
(Prof. Lowenberg)



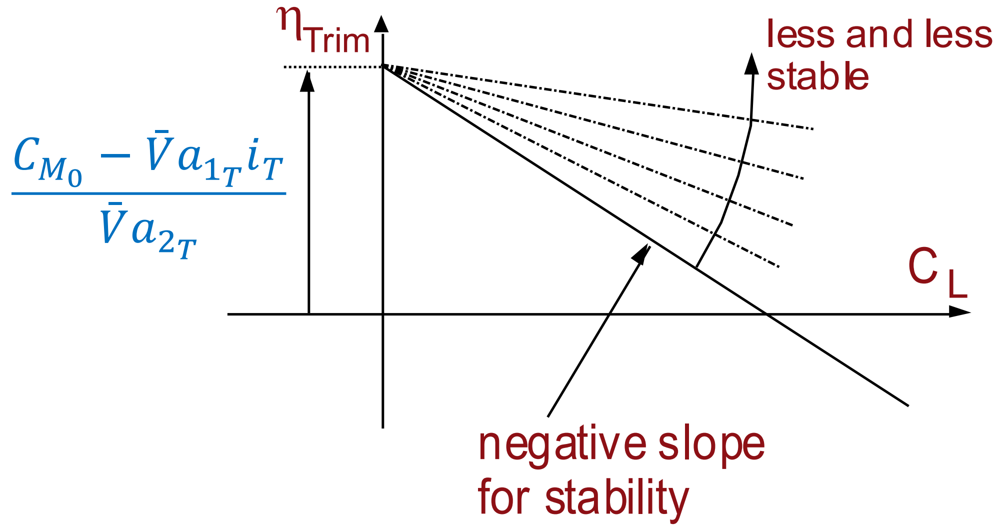
bristol.ac.uk

Static Stability

Flight Test: Static Stability

1. It is relatively straightforward to obtain measurements of the elevator angle η required to trim an aircraft at a chosen value of lift coefficient C_L.
2. A flight test exercise conducted in a Handley Page Jetstream by the author (Flight Dynamics Principles), under these conditions, provided the trim data plotted in Fig. 3.10 for three different cg positions.
3. The plots are clearly non-linear and the non-linearity in this aircraft is almost entirely due to the effects of power.

From the slides on: Static Stability



Cook, M.V. Flight Dynamics Principles

Flight Test: Static Stability

1. Since the gradients of the plots shown in Fig. 3.10 are all negative the aircraft is statically stable in accordance with 'equation (3.20)'.
2. To establish the location of the controls fixed neutral point h_n equation (3.20) must be solved at each value of trim lift coefficient.
3. This is most easily done graphically as shown in Fig. 3.11..

Cook, M.V. Flight Dynamics Principles

Stability?

