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Flight Flutter Test of a Nomad N24A Aircraft Fitted with One Modified Aileron

P.A. Farrell and S.A. Dunn

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P.A. Farrell and S.A. Dunn

Airframes and Engines Division
Aeronautical and Maritime Research Laboratory

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ABSTRACT

A Nomad aileron was modified by the addition of strain gauges and associated wiring, to permit its use in loads-measurement trials. This modification rendered the aileron non-standard, so a flight flutter trial was conducted to verify the aeroelastic stability of the loads aircraft when fitted with this aileron. This report describes the flight flutter trial and presents the results.

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EXECUTIVE SUMMARY

Following an accident to Nomad A18-403 at RAAF Base Tindal on 17 September 1991, doubts were raised as to the adequacy of the Nomad ailerons to cope with the loads experienced in flight. Subsequent structural tests at AMRL showed that the ailerons were more than adequate for the theoretically-determined loads used by the manufacturer, Government Aircraft Factory (GAF), in the design of the aileron. However the aileron had failed at Tindal, so one possible explanation was that the flight loads experienced by the aileron were much higher than the design loads. Consequently the decision was made to initiate a flight test program to measure the flight loads acting on the aileron.

To this end an aileron was instrumented with strain gauges and associated wire looming to measure flight loads. The ailerons on the Nomad aircraft are mass balanced, and doubt was raised that the instrumentation added to the aileron may have modified its mass distribution sufficiently to render the mass balance inadequate. Incidents involving aileron deformation on civil Nomad aircraft overseas had increased concern about possible aileron flutter, even with standard ailerons. Consequently a flight flutter test program was initiated to demonstrate that the ARDU test aircraft A18-407, when fitted with the instrumented aileron, would not experience flutter within the envelope to be flown for the loads measurement trial.

This report describes the flight flutter trial which was conducted at RAAF Base Edinburgh over the period 5-21 April 1995, and presents the results. This trial demonstrated that the instrumented aircraft was aeroelastically stable within the desired envelope, permitting the loads measurement trial to commence.

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1. Introduction

The Aircraft Research and Development Unit (ARDU) of the RAAF has been tasked (TASK 0154) with measuring the loads acting on a Nomad aileron and flap whilst the aircraft is flying with specified flap setting during various manoeuvres. Initially the task concentrated on the aileron loads and to this end a single aileron was instrumented with 15 strain gauges to give the bending, shear and torque at five locations on the aileron, together with another gauge to measure the aileron control rod loads. This aileron was then fitted to the starboard wing of Nomad aircraft N24A-142, designated A18-407 by the RAAF. The aircraft was equipped with a data acquisition system permitting both onboard recording of the measured data and telemetry of the data to a ground station.

Since the fitting of this instrumentation, especially of the associated wiring looms, rendered the aileron non-standard, it was deemed prudent to verify that the aircraft was still aeroelastically stable within the envelope to be flown. It was decided that this would best be accomplished by conducting a flight flutter trial prior to the loads trials. This flight flutter trial was not intended to test the aeroelastic stability of the Nomad fleet in general but rather to verify that A18-407 when fitted with the instrumented aileron would not flutter within the envelope to be flown during the aileron-loads trial. Due to time constraints, the minimum of additional instrumentation commensurate with the limited aims of the trial (whilst still ensuring aircraft safety), could be fitted. Furthermore to ensure that the testing was valid, no further alteration was to be made to the aileron (i.e. no additional instrumentation was to be added to the aileron).

Prior to the flight test, a Ground Vibration Test (GVT) was carried out on the instrumented aircraft to provide data which would assist with analysis of the data from the flight flutter trial (Reference 1).

2. Instrumentation

As stated above, the starboard aileron had been fitted with strain gauges for the loads trial. The GVT (Reference 1) was used to determine which of these gauges would be suitable for monitoring aileron motion in flight. In addition two accelerometers were fitted to the aircraft's starboard wing tip - one on the front spar, one on the rear. Although a third accelerometer on the port wing tip would have been highly desirable, it was not considered absolutely necessary and so was not installed due to time constraints. This meant that symmetric modes could not be easily separated from the antisymmetric.

The aircraft was not fitted with any flutter excitation system, so excitation consisted of pilot inputs (aileron reversals, aileron strikes, rudder kicks, elevator impulses) and natural buffet/turbulence. (No pilot inputs were used at the flap overspeed test points i.e. at speeds greater than those authorised in the flight manual.)

3. Flight Test Matrix

The N24A aircraft has three selectable flap extension angles, namely 0°, 10° and 38°. Of these, 38° flap was considered the most critical from both a loads and a flutter point of view. Consequently the test plan called for the 0° and 10° flap cases to be completed before testing of the 38° flap case progressed beyond 75 KIAS. The flight test matrix was formulated to include test points at the following key speeds:

0° flap	
V_H	(143 KIAS)
V_{NE}	(166 KIAS)
10° flap	
V_{F10}	(120 KIAS)
$V_{F10}/0.9$	(132 KIAS)
38° flap	
V_{F38}	(107 KIAS)
$V_{F38}/0.9$	(118 KIAS)

All testing was carried out at 5000 feet AGL.

For the loads test the aircraft is to be flown in three weight conditions, namely:

light	6000 to 7500 lb
medium	7500 to 8500 lb
heavy	8500 to 9400 lb.

For the flutter test the philosophy adopted was to progressively expand the cleared envelope for the medium weight condition, followed by flights to the envelope extremes at the other weight conditions; however for the more critical 38° flap case, additional test points were flown near the end of the envelope for the light and heavy weight conditions.

The matrix of test points flown is shown in Table 1. Where testing of a flap/weight configuration extended over more than one flight, the last point flown was repeated to verify consistency between flights.

4. Test Methodology

The test aircraft was equipped with a telemetry system permitting the analysis of data whilst the aircraft was in flight, thus allowing the testing to proceed over a number of test points within any one flight. For each test point, the aircraft was smoothly accelerated in level flight from the previously cleared speed, during which the response of the aircraft vibration sensors was monitored on two eight-pen strip recorders for indications of low damping in any modes. Upon attaining the required speed the aircraft was stabilised for about 90 seconds during which the response of the aircraft to natural turbulence/buffet was obtained, and one channel (the wing leading edge accelerometer) was analysed by PSD methods whilst another channel (the wing trailing edge accelerometer) was analysed by Random Decrement methods (Reference 2). The aircraft was then subjected to a number of pilot inputs - aileron reversals, aileron strikes, rudder stamps and elevator strikes. After the first flight the rudder and elevator inputs were discontinued as they produced negligible response at the vibration sensor locations. Although the frequency content of the aileron inputs was severely limited, they did excite the low order aircraft modes and gave additional confirmation of aeroelastic stability as well as some loads information. Provided the analyses indicated no mode was likely to become unstable before the next test point, the aircraft was cleared to commence accelerating, and the whole process repeated.

Between flights the data from all the vibration transducers, as recorded on the on-board recorder (to eliminate any noise introduced by the telemetry process) were analysed by the Eigensystem Realisation Algorithm/Data Correlation (ERA/DC) method. This time-domain analysis procedure, described in Reference 3, was developed at NASA and is used within the aerospace community for system identification. It is more accurate than the curve fitting used with the Random Decrement, but its computational time precludes its use in the near real-time environment required whilst the aircraft is in flight. The numerical estimates of natural frequency and damping ratio presented in this report are all derived from ERA/DC analyses.

5. Results

Results from the trial are presented in two main forms, namely PSD "cascade" plots, and figures showing estimates of the natural frequencies and damping ratios. It was found both from the GVT (Reference 1) and also as the flutter trial progressed that the best channels for analysis were the two accelerometers on the wing and strain gauge 17.111 on the aileron. This is a torsion gauge at a location adjacent to the outboard face of the outboard hinge plate.

Figures 1a to 1c show the PSD curves for the medium weight condition at 0° flap for each of the relevant speeds in the test matrix. The PSD curves in each figure are drawn to the same scale, permitting a ready comparison of variations with airspeed. The sharp peak at 34.4 Hz in each PSD curve in Figure 1a corresponds to the propeller shaft rotation frequency; in the 80 KIAS curves of Figures 1b and 1c (measured at Test Point 1 in Table 1) this engine frequency has been filtered out. The filters were removed after this first Test Point and all subsequent PSD curves are for unfiltered data. Figures 2 and 3 show the PSD comparisons for the 10° and 38° flap cases.

Figure 4a to 4c show the variation with aircraft weight of the PSD measured at the highest speed flown at 0° flap (166 KIAS). Similarly Figures 5 and 6 show the PSD variation with weight for the 10° and 38° flap cases respectively.

The frequency parameter (or non-dimensional frequency), ν, is defined as:

$$\nu = (\omega b)/V$$

where ω is circular frequency
b is a reference length
V is airspeed.

