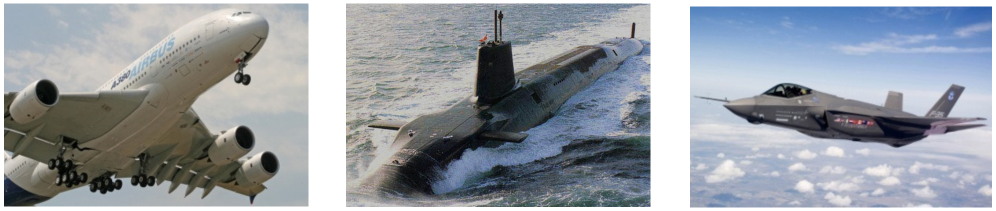
Stirling Dynamics



Partial Wing-Box Testing and Non-Linear Damping Identification

Presentation to:

Nonlinear Aeroelastic Simulation for Certification

University of Liverpool 13-15 September, 2010

Introduction

- **Dr. Simon Hancock**
- **Caroline Havill**
- **Project Consultant – Prof. Jan Wright**

- **Presentation Structure**
  - The Partial Wing Box (PWB)
  - Modal Testing
  - Free-Release Testing
  - Non-Linear Damping Analysis
  - Conclusions

Objectives

- **Overall Customer Objective**
  - Is there any evidence of non-linear damping in the composite wingbox/engine structure that would alleviate the predicted gust / turbulence response loads?