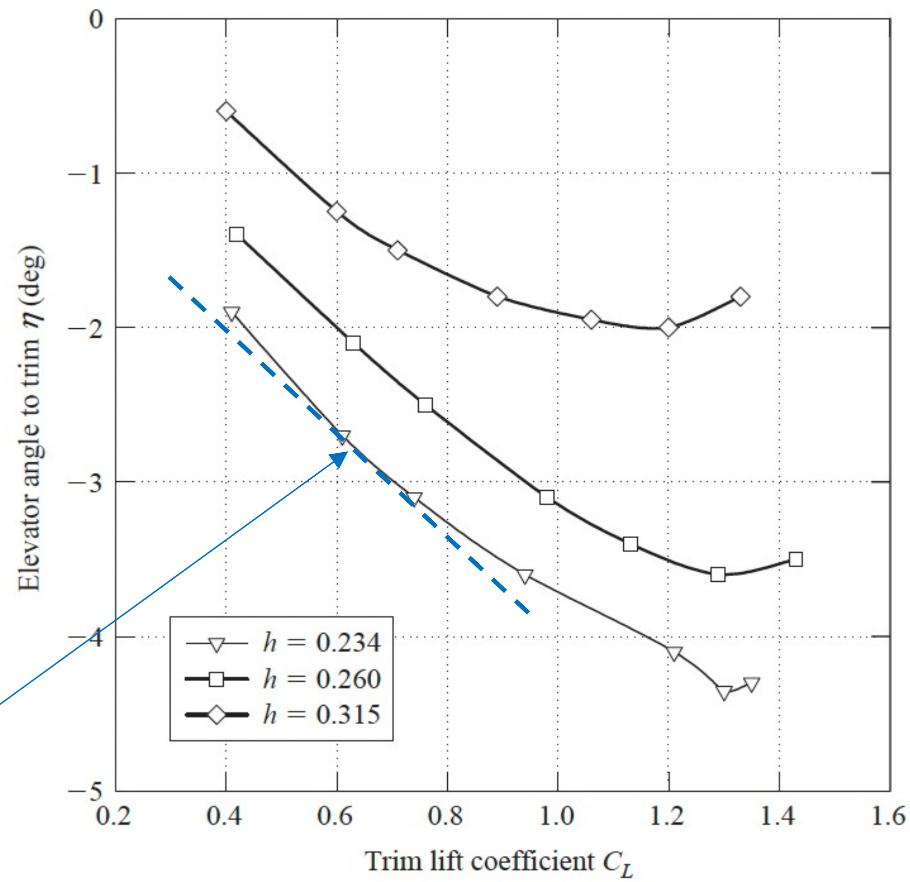


Figure 3.10 *Plot of elevator angle to trim.*

Flight Test: Static Stability

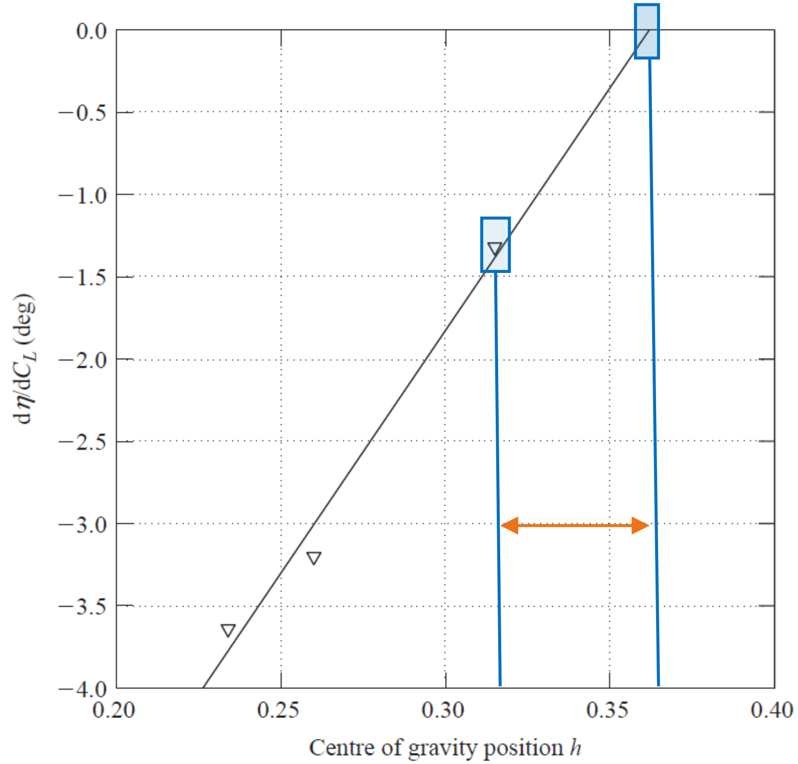


Figure 3.11 *Determination of controls fixed neutral point.*

- 'Equation (3.20)' is solved by plotting $d\eta/dC_L$ against *cg* position *h* as shown. In this example, the mean gradient for each *cg* position is plotted rather than the value at each trim point.
- Extrapolation to the neutral stability point at which $d\eta/dC_L = 0$ corresponds with a cg position of approximately h=0.37.
- A controls fixed neutral point h_n at 37% of mac correlates well with the known properties of the aircraft.
- Note the equivalent for Manoeuvre Margin in your notes.

- 'Note CG position can be changed in X-Plane 12.
- Note: that data collection is not easy!

Longitudinal Dynamic Stability

Flight Test: Longitudinal Response

- Since the longitudinal stability modes are usually well separated in frequency, it is possible to excite the modes more or less independently for the purposes of demonstration or measurement.
- Indeed, it is a general flying qualities requirement that the modes be well separated in frequency in order to avoid handling problems arising from dynamic mode coupling.
- The short period pitching oscillation may be excited by applying a short duration disturbance in pitch to the trimmed aircraft. This is best achieved with an elevator pulse having a duration of a second or less.

Cook, M.V. Flight Dynamics Principles

Flight Test: Longitudinal Response

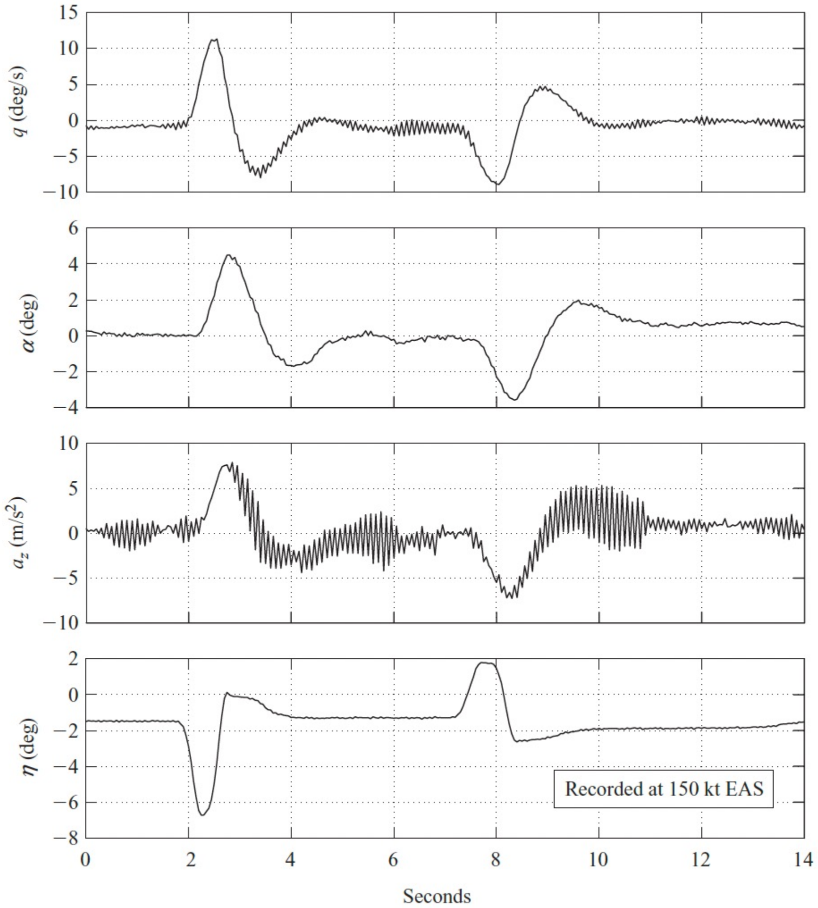


Figure 6.10 *Flight recording of the short period pitching oscillation.*

- An example of a short period response recorded during a flight test exercise in a Handley Page Jetstream aircraft is shown in Fig. 6.10.
- In fact two excitations are shown, the first in the nose up sense and the second in the nose down sense. The pilot input "impulse" is clearly visible and represents his best attempt at achieving a clean impulse like input; *some practice is required before consistently good results are obtained*.
- Immediately following the input, the pilot released the controls to obtain the controls free dynamic response which explains why the elevator angle does not recover its equilibrium trim value until the short period transient has settled.

Cook, M.V. Flight Dynamics Principles

Flight Test: Longitudinal Response

- The phugoid mode may be excited by applying a small speed disturbance to the aircraft in trimmed flight. This is best achieved by applying a small step input to the elevator ....
- If the power is left at its trimmed setting, then the speed will decrease, or increase, accordingly. When the speed has diverged from its steady trimmed value by about 5% or so, the elevator is returned to its trim setting. This provides the disturbance, and a stable aircraft will then execute a phugoid oscillation as it recovers its trim equilibrium.
- It is clear from an inspection of Fig. 6.11 that the phugoid damping is significantly higher than might be expected from the previous discussion of the mode characteristics.