At 166 KTAS, 30 Hz corresponds to a frequency parameter of 4 based on the wing chord, while at higher frequencies or lower speeds the frequency parameter is even higher. Experience shows that classical flutter is most unlikely to occur at higher frequency parameters, so the analysis concentrated on modes below 30 Hz. For those modes less than 30 Hz for which the level of response is sufficiently large to make analysis reliable, estimates of natural frequency and damping ratio are shown in Figure 7. The results plotted for frequency and damping are a combination of the results derived from the three transducers. The damping ratio (usually designated by ζ in American literature or by γ in British literature) is the ratio of damping to critical and is numerically half the damping coefficient, g, which is used in most regulatory literature of American origin. The logarithmic decrement, δ, is another measure of damping, and the three are related (for small damping) by:

$$g \approx \delta/\pi$$
$$\gamma \approx \delta/(2\pi)$$
$$g = 2\gamma$$

Figures 8 and 9 present the same information for the 10° and 38° flap cases respectively.

6. Discussion

6.1 0° flap

The PSD curves presented in Figures 1a to 1c show that there is a general increase in the response of the wing/aileron as the airspeed is increased from 80 KIAS to 166 KIAS (V_{NE}); however this is mainly due to an increase in the level of excitation (natural turbulence/buffet) although there are changes in the damping (and hence dynamic magnification) of some of the modes.

The first clearly defined peak in the PSD curves (especially in Figure 1c) is at 6.4 Hz. Neither the frequency nor the damping of this response (plotted as mode 1 in Figure 7) varies with airspeed (allowing for the experimental scatter associated with estimating these quantities), and so may not correspond to a structural mode. Since the excitation is not measured, such a peak in the response may result not from the dynamic magnification associated with a structural mode but rather be caused by a concentrated excitation at that frequency. The very limited spatial distribution of transducers does not allow an estimation of the displacement pattern (i.e. mode shape), not even of its symmetry/antisymmetry. However since the apparent frequency and damping of this response do not alter with airspeed throughout the flight envelope, it does not represent an aeroelastic problem.

The other modes whose frequencies and damping ratios are shown in Figure 7 display more interaction with the aerodynamic forces. In particular mode 2, at about 7 Hz, displays a pronounced decrease in damping as speed is increased, reaching a level of about 1.4% near 135 KIAS, before increasing again as V_{NE} is approached. The level of damping at curve's minimum is sufficient to confirm aeroelastic stability at that speed. The other modes are all well damped throughout the envelope.

Figures 4a to 4c show a comparison of the PSD curves calculated at 166 KIAS for the three weight conditions. These show that the aeroelastic behaviour of the aircraft at the light and heavy weight conditions is essentially the same as at the medium weight condition.

6.2 10° flap

As with the 0° flap case above, the PSD curves in Figures 2a to 2c show a general increase in response levels as the airspeed is increased. In particular Figure 2a and 2b show an increase in the peak near 7 Hz but the damping estimated from this response does not alter greatly (mode 2 in Figure 8). As with the 0° flap case, there is a response at 6.4 Hz which is invariant with airspeed whilst the other modes show varying degrees of interaction with the aerodynamics; however all of these modes display adequate damping, even at the overspeed test point.

Figures 5a to 5c show the effect of aircraft weight variation at the highest speed point for this flap angle (132 KIAS). These show that the aeroelastic characteristics of the aircraft at the heavy and light weight conditions is not significantly different to that at the medium weight.

6.3 38° flap

Figures 3a to 3c show the variation in response of the aircraft to increasing airspeed. Again there is an increase in the response of the airframe as the airspeed is increased but the derived estimates of natural frequency and damping ratio (Figure 9) show that there is adequate damping in the relevant modes even at the overspeed test points. (The authorised V_{F38} is 108 KIAS whereas testing was carried out to 124 KIAS.) The response at 6.4 Hz (mode 1) is again present but, as with the other flap angle cases above, it does not appear to interact with the aerodynamics.

Figures 6a to 6c present the PSD curves which show that the light and heavy weight conditions have similar aeroelastic stability to the medium weight case.

7. Conclusions and Recommendations

Nomad aircraft A18-407, fitted with a non-standard aileron, has undergone flight flutter testing through a flight envelope more extensive than that to be used for loads measurements. Analysis of data derived from the flutter trial shows that the critical modes have sufficient damping throughout the test envelope.

From an aeroelastic perspective it is recommended that the loads test program for aircraft A18-407 fitted with the instrumented aileron on the starboard wing, proceed without modification.

8. References

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2. Farrell PA, Ryall TG. *Flight flutter test techniques at ARL.* ARL Structures Technical Memorandum 569, August 1990.

3. Juang, J-N, Cooper JE, Wright JR. *An eigensystem realization algorithm using data correlations (ERA/DC) for modal parameter identification.* Control Theory and Advanced Technology, Vol 4, No 1, pp 5-14, 1988.

Table 1. Test Points flown.

FLIGHT	DATE	TEST POINT	WEIGHT	FLAP	AIRSPEED
1	5/4/95	1	MEDIUM*	0	80 KIAS
		2	MEDIUM*	0	100 KIAS
2	11/4/95	3	MEDIUM	0	100 KIAS
		4	MEDIUM	0	120 KIAS
		5	MEDIUM	0	143 KIAS
		6	MEDIUM	10	75 KIAS
		7	MEDIUM	10	90 KIAS
		8	MEDIUM	10	100 KIAS
		9	MEDIUM	38	65 KIAS
		10	MEDIUM	38	75 KIAS
3	11/4/95	5R	MEDIUM	0	143 KIAS
		11	MEDIUM	0	155 KIAS
		12	MEDIUM	0	166 KIAS
		8R	MEDIUM	10	100 KIAS
		13	MEDIUM	10	110 KIAS
		14	MEDIUM	10	120 KIAS
		15	MEDIUM	10	132 KIAS
4	12/4/95	16	LIGHT	0	166 KIAS
		17	LIGHT	10	132 KIAS
5	12/4/95	18	HEAVY	0	166 KIAS
		19	HEAVY	10	132 KIAS
6	19/4/95	10R	MEDIUM	38	75 KIAS
		20	MEDIUM	38	85 KIAS
		21	MEDIUM	38	95 KIAS
7	21/4/95	21R	MEDIUM	38	95 KIAS
		22	MEDIUM	38	100 KIAS
		23	MEDIUM	38	107 KIAS
		24	MEDIUM	38	112 KIAS
		25	MEDIUM	38	124 KIAS
8	21/4/95	26	LIGHT	38	107 KIAS
		27	LIGHT	38	112 KIAS
		28	LIGHT	38	124 KIAS
9	21/4/95	29	HEAVY	38	107 KIAS
		30	HEAVY	38	112 KIAS
		31	HEAVY	38	118 KIAS
		32	HEAVY	38	124 KIAS