- **Stirling Dynamics Objective**
  - Conduct physical testing and subsequent analysis to investigate the damping characteristics of the system.

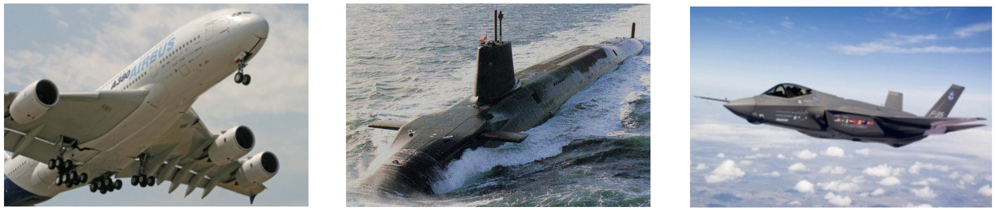
Partial Wing Box (PWB)

Challenges

- **Approach**
  - GVT to identify modes and compare against dynamic FE model
  - Use identified modes to initiate non-linear analysis
  - High amplitude impulse to force a non-linear response

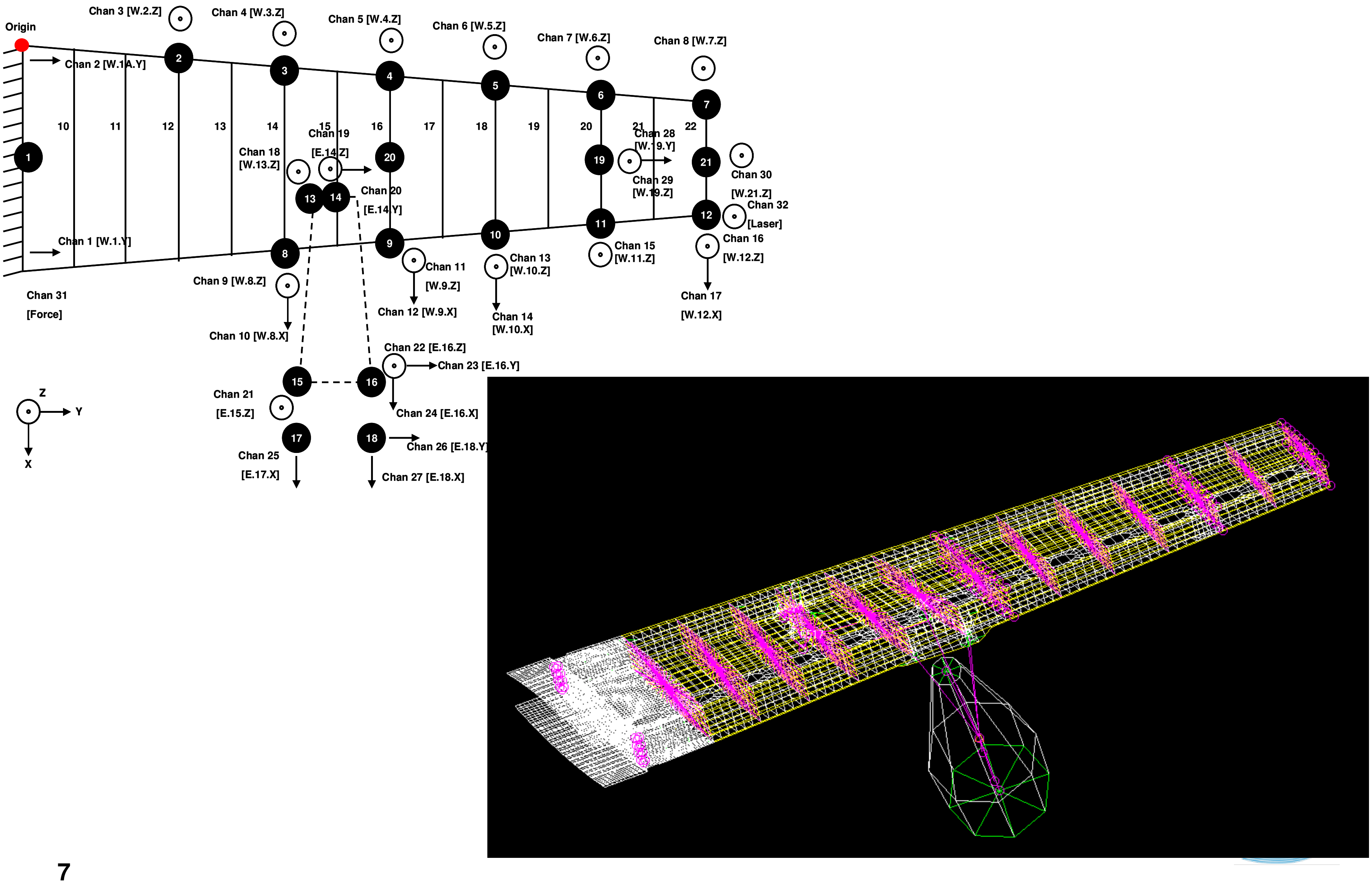
- **Challenges**
  - How to excite a large and heavy structure for modal testing?
  - How to deflect the PWB whilst allowing a ‘clean’ release?
  - How to analyse obtained data in an appropriate manner to extract true modal damping for the PWB?