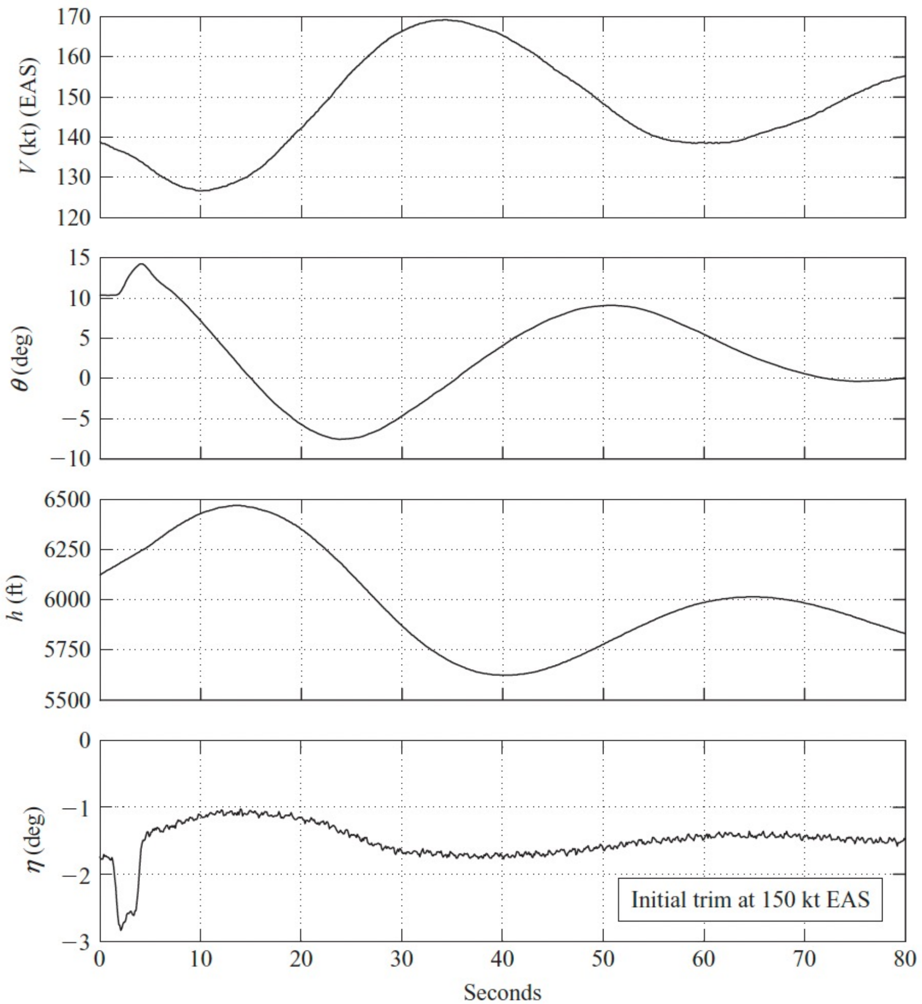


Figure 6.11 *Flight recording of the phugoid.*

Flight Test: Longitudinal Response

- What is in fact shown is the aerodynamic, or basic airframe, phugoid modified by the inseparable effects of power.
- The Astazou engines of the Jetstream are governed to run at constant rpm and thrust changes are achieved by varying the propeller blade pitch. Thus, as the aircraft flies the sinusoidal flight path during a phugoid disturbance the sinusoidal propeller loading causes the engine to automatically adjust its power to maintain constant propeller rpm.
- This very effectively increases the apparent damping of the phugoid. It is possible to operate the aircraft at a constant power condition when the "power damping" effect is suppressed. Under these circumstances it is found that the aerodynamic phugoid is much less stable, as predicted by the simple theoretical model, and at some flight conditions it is unstable.

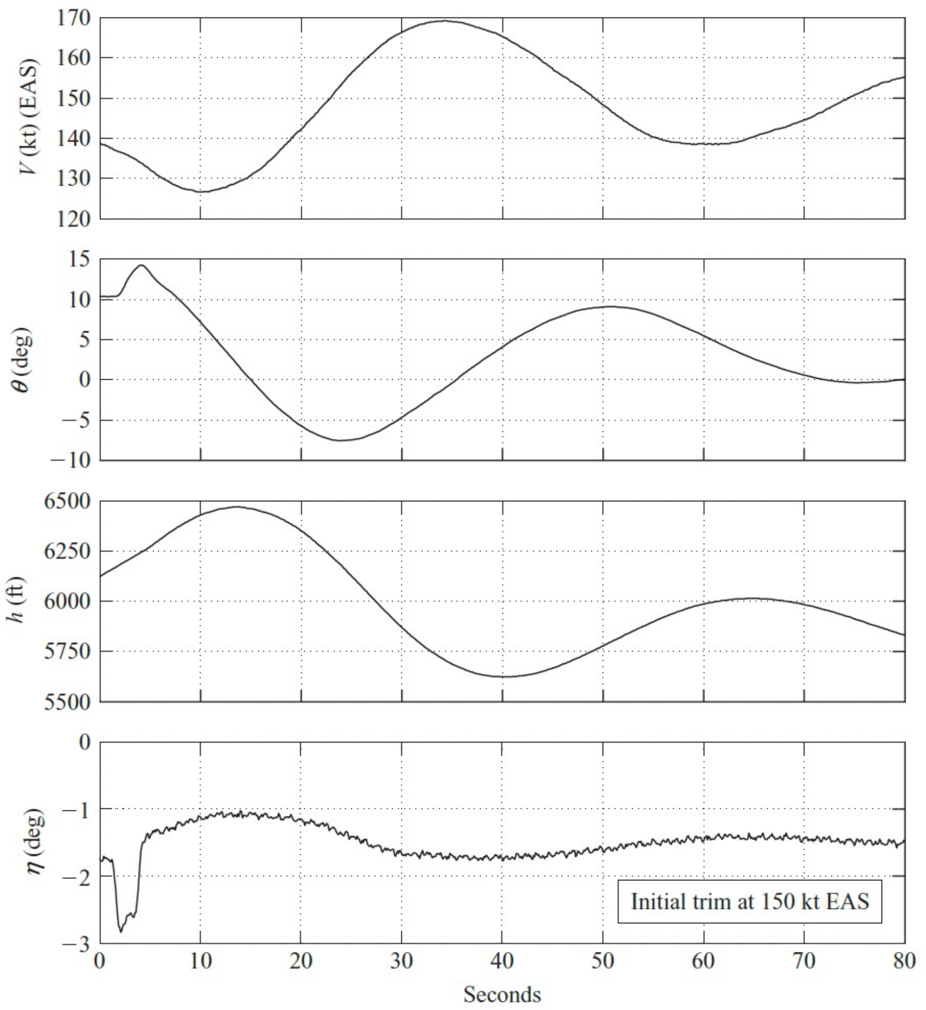
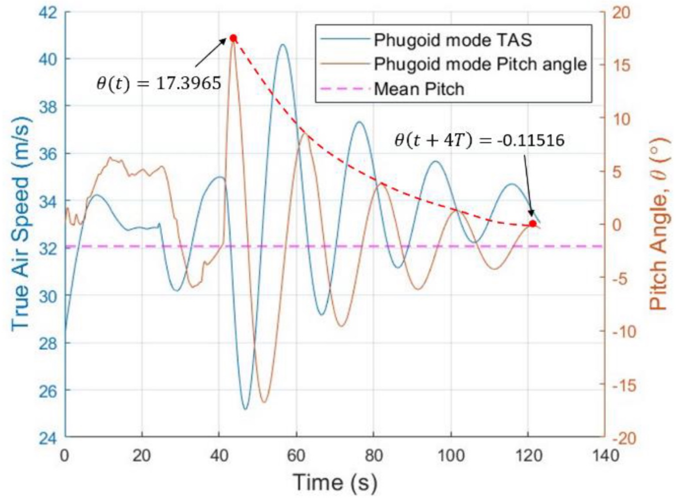
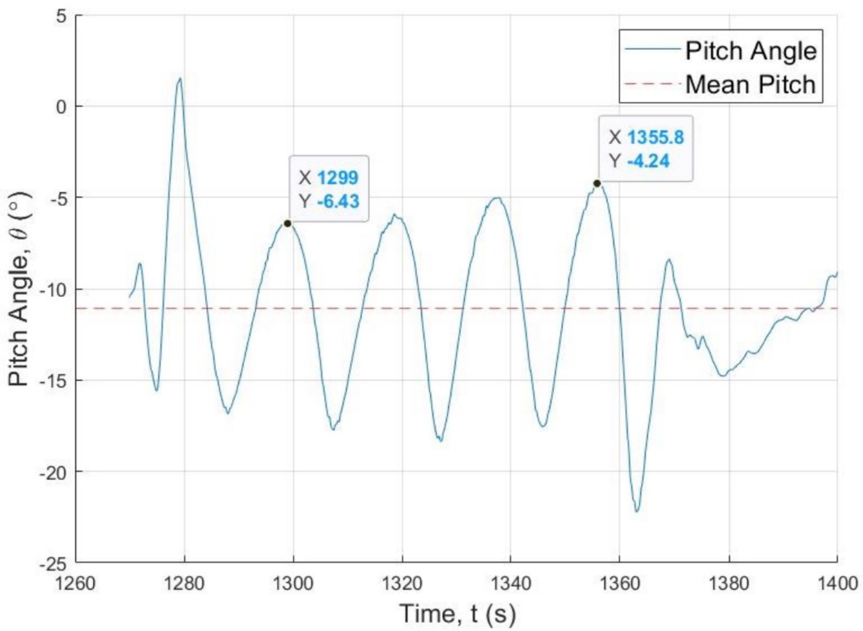