where * indicates forward CG
and R indicates the repeat of a previous Test Point

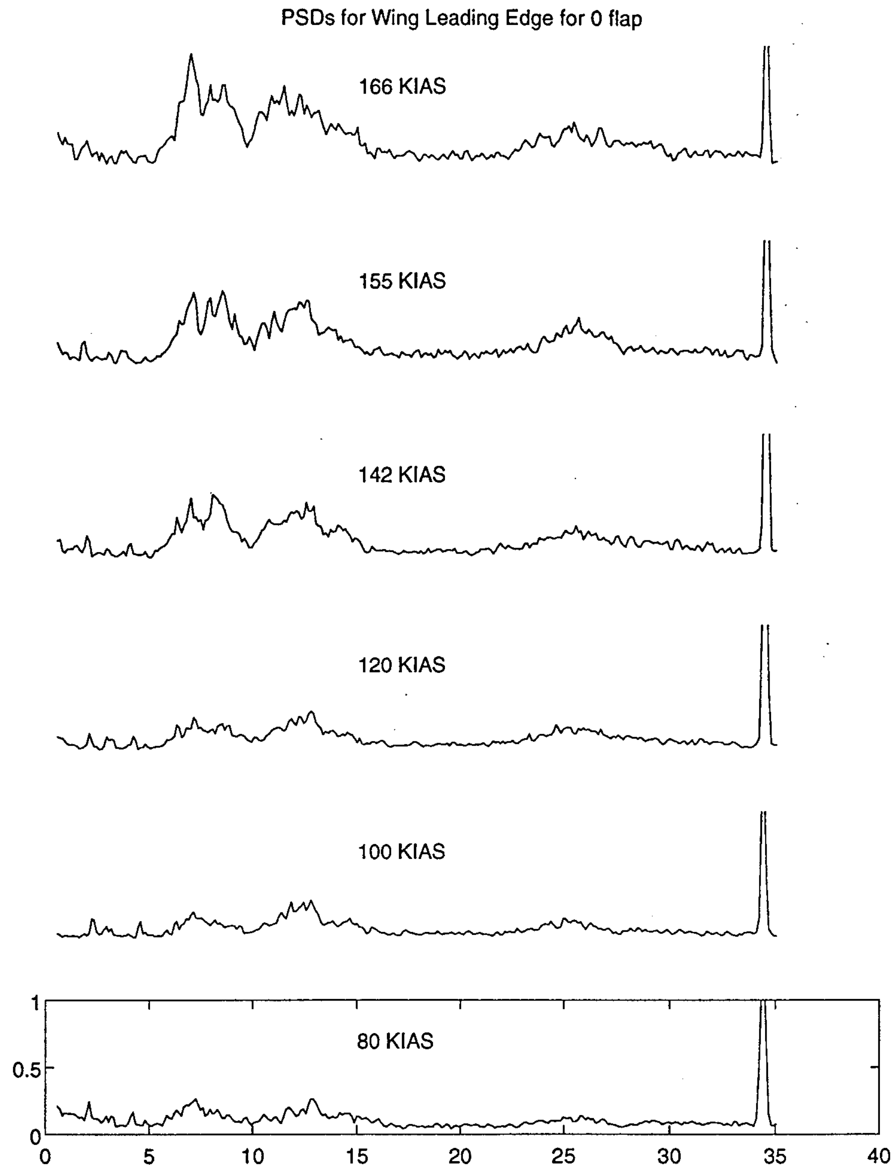

Figure 1a. *PSD curves - 0° flap angle - wing leading edge accelerometer*

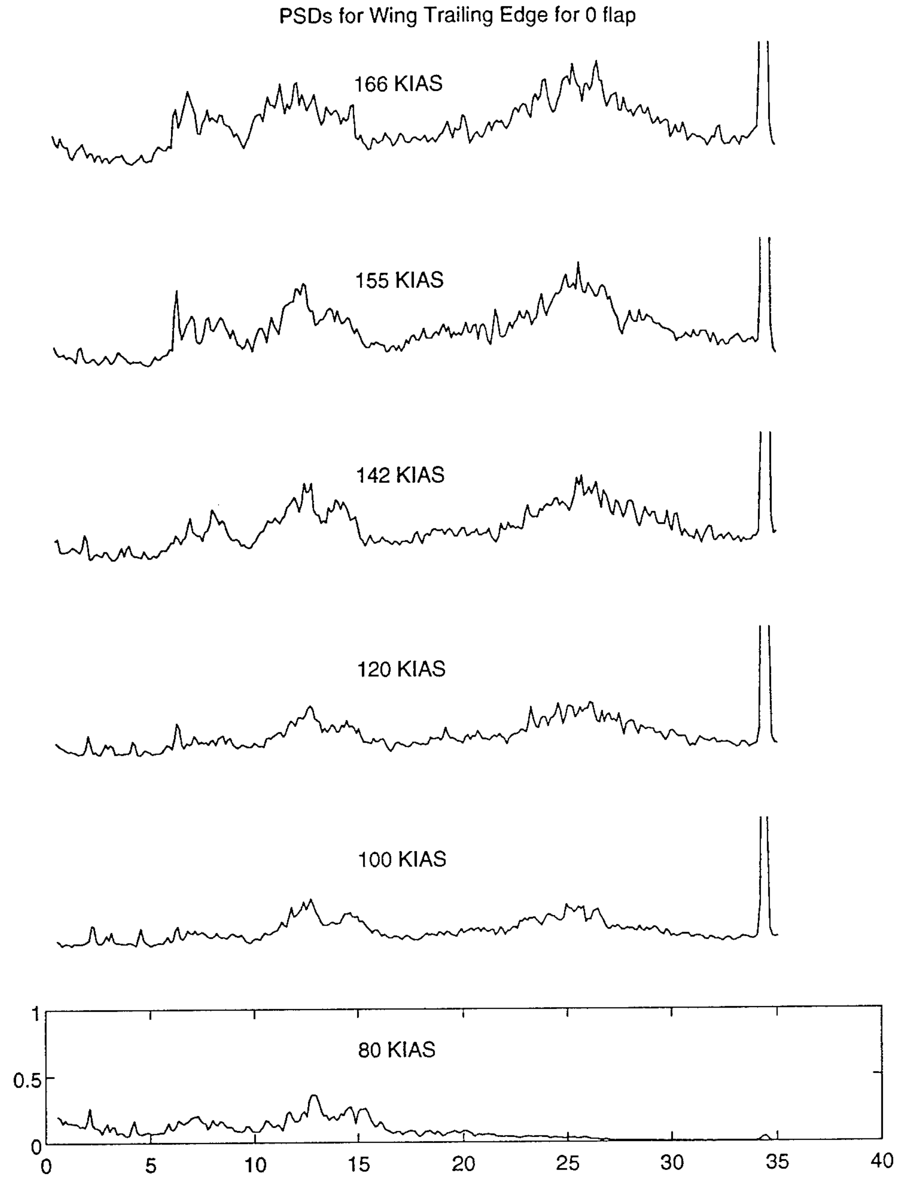

Figure 1b. PSD curves - 0° flap angle - wing trailing edge accelerometer

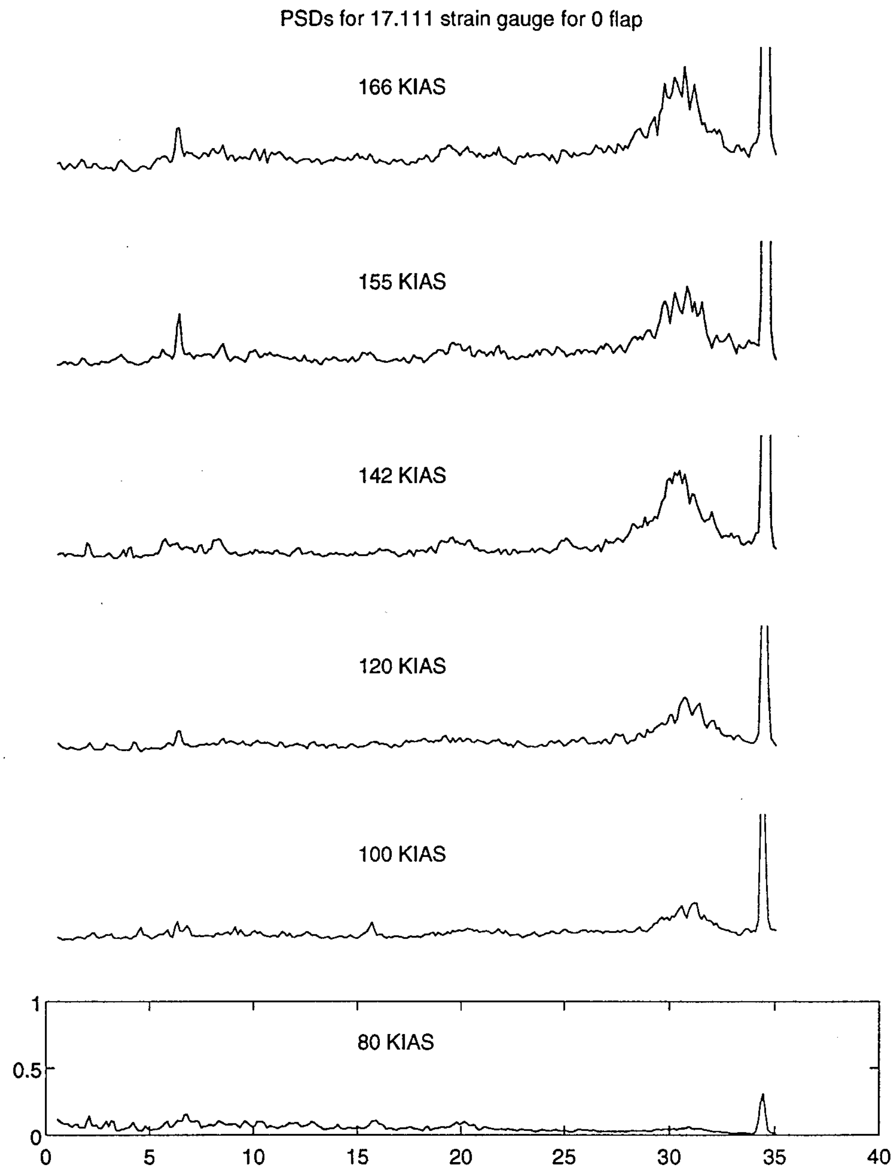

Figure 1c. *PSD curves - 0° flap angle - strain gauge 17.111*

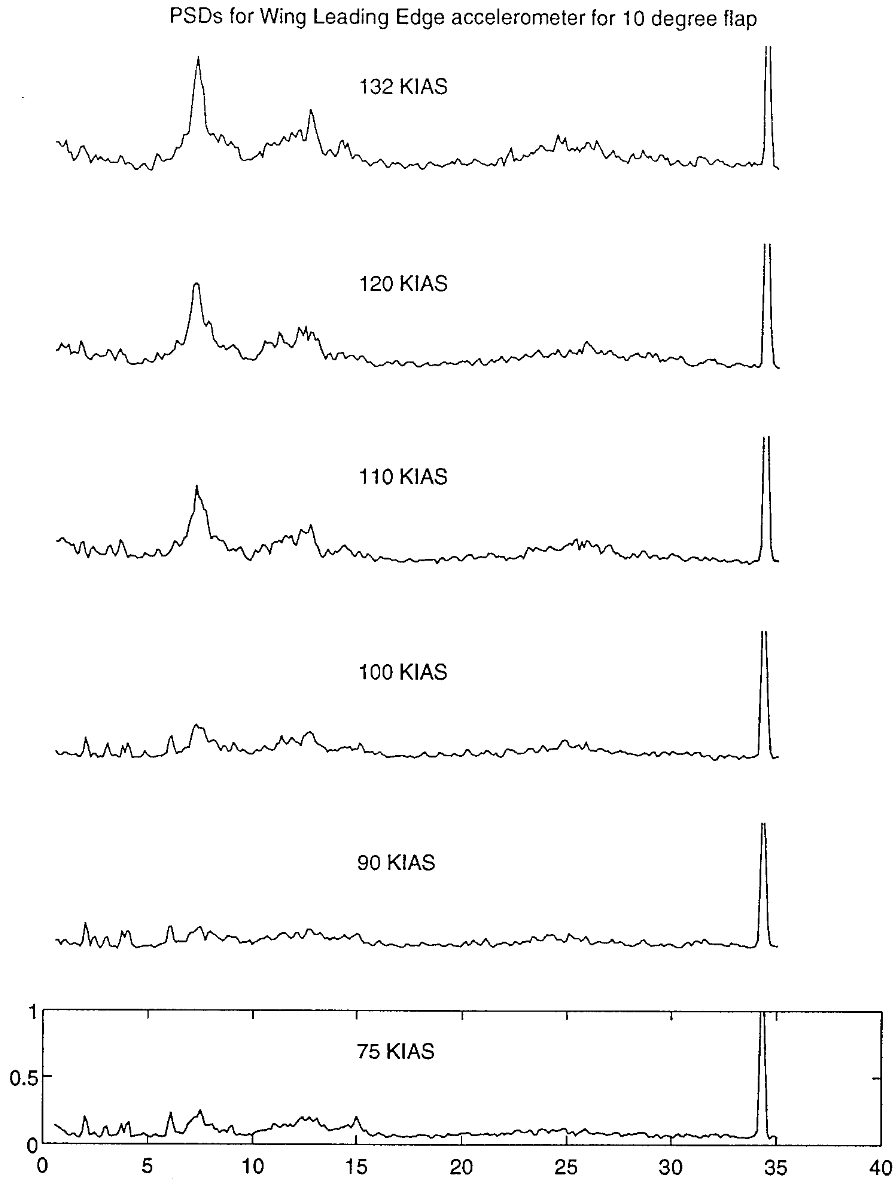