Modal Testing



Presentation to:
Nonlinear Aeroelastic Simulation for Certification
University of Liverpool 13-15 September, 2010

PWB Dynamic Testing



Modal Testing

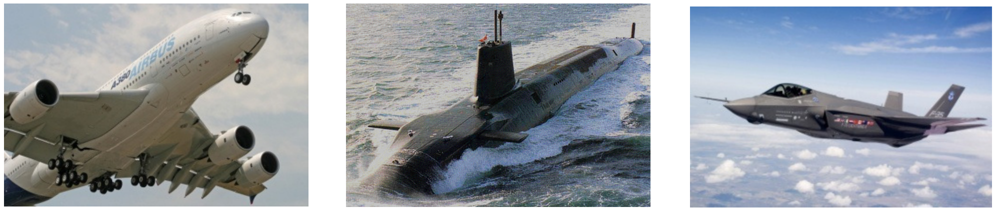
- **32 Piezo electric accelerometers**
- **Rib 16, wing tip and engine excitation**
- **Identification of modes**
- **Force levels up to +/- 400 N**
  - Swept sine
  - Stepped sine
  - Burst random
- **Hard attachment point at rib 16**
- **Vacuum pad at wing tip (fore/aft) and engine (lateral)**
- **Force hammer tests**

Shaker

Modal Test Results

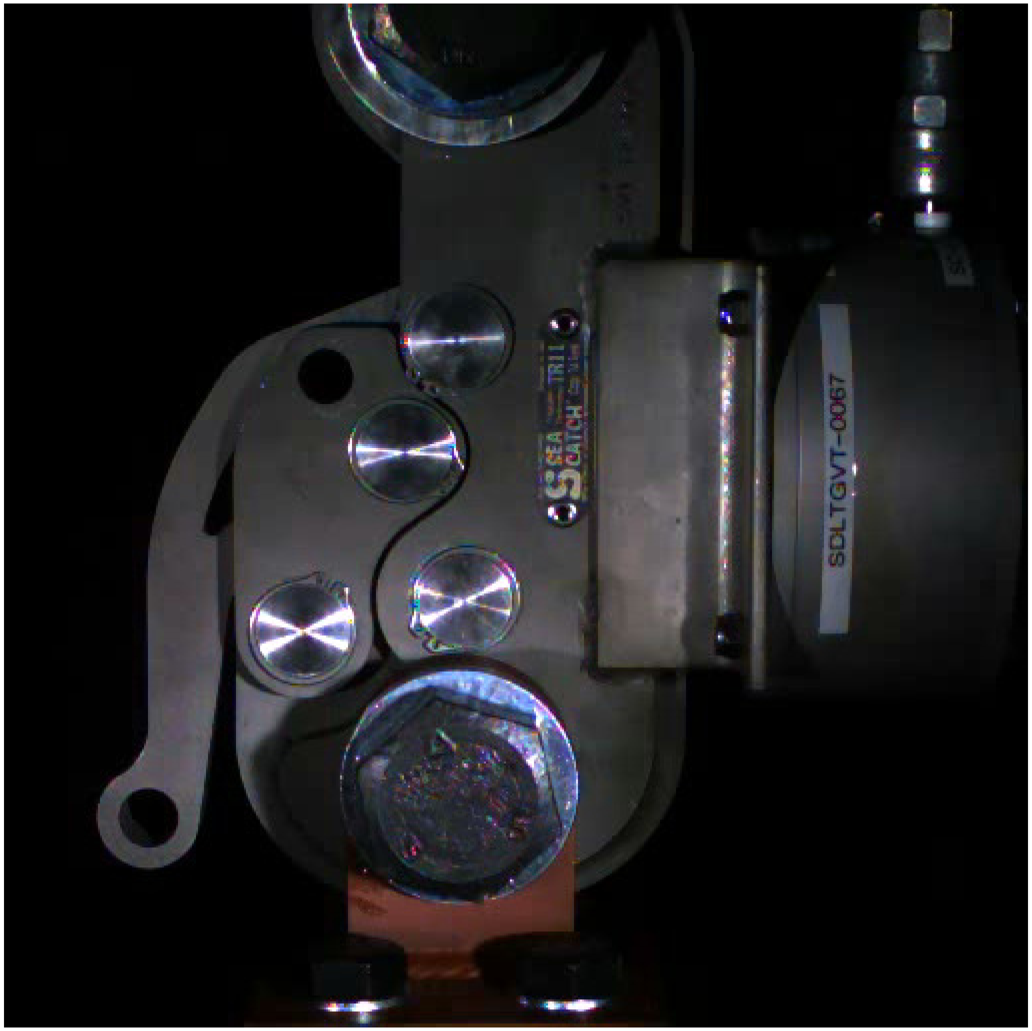
Mode Number	Calculated Frequency / [Hz]	Measured Frequency / [Hz]	Damping / [%]	Description
1	3.82	3.68	0.48	**Wing vertical bending 1**
2	4.90	4.78	0.39	**Vertical bending 1 with engine pitch**
3	6.45	6.25	0.37	**Engine yaw**
4	11.36	-	-	**Wing overtone bending with wing fore and aft.**
5	12.94	-	-	**Wing fore and aft**
6	15.86	14.21	1.47	**Wing overtone bending and engine pitch**
7	26.48	16.16	1.66	**Outer wing torsion.** During the test engine lateral as well
8	29.40	-	-	**Wing fore and aft overtone**
8A	-	18.20	2.07	Wing torsion with sympathetic engine yaw and pitch
9	34.63	32.27	1.20	**Wing 2nd overtone bending and engine and outer wing torsion** Measured mode has overtone bending and engine pitch. No torsion observed
10	58.11	62.82	0.36	**Engine yaw and wing bending** Note no wing bending observed during test