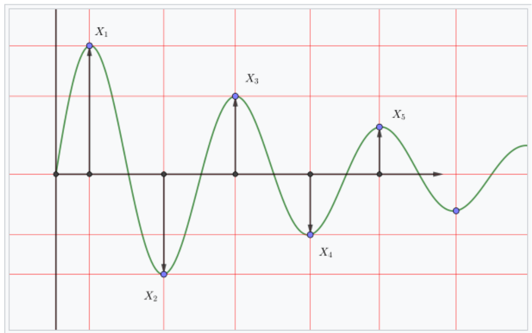
Figure 6.11 *Flight recording of the phugoid.*

Student Assignment
Piper Cub Simulation Data, X-Plane





Student Assignment
DG 1001S Actual Flight Data
Prof. Lowenberg



The logarithmic decrement can be obtained e.g. as $\ln(x_1/x_3)$.

(Wikipedia)

Relevant Parameters

- *Time section to use*
- *Damping ratio & frequency*
- *E.g. Logarithmic decrement*
- *Limitations & observations*

Lateral Directional
Dynamic Stability

Flight Test: Lateral-Directional Response

- An example of a roll response showing the roll subsidence mode recorded during a flight test exercise in a Handley Page Jetstream aircraft is shown in Fig. 7.11.
- The input aileron pulse is clearly seen and has a magnitude of about 4◦ and duration of about 4 s. The shape of this input will have been *established by the pilot by trial and error* since the ideal input is very much aircraft dependent.
- The effect of the roll mode time constant is clearly visible since it governs the exponential rise in roll rate p as the response attempts to follow the leading edge of the input ξ.
- The barely perceptible oscillation in roll rate during the “steady part” of the response is, in fact, due to a small degree of coupling with the Dutch roll mode.