Figure 2a. *PSD curves - 10° flap angle - wing leading edge accelerometer*

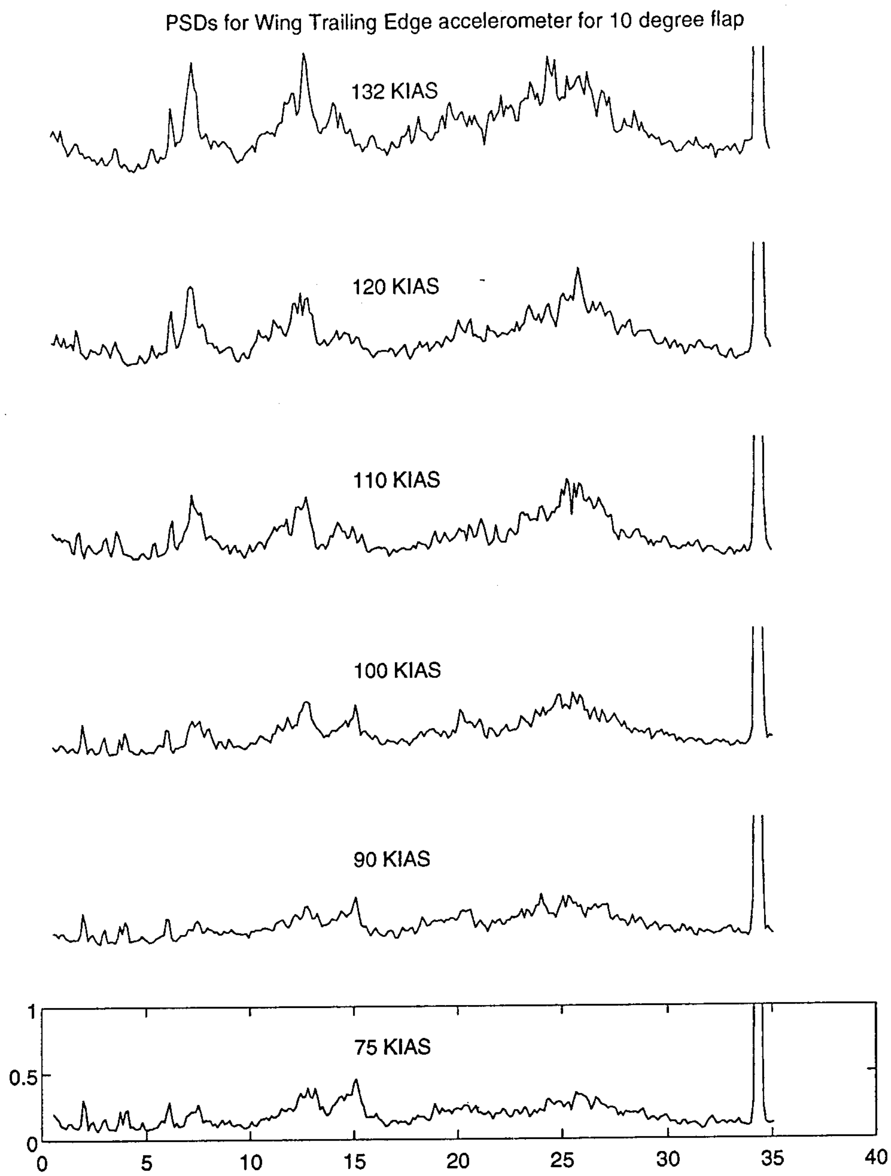

Figure 2b. *PSD curves - 10° flap angle - wing trailing edge accelerometer*

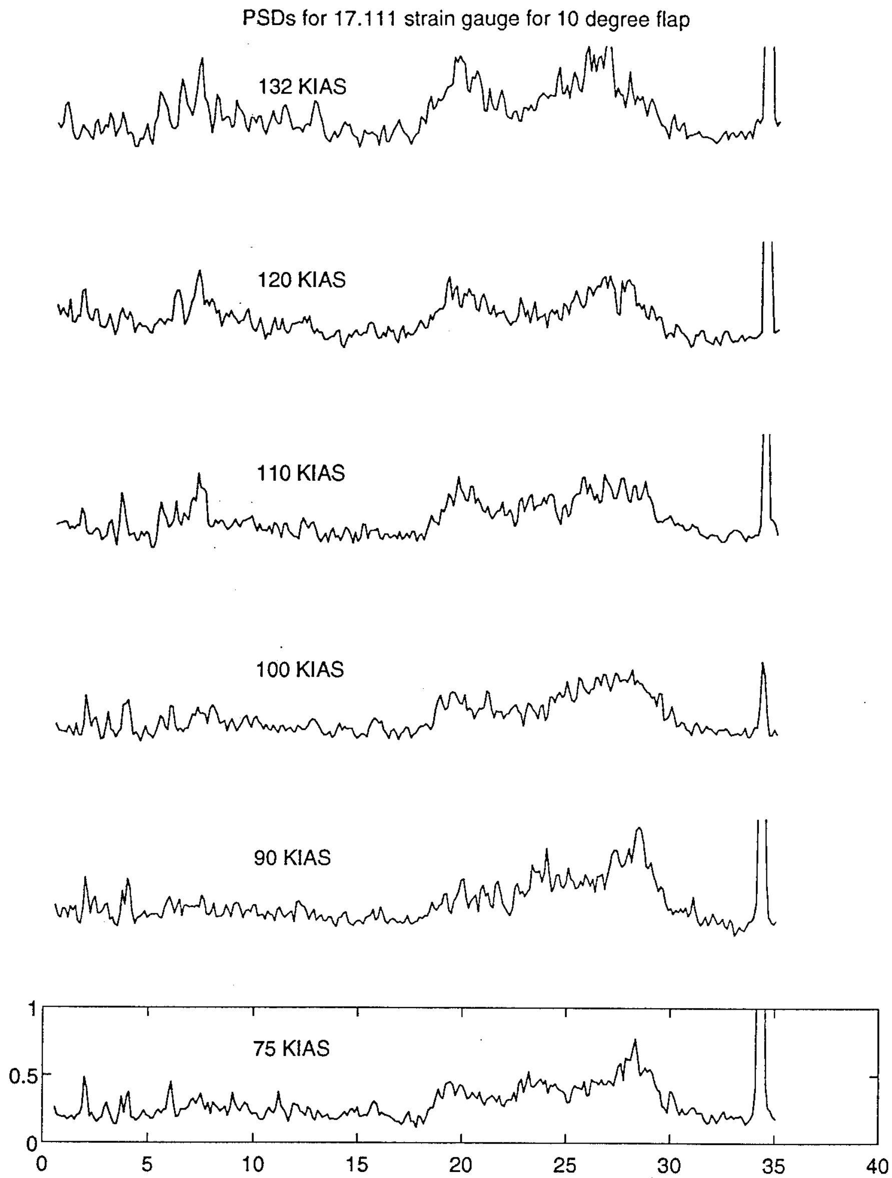

Figure 2c. *PSD curves - 10° flap angle - strain gauge 17.111*

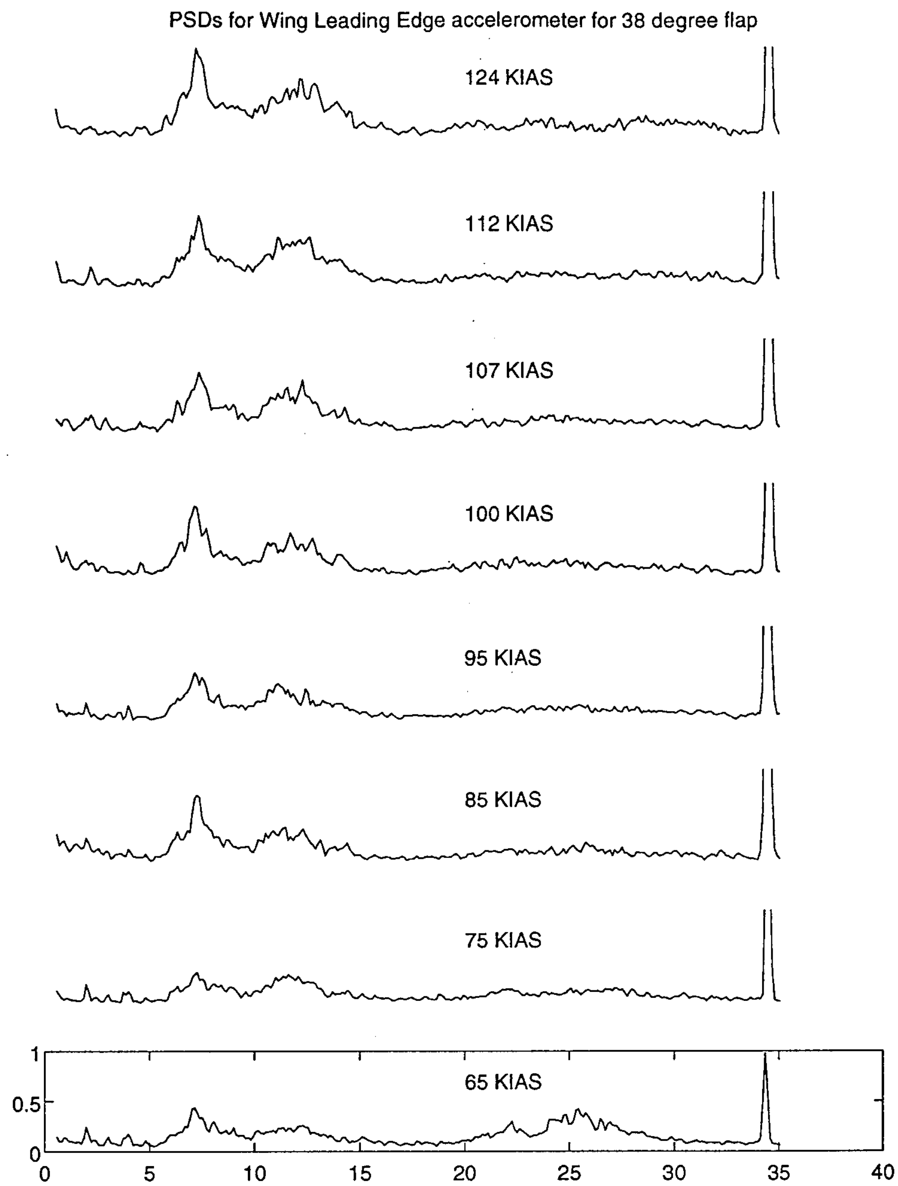

Figure 3a. PSD curves - 38° flap angle - wing leading edge accelerometer

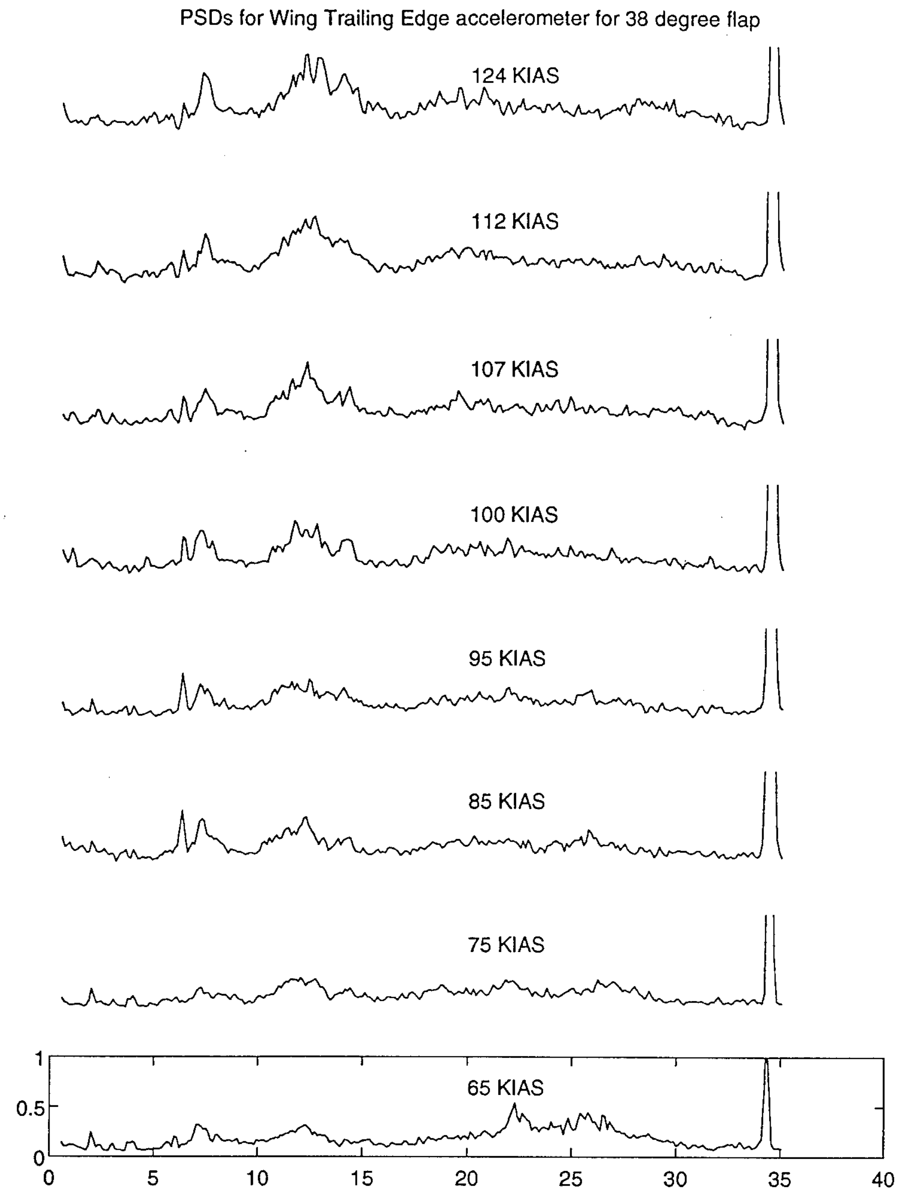