Free-Release Testing

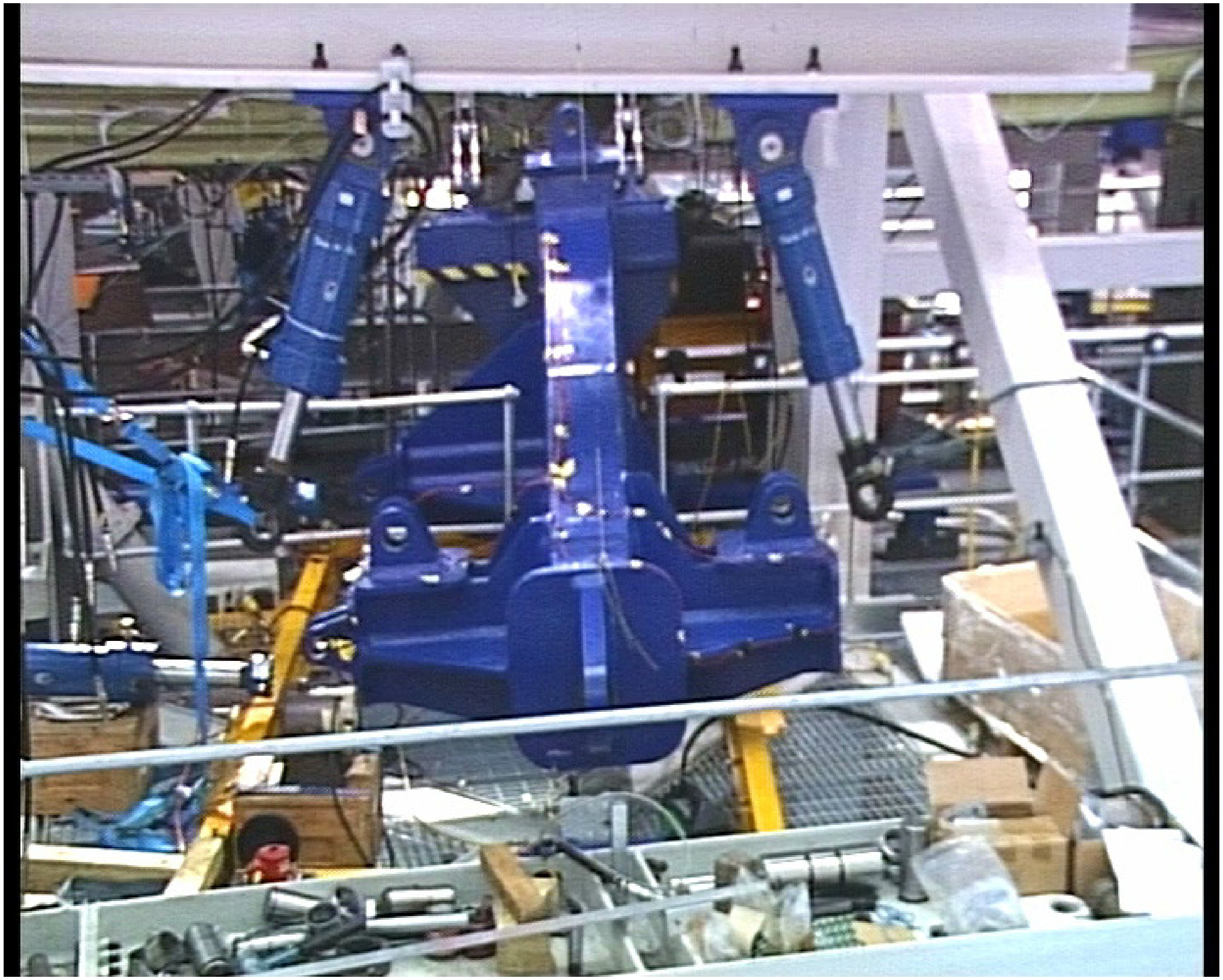


Presentation to:
Nonlinear Aeroelastic Simulation for Certification
University of Liverpool 13-15 September, 2010

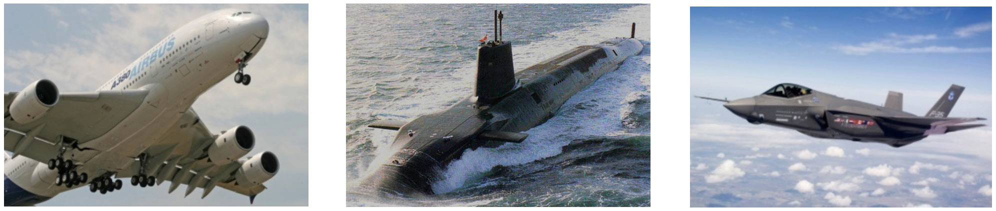
Release Mechanism



Free Release



Analysis of Damping Characteristics



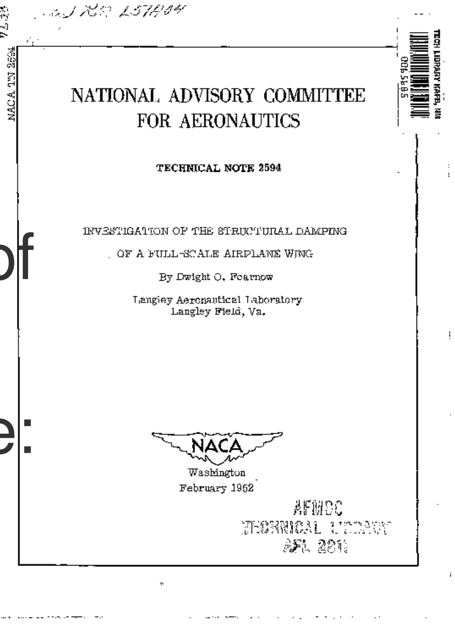
Presentation to:
Nonlinear Aeroelastic Simulation for Certification
University of Liverpool 13-15 September, 2010

Expected Non-Linear Damping Trend

- **Similar test performed in the 1950s:**
  - Test conducted on a modified wing: C-46D Aircraft.
  - Test specimen vibrated at bending mode @ 1.69Hz
  - Only first 2-3 cycles showed any indication of higher frequency modes.
  - Damping of bending mode found to increase:

    from 0.002 @ amplitude of ± 0.05

    to 0.006 @ amplitude of ±5



NACA TN 2594

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL NOTE 2594

INVESTIGATION OF THE STRUCTURAL DAMPING
OF A FULL-SCALE AIRPLANE WING

By Dwight O. Fearnow

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
February 1952

- **Aerodynamic damping would show a linear increase of damping with amplitude**

Estimation of Non-linear Damping from Free Decay Response Data

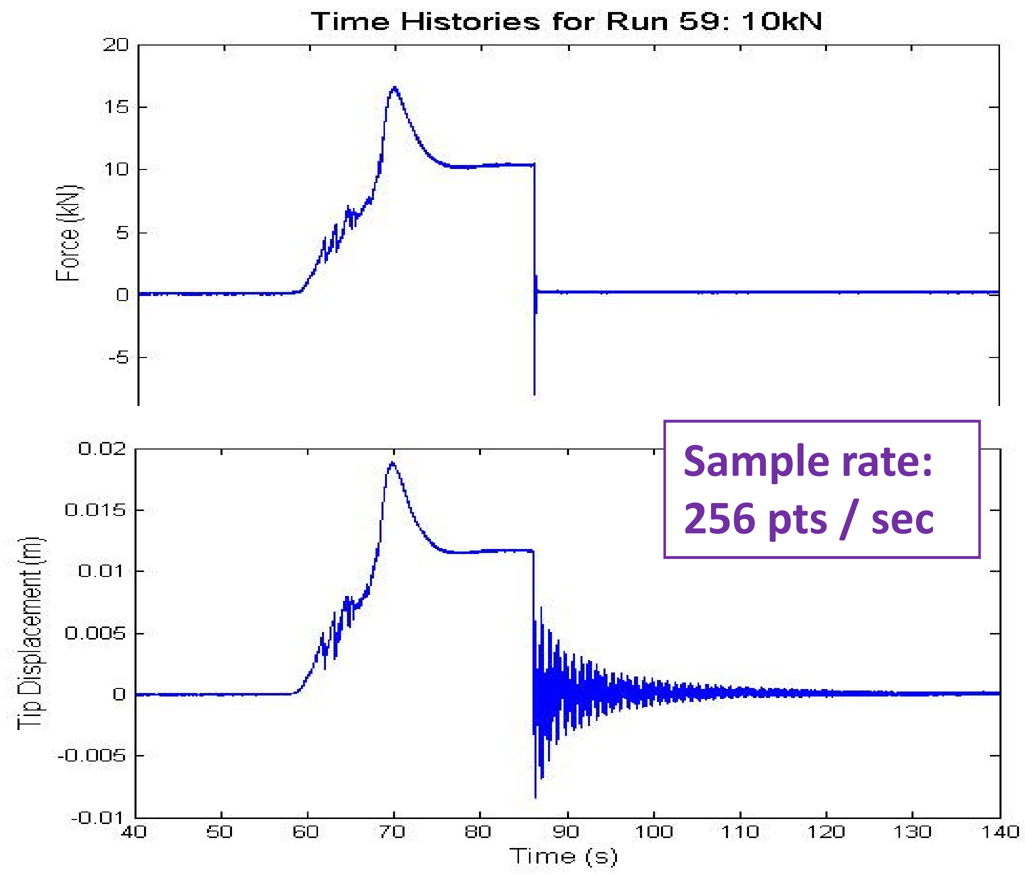
- **For an SDoF non-linear system:**
  - Cycle-by-cycle logarithmic decrement analysis would yield a variation of instantaneous damping against amplitude.
  - Analysis would be pseudo or piecewise linear
- **For an MDoF non-linear system**
  - Presence of more than one mode means that any SDoF approach is meaningless

    Unless it is possible to decouple the modes into SDoF using a modal transformation
  - Alternatively an MDoF curve fitter would need to be employed; analysis would be piecewise linear

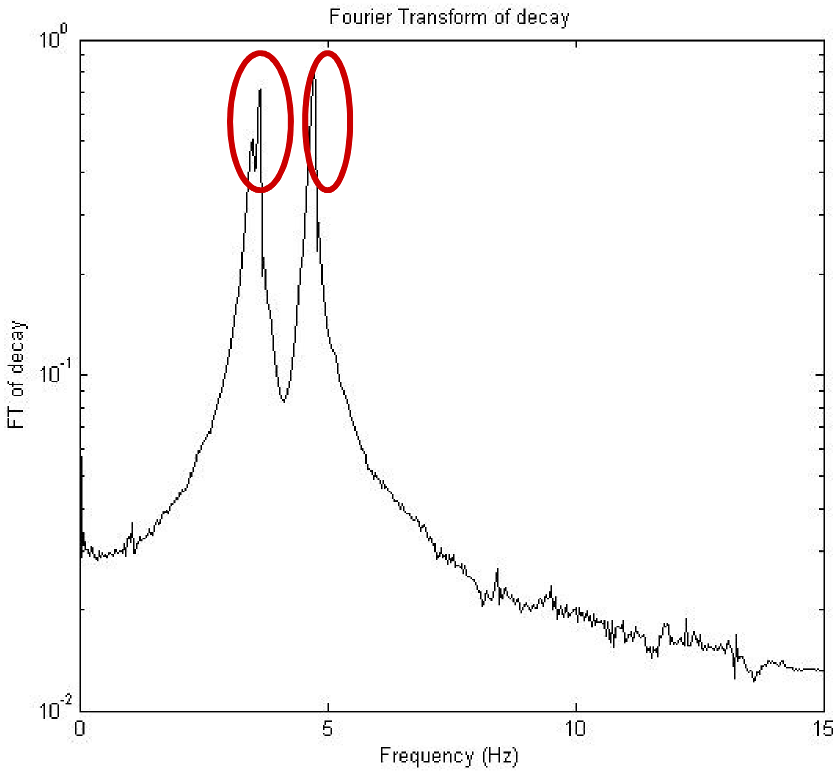
Theoretical Investigation for an MDoF System

