C.P. No. 898

C.P. No. 898

MINISTRY OF AVIATION

AERONAUTICAL RESEARCH COUNCIL
CURRENT PAPERS

Measurements of the Rolling Response of a Fighter Aeroplane (Hunter Mk.6) to Turbulent Air and a Comparison with