Figure 3b. PSD curves - 38° flap angle - wing trailing edge accelerometer

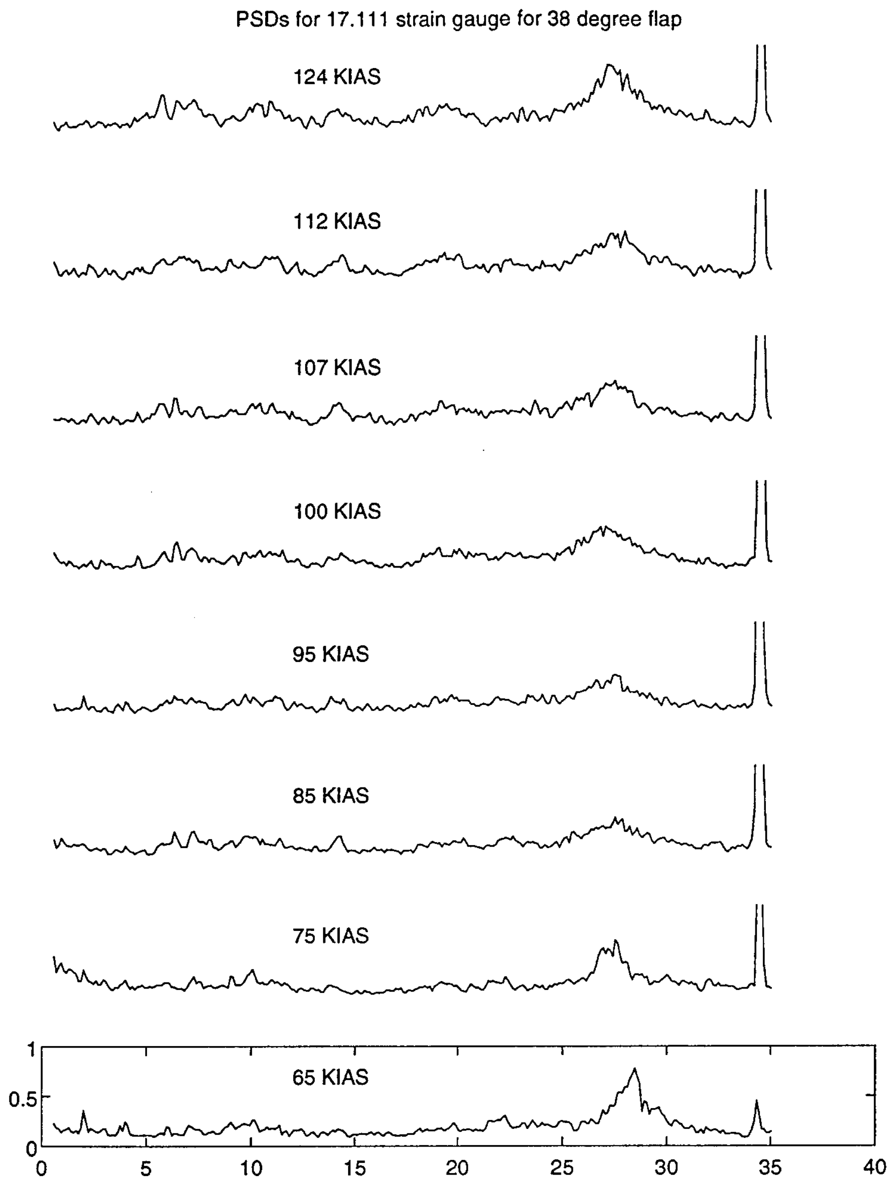

Figure 3c. PSD curves - 38° flap angle - strain gauge 17.111

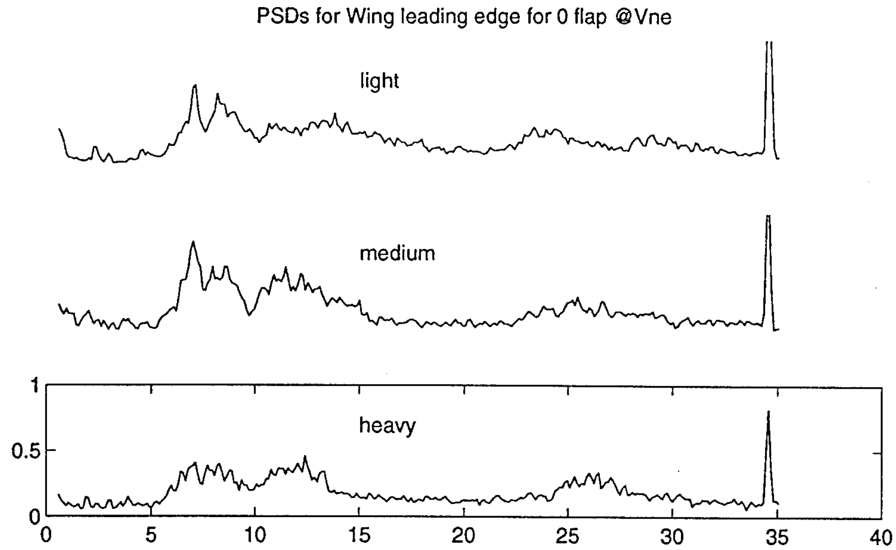

Figure 4a. *PSD curves for light, medium, heavy weights at 0° flap - wing leading edge accelerometer at 166 KIAS*

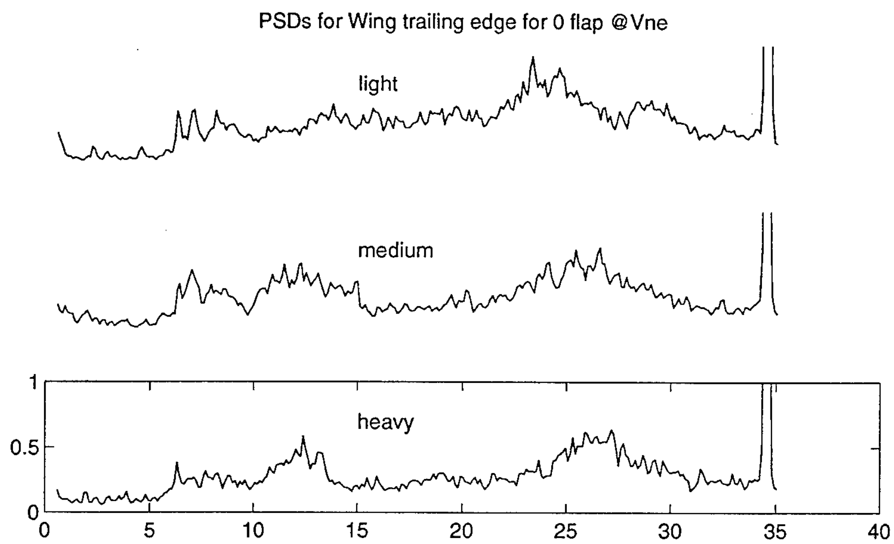

Figure 4b. *PSD curves for light, medium, heavy weights at 0° flap - wing trailing edge accelerometer at 166 KIAS*