- **Analysis program based on the Polyreference method with ability to**
  - Use time or amplitude “bins”
  - Use single or multiple transducers
  - Transform to modal coordinates
- **Theoretical 3DoF modal model used to test program:**
  - Modes extracted from FE model.
  - Quadratic damping applied to bending mode.
- **Theoretical test cases**
  - Time bins more suitable than amplitude bins
  - Transforming to modal coordinates makes analysis potentially simpler

Test Data



Sample rate: 256 pts / sec

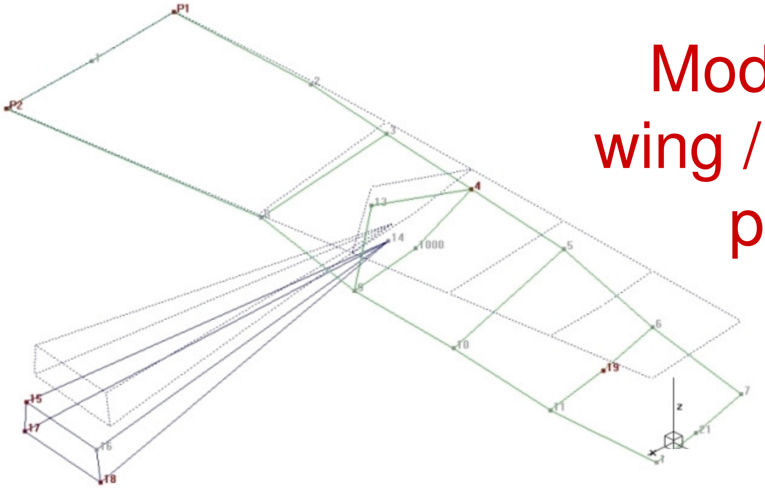


- Dominated by Modes 1 and 2
- Some evidence of 2 very close modes around 3.5-3.6Hz

Analysis of Free-Release Responses

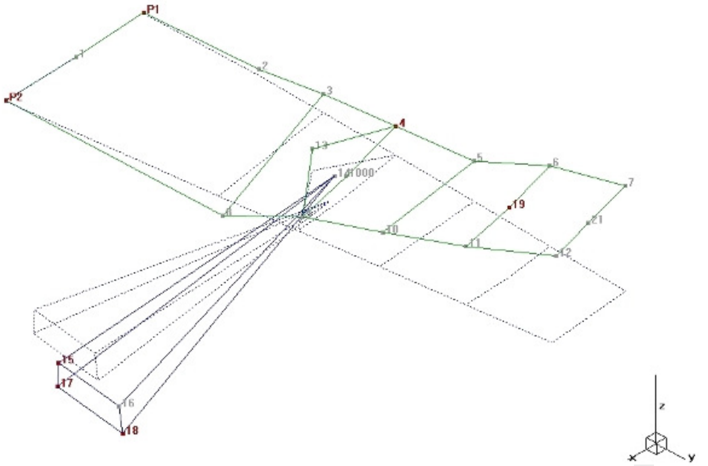
- **It is possible to analyse the data in one of several ways**
  - Tip displacement
  - Single / multiple acceleration
  - Modal acceleration
- **Model accelerations obtained using mode shapes obtained from GVT**
  - 7 accelerations from wing & engine analysed
  - Transformed to 2 modes using pseudo-inverse.
- **Time data decimated by factor of 16 to reduce sample rate so that points per cycle are of order (4/5)**
- **Consider entire time history initially (i.e. no bins) then later analyse responses in multiple overlapping bins**