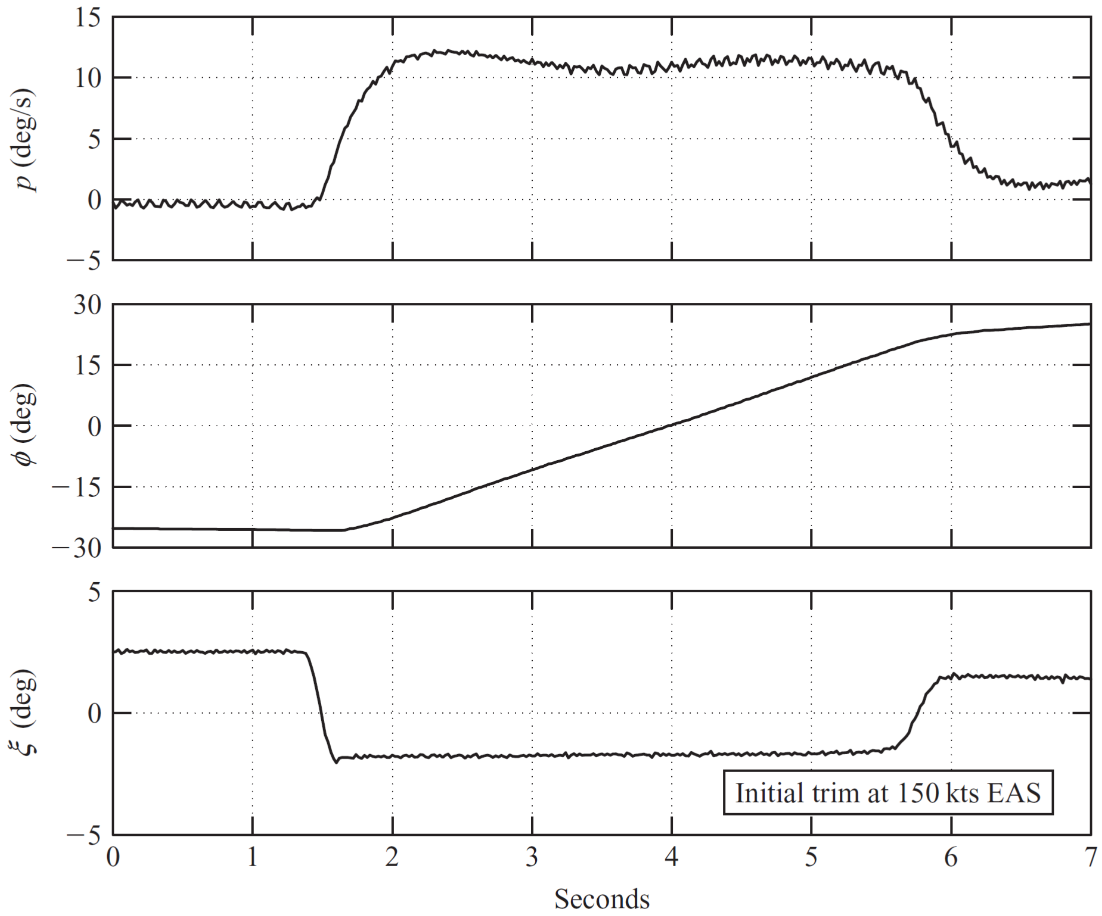


Figure 7.11 *Flight recording of the roll subsidence mode.*

Flight Test: Lateral-Directional Response

- In order to conduct the flight experiment without large excursions in roll attitude φ it is usual to first establish the aircraft in a steady turn with, in this illustration, −30° of roll attitude.
- This is also clearly visible in Fig. 7.11. The effect of the roll mode time constant on the roll attitude response is to smooth the entry to and exit from the steady part of the response. Since the roll mode time constant is small, around 0.4 s for the Jetstream, its effect is only just visible in the roll attitude response..