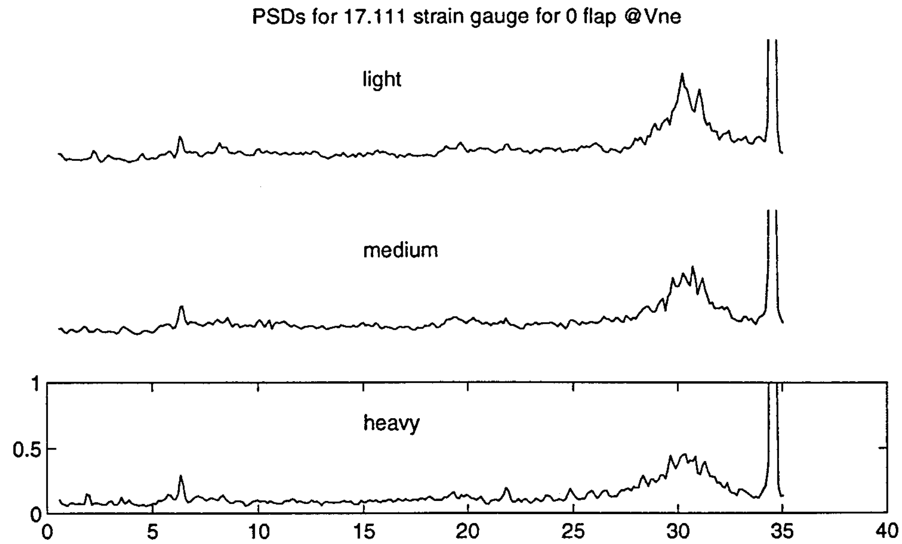

Figure 4c. *PSD curves for light, medium, heavy weights at 0° flap - strain gauge 17.111 at 166 KIAS*

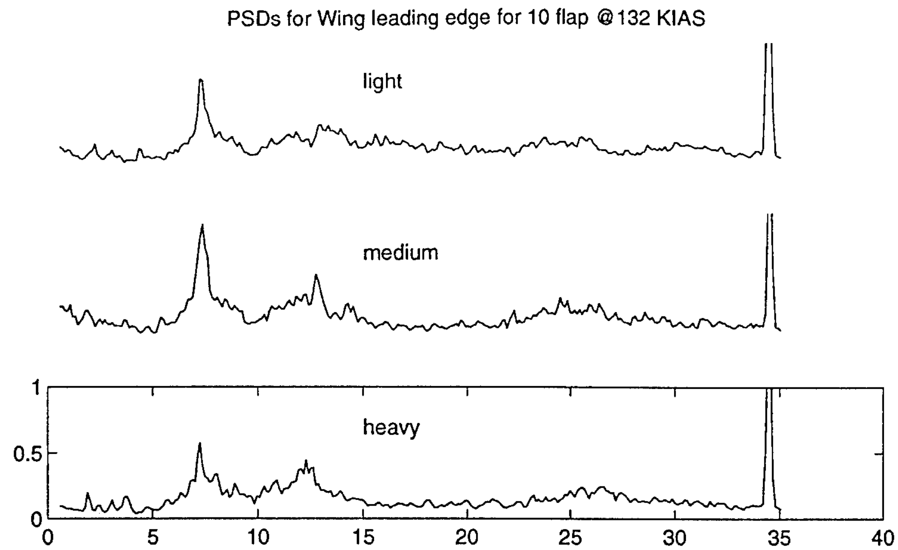

Figure 5a. *PSD curves for light, medium, heavy weights at 10° flap - wing leading edge accelerometer at 132 KIAS*

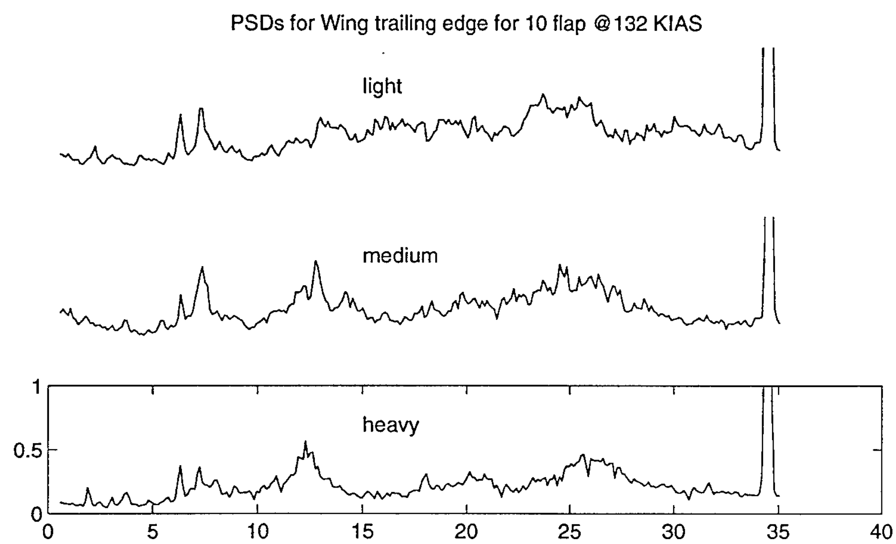

Figure 5b. *PSD curves for light, medium, heavy weights at 10° flap - wing trailing edge accelerometer at 132 KIAS*