Mode Shapes for Modes 1 and 2 involve different Relative Wing / Engine Motions



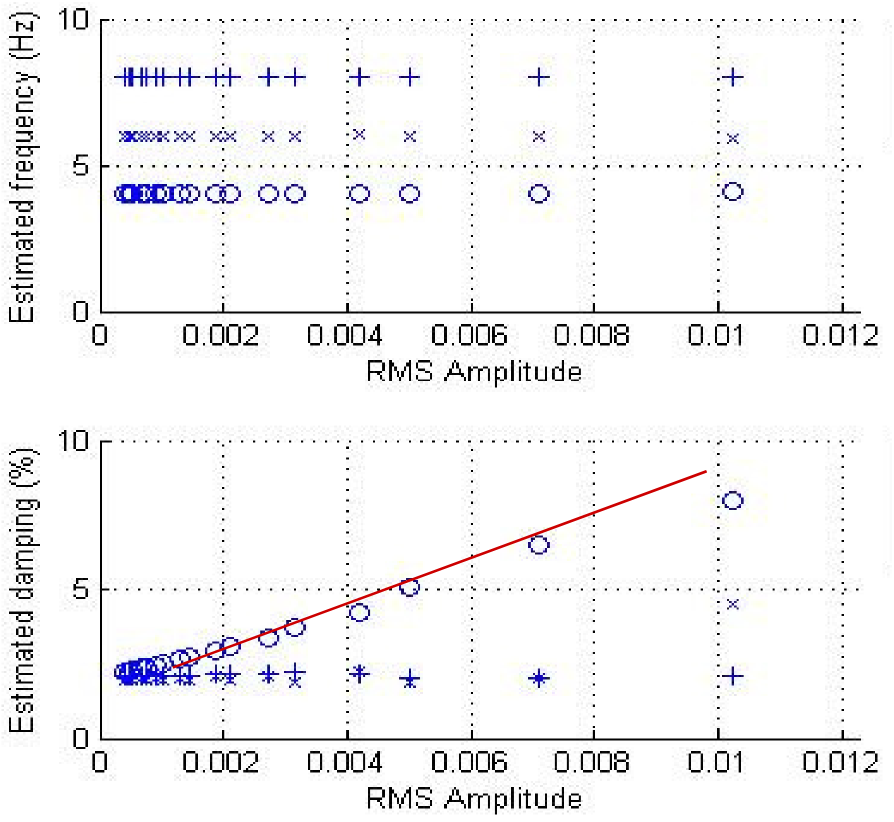
Mode 1 has
wing / engine in
phase

Mode 2 has
wing / engine
out of phase



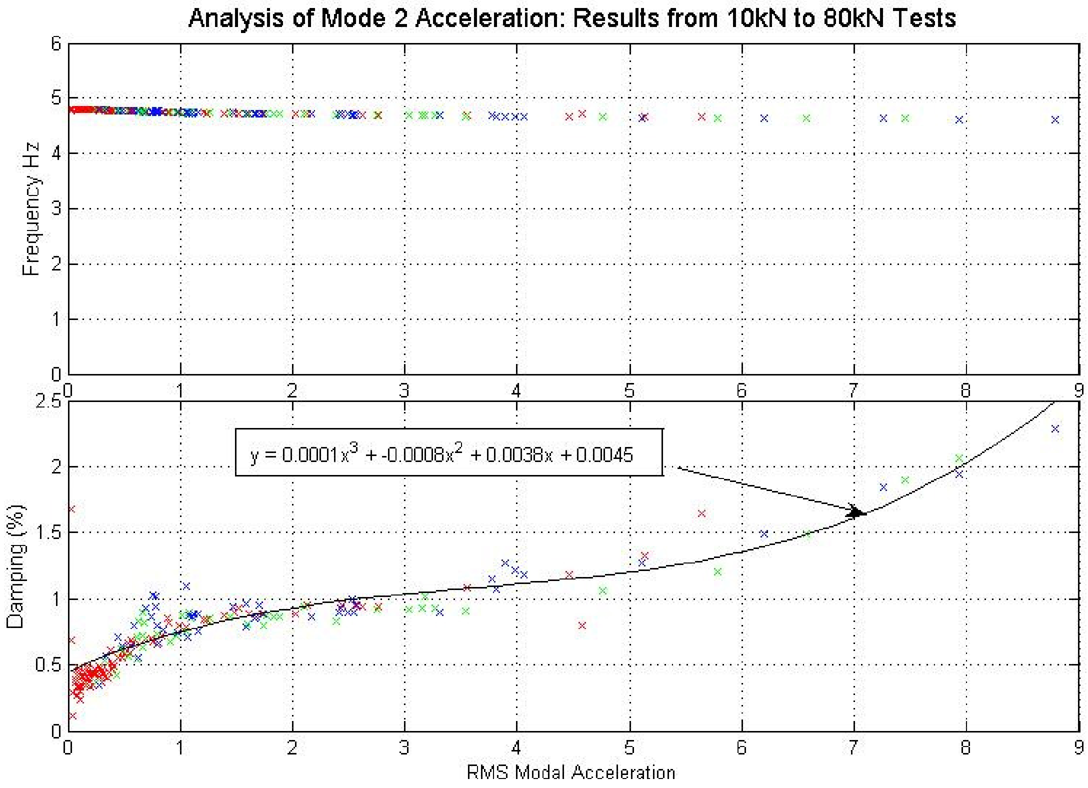
Variation of Frequency/Damping with Amplitude: Mode 1

- **Only possible to consider entire time history due to presence of two close frequencies modes.**
- **Damping shows a linear increase, as expected for quadratic damping**