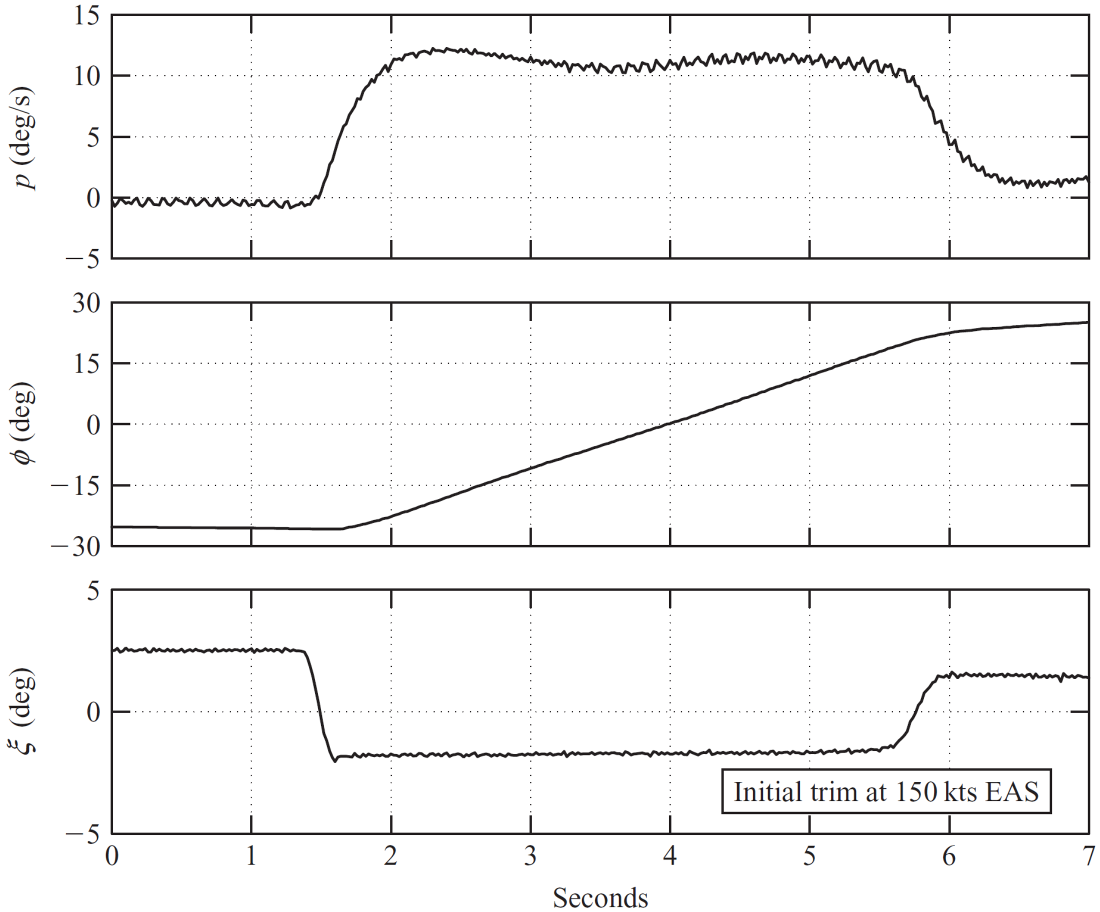


Figure 7.11 *Flight recording of the roll subsidence mode.*

Flight Test: Lateral-Directional Response

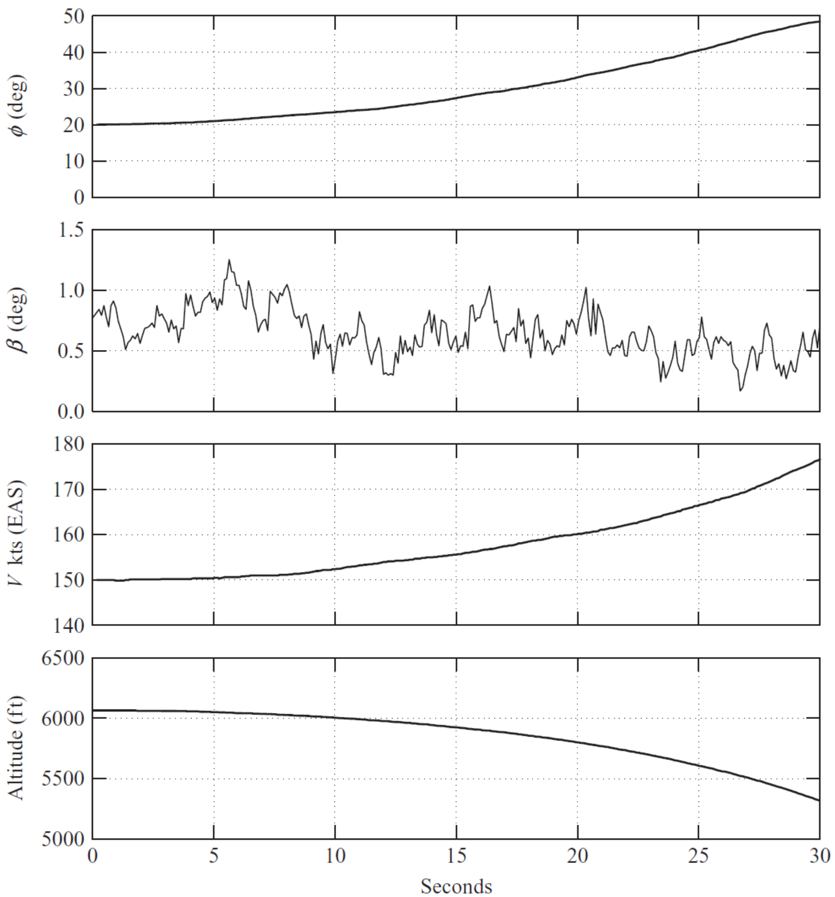


Figure 7.12 *Flight recording of the spiral mode departure.*

- The spiral mode may be excited by applying a small step input to rudder ζ, the remaining controls being held at their trim settings. The aeroplane responds by starting to turn, the wing on the inside of the turn starts to drop and sideslip develops in the direction of the turn.
- When the roll attitude has reached about 20 degrees the rudder is gently returned to datum and the aeroplane left to its own devices.
- When the spiral mode is stable the aeroplane will slowly recover wings level flight, the recovery being exponential with spiral mode time constant. When the mode is unstable the coupled roll-yaw-sideslip departure will continue to develop exponentially with spiral mode time constant.
- An example of an unstable spiral mode, captured from the time the disturbing rudder input is returned gently to datum, and recorded during a flight test exercise in a Handley Page Jetstream aircraft is shown in Fig. 7.12.

Flight Test: Lateral-Directional Response

- Ideally, the Dutch roll mode may be excited by applying a doublet to the rudder pedals with a period matched to that of the mode, all other controls remaining at their trim settings. In practice the pilot pedals continuously and cyclically on the rudder pedal and *by adjusting the frequency it is easy to find the resonant condition*.
- In this manner a forced oscillation may easily be sustained. On ceasing the forcing input the free transient characteristics of the Dutch roll mode may be seen.
- This free response is shown in the flight recording in Fig. 7.13 which was made in a Handley Page Jetstream aircraft.
- The rudder input ζ shows the final doublet before ceasing the forcing at about 5 s, the obvious oscillatory rudder motion after 5 s is due to the cyclic aerodynamic load on the free rudder.

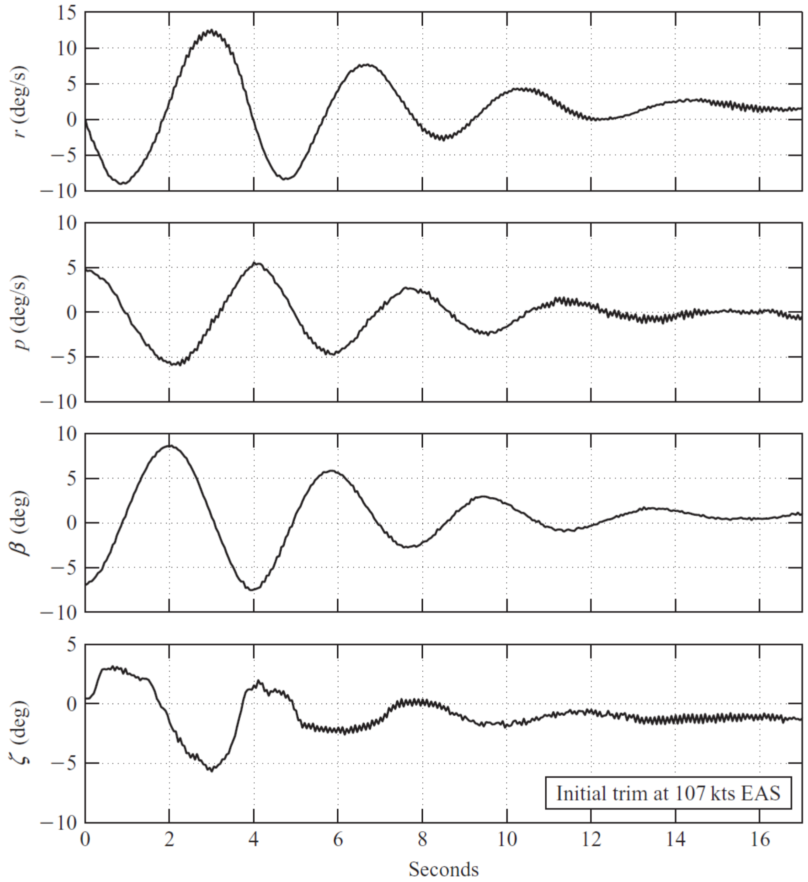


Figure 7.13 *Flight recording of the dutch roll mode.*

X-Plane 12

Flight Test Data Capture

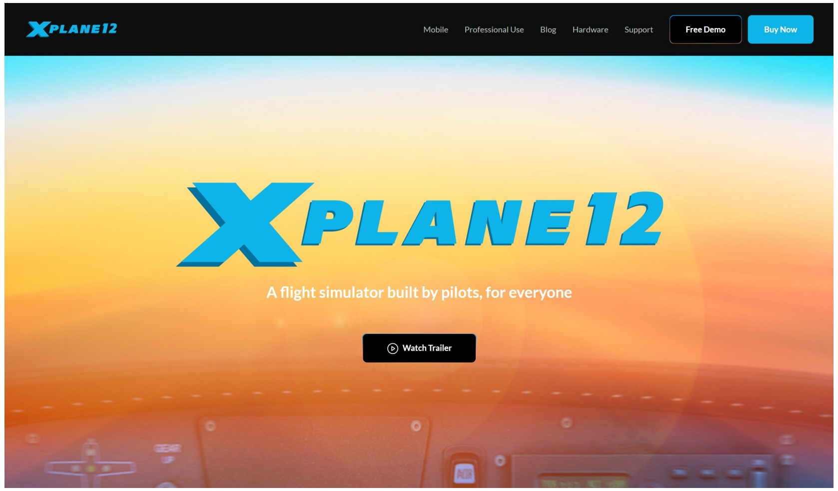
Flight Test Data Capture

1. Introduction: X-Plane
2. Simulation and Data Capture
3. Data Processing

https://www.x-plane.com/

X-Plane: Introduction

1. https://en.wikipedia.org/wiki/X-Plane_(simulator)
2. https://www.x-plane.com/
3. Flight Simulators in Queens Building in the BLADE Labs to the right at the entrance
4. Simulation on your own computer