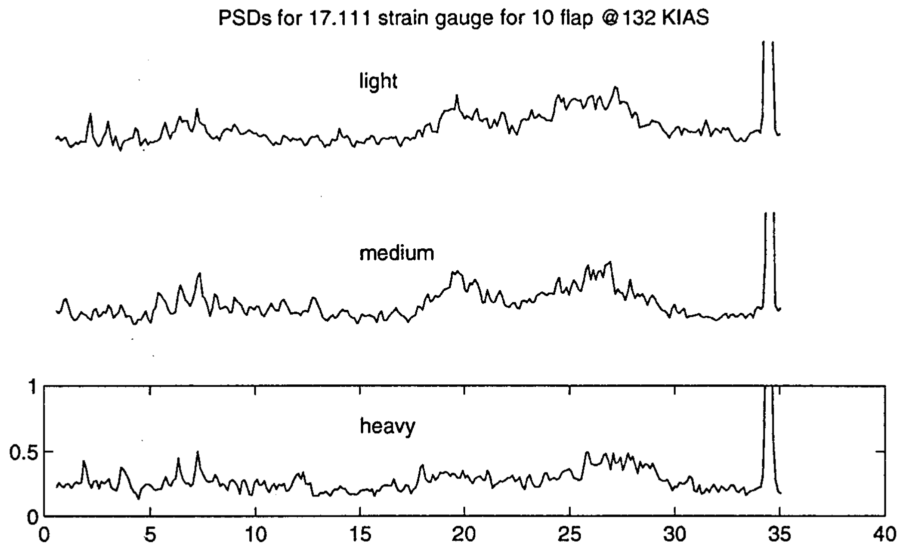

Figure 5c. PSD curves for light, medium, heavy weights at 10° flap - strain gauge 17.111 at 132 KIAS

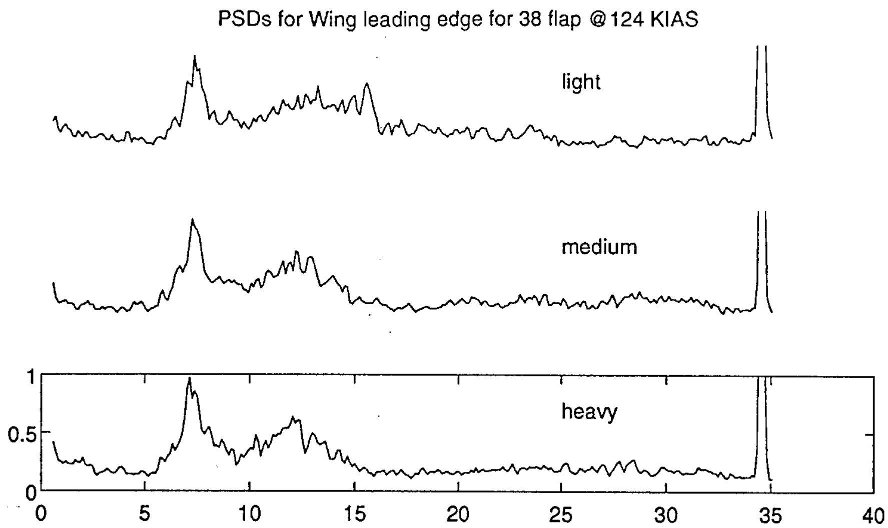

Figure 6a. *PSD curves for light, medium, heavy weights at 38° flap - wing leading edge accelerometer at 124 KIAS*

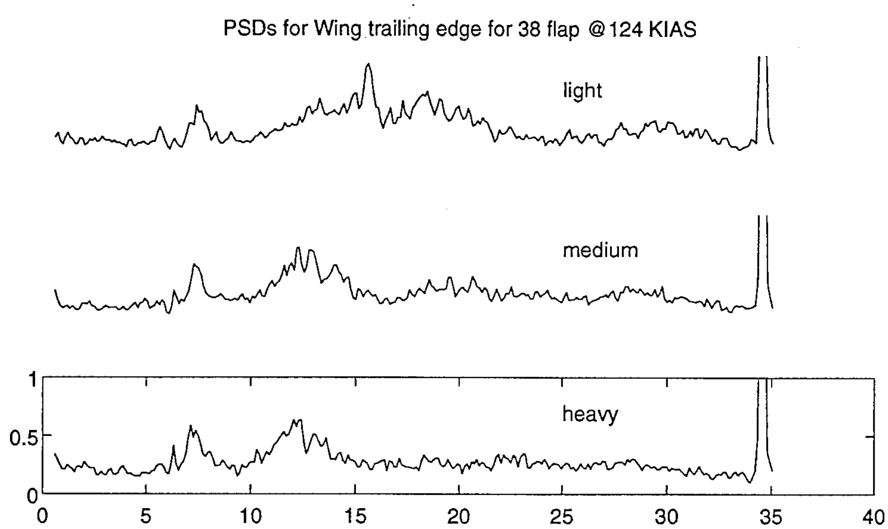

Figure 6b. *PSD curves for light, medium, heavy weights at 38° flap - wing trailing edge accelerometer at 124 KIAS*

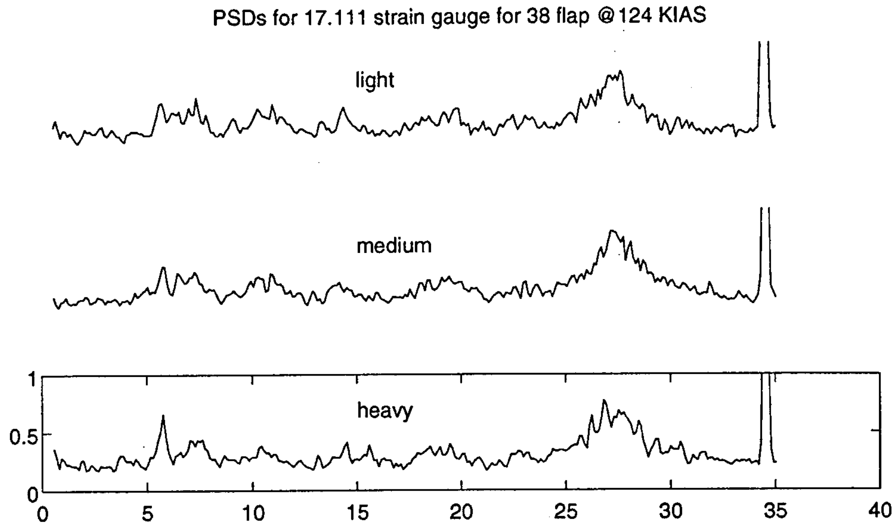

Figure 6c. *PSD curves for light, medium, heavy weights at 38° flap - strain gauge 17.111 at 124 KIAS*