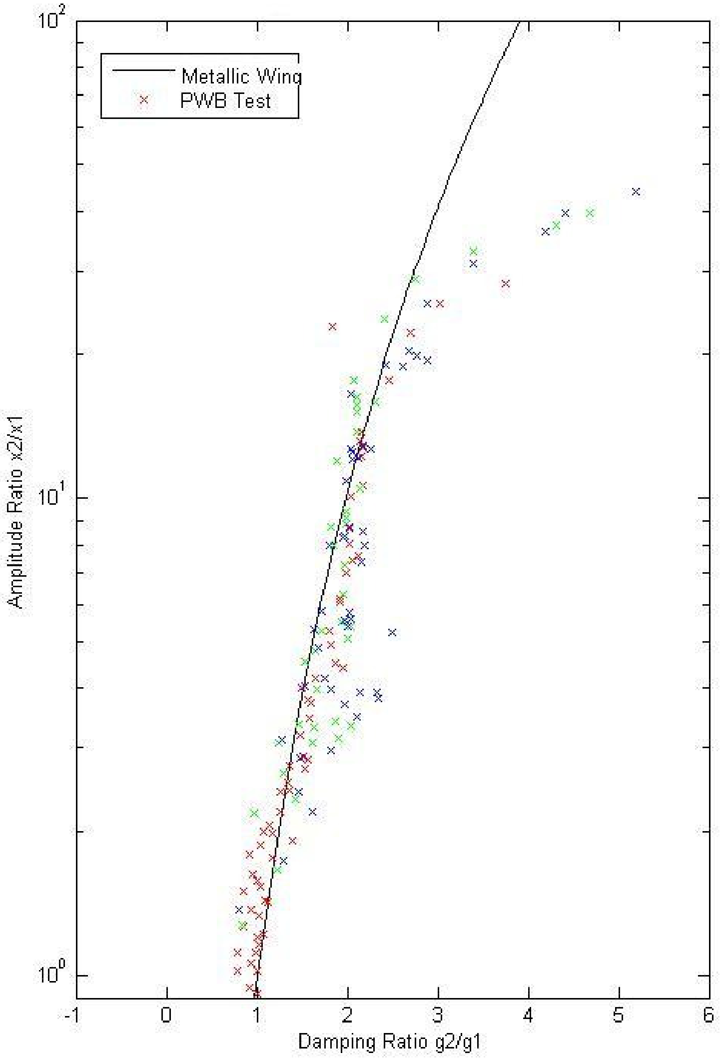
Variation of Frequency/Damping with Amplitude: Mode 2

- **(Almost) SDOF decay from modal transformation.**
- **Number of overlapping time bins used on response for each load**
- **Damping trend - fitted cubic curve.**



Results supported by log-dec analysis of SDOF decay.

Comparison of Normalised Modal Damping vs RMS Modal Acceleration with Metallic Wing Results



Test data
normalised
for 0.44%
damping
and 0.2 rms

Summary of Results

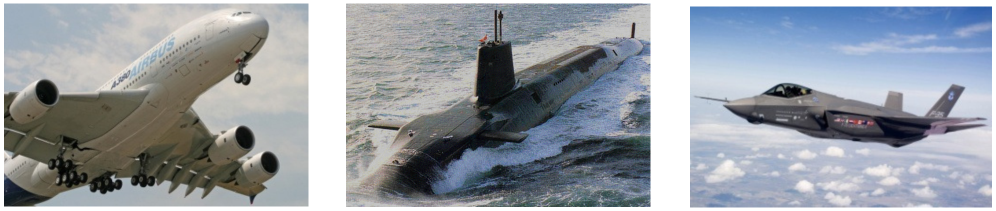
- **Mode 2** – 4.78Hz - wing / engine out of phase – shows non-linear damping broadly

- **Mode 1** – 3.68Hz - wing / engine in phase – shows non-linear damping at relatively low levels but problem of two very close modes means that analysis is less suitable for showing the true behaviour

- Exploration and understanding of Modes 1a and 1b might provide reasons for the different damping behaviour

- Note that aerodynamic damping would show a linear increase of damping ratio with amplitude

Conclusions



Presentation to:
Nonlinear Aeroelastic Simulation for Certification
University of Liverpool 13-15 September, 2010

Conclusions

- Difficult experimental set-up and methodology successfully completed
- Successful implementation of the Polyreference approach
- Results enabled customer to justify an increase in damping levels in their loads analysis

Questions

Head Office
26 Regent Street
Clifton
Bristol, BS8 4HG
United Kingdom
Tel +44 (0)117 9152 500

Filton Office
Brabazon Office Park
Golf Course Lane
Filton
Bristol, BS34 7PZ
United Kingdom
Tel +44 (0)117 9152 500

Farnborough Office
Terminal Building
Blackbushe Airport
Camberley
Surrey, GU17 9LQ
United Kingdom
Tel +44 (0)117 9152 500

Stirling Dynamics Inc
Crowne Pointe Corporate Center
Suite 205
4030 Lake Washington Blvd NE
Kirkland, WA 98033-7870
USA
Tel +1 425 827 5222