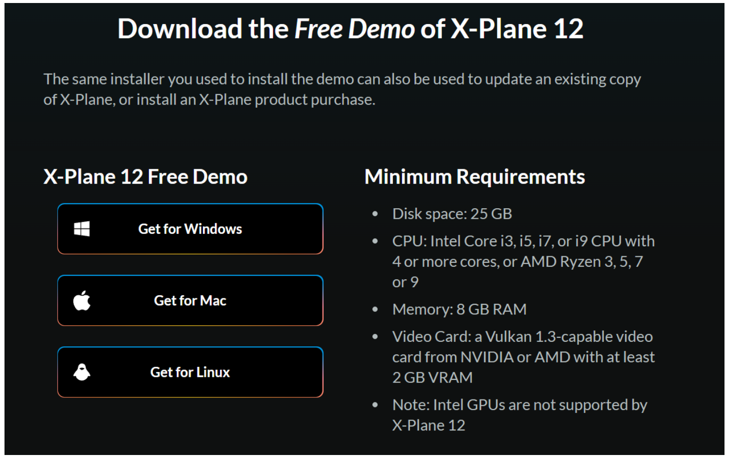


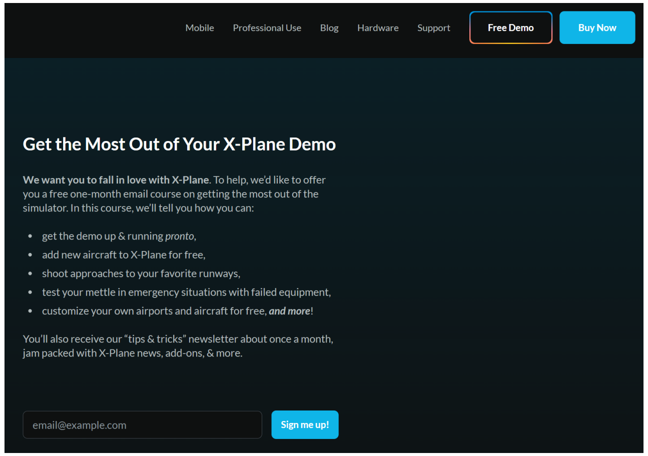
X-Plane: University of Bristol Flight Simulators

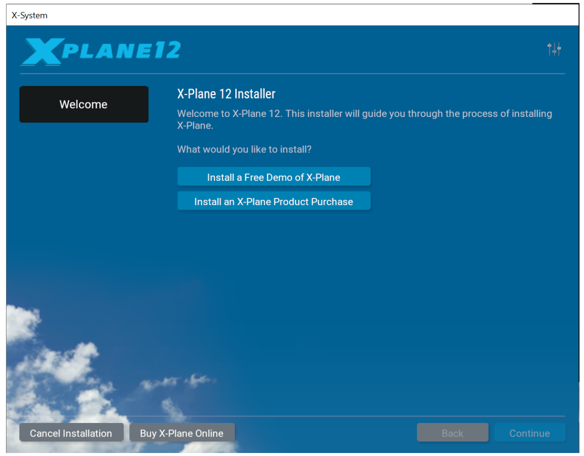
- Flight Simulation: Room M003
- Down the stairs to the right of the Main Entrance to Queens Building
- Three simulators are up and running with X-Plane 12

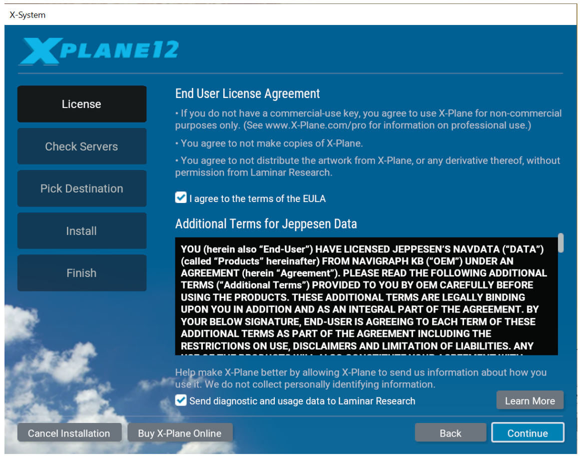
1. Please do not modify these in any way, if you try to install additional plug-ins etc this might make them in-operable for others
2. Please do log out completely. If you only swap user, this will make them in-operable for others
3. The brake release is on the pedals