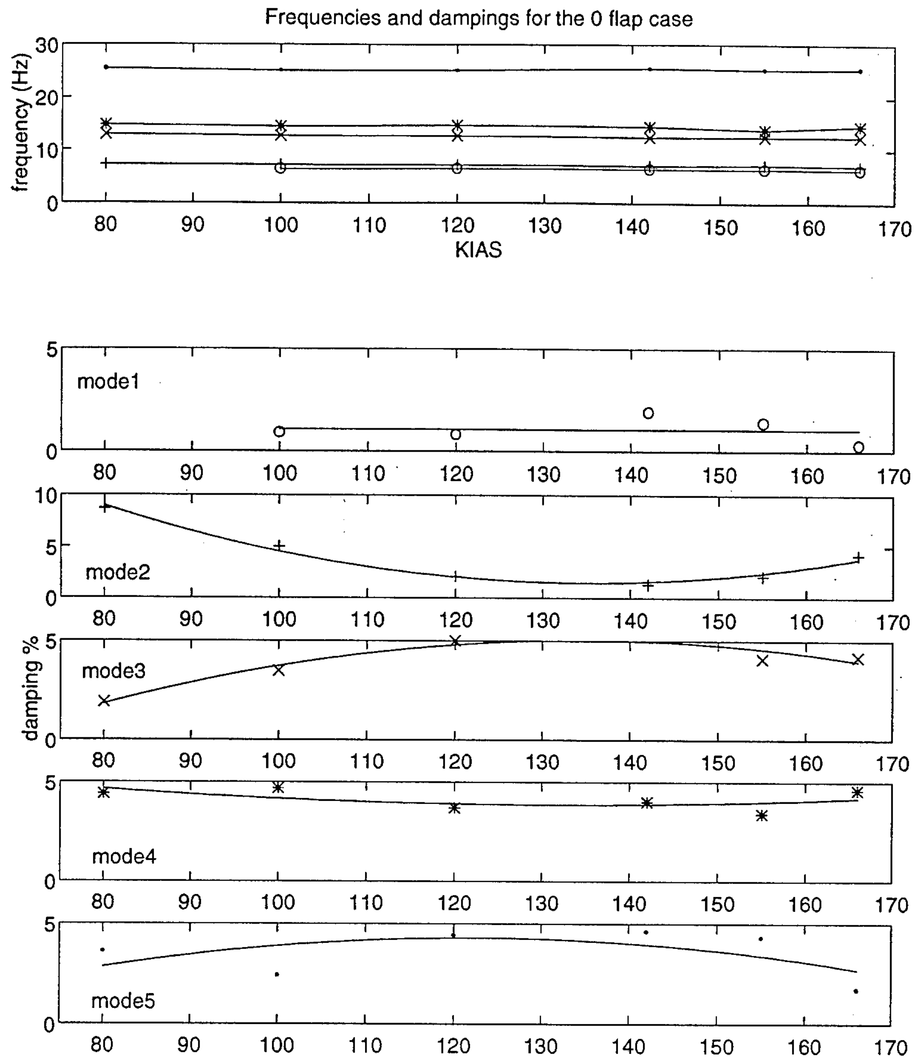

Figure 7. Natural frequency and damping ratio estimates, medium weight - 0° flap

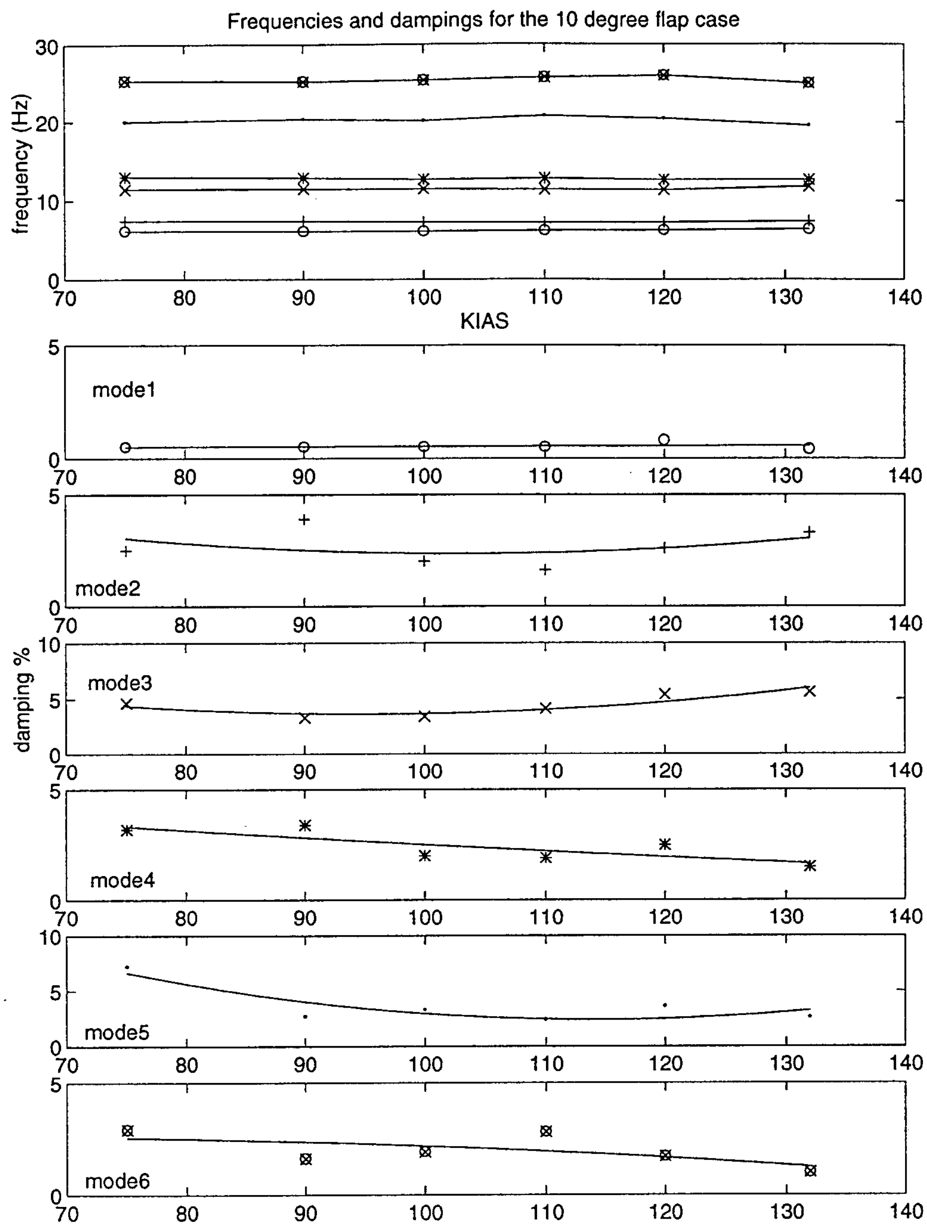

Figure 8. Natural frequency and damping ratio estimates, medium weight - 10° flap

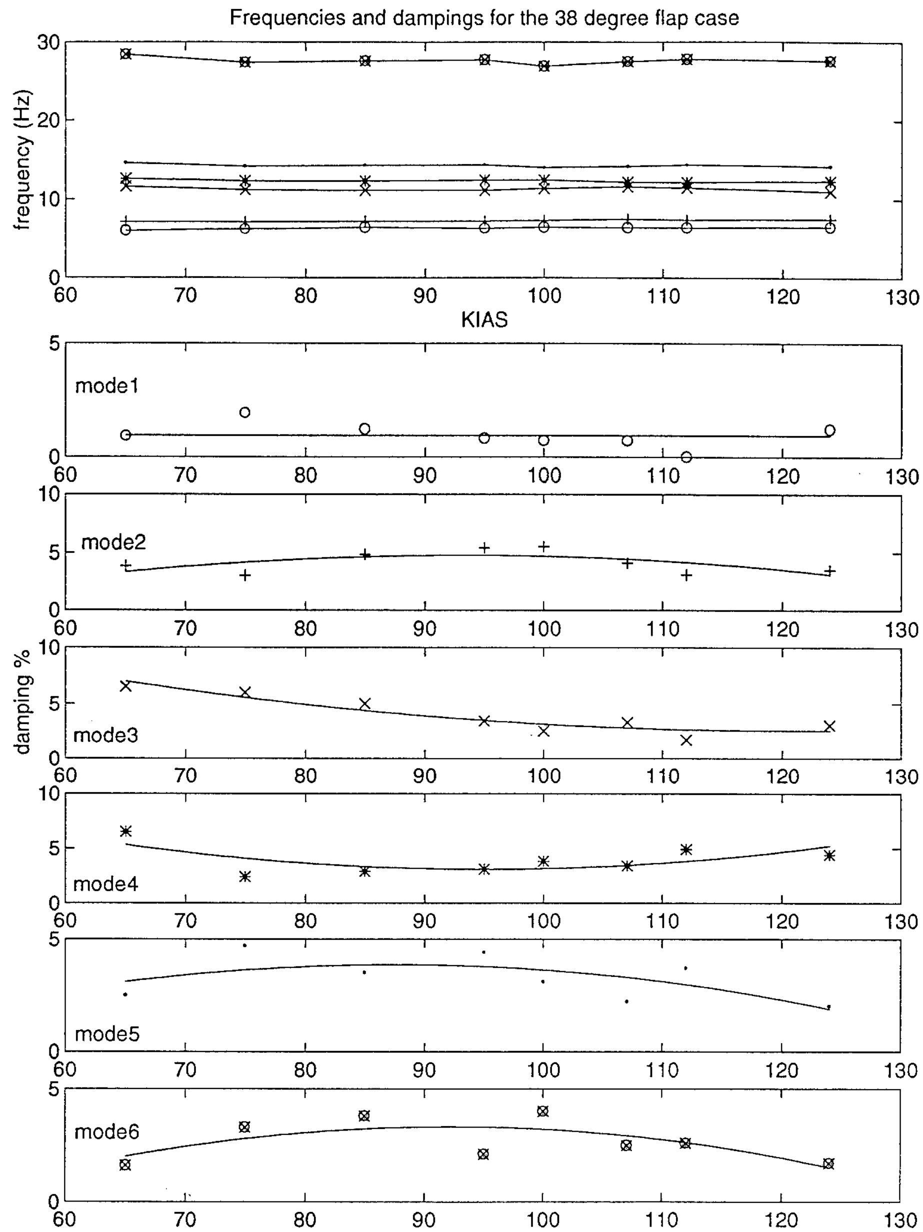

Figure 9. *Natural frequency and damping ratio estimates, medium weight - 38° flap*

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P.A. Farrell and S.A. Dunn

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MELBOURNE VIC 3001 AUSTRALIA

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A Nomad aileron was modified by the addition of strain gauges and associated wiring, to permit its use in loads-measurement trials. This modification rendered the aileron non-standard, so a flight flutter trial was conducted to verify the aeroelastic stability of the loads aircraft when fitted with this aileron. This report describes the flight flutter trial and presents the results.

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