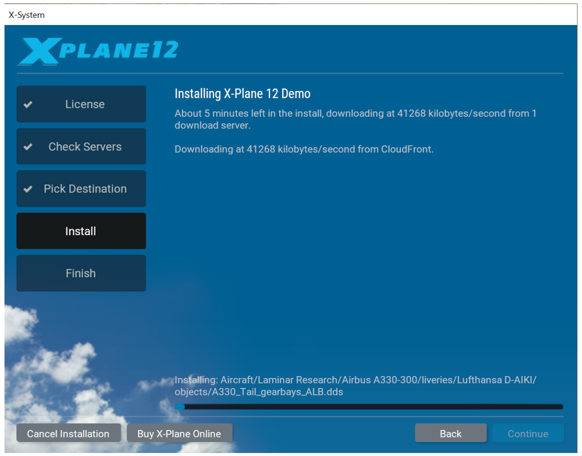
X-Plane: Home Installation

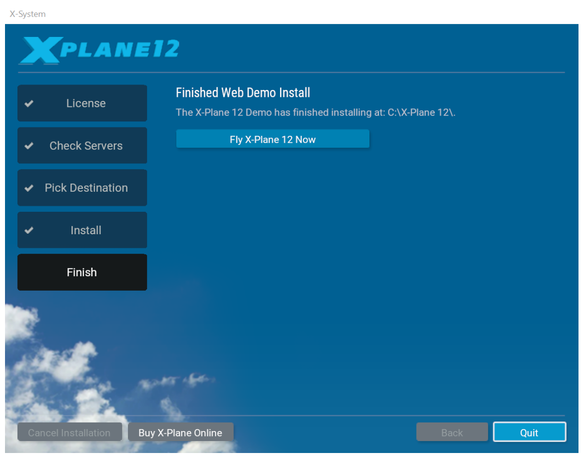






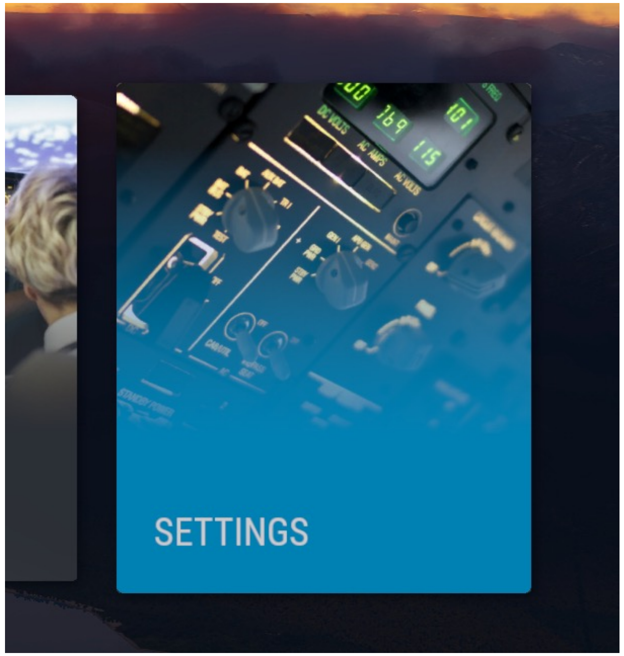


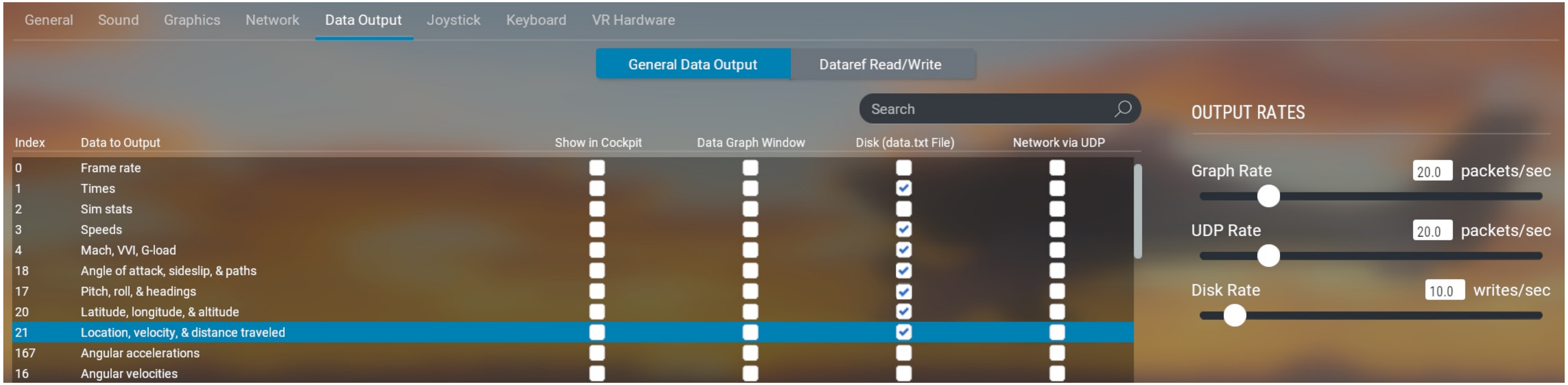




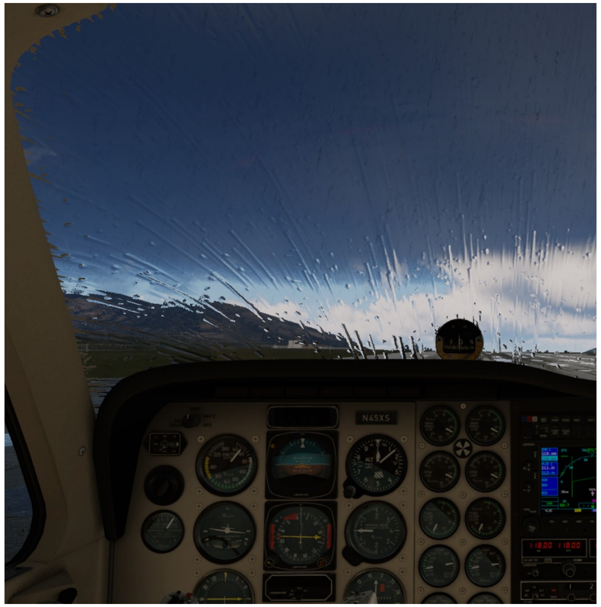
X-Plane: Collecting Data

1. X-Plane 12 Screenshots.
2. Select the data you wish to collect under Disk (data.txt File)
3. Update the Disk Rate you wish to capture the data at
4. Files can become very large if you collect significant data!
5. Recommend short flights to capture the data required
6. Use of a joystick is recommended





X-Plane: Collecting Data



https://www.x-plane.com/

1. Select the data you wish to collect under Disk (data.txt File)
2. Update the Disk Rate for the data capture
3. Files can become very large if you collect significant data!
4. Recommendation is for short flights to capture the data required

1. Decide on the information that you need to collect e.g.
2. Choose your aircraft
3. Suggest starting at altitude: i.e. the 10nm from the airport option or bespoke starting conditions
4. Reduce thrust to zero and trim the aircraft at different airspeeds

Data Processing

- The data file can be found in the X-Plane directory, e.g.

Data 19/03/2024 10:58 Text Document 498 KB

- The file is as simple text file and can be opened with notepad….

Data - Notepad

File Edit Format View Help

_real,_time	_totl,_time	missn,_time	timer,_time	_zulu,_time	local,_time
312.06366	0.05025	0.05025	0.00000	13.68001	5.68001
319.14267	0.13102	0.13102	0.00000	13.68004	5.68004
319.33716	0.25462	0.25462	0.00000	13.68007	5.68007
319.43823	0.34627	0.34627	0.00000	13.68010	5.68010
319.51703	0.42504	0.42504	0.00000	13.68012	5.68012
319.59631	0.50435	0.50435	0.00000	13.68014	5.68014
319.70575	0.55460	0.55460	0.00000	13.68015	5.68015
320.11087	0.68936	0.68936	0.00000	13.68019	5.68019
320.19717	0.77568	0.77568	0.00000	13.68022	5.68022
320.28683	0.86533	0.86533	0.00000	13.68024	5.68024

- For processing the data, I would suggest MATLAB, Excel or Python
- Identifying regions of trimmed aircraft data, or mode demonstrations can be challenging.
- Multiple attempts might be needed to collect clear flight data
- Note: the data does not need to be perfect

https://www.x-plane.com/

X-Plane 12

(and why doing demos in lectures should be avoided!)

Next Session

Flight Test: Continued
Aircraft Control

bristol.ac.uk

https://www.x-plane.com/

University of BRISTOL

ANY QUESTIONS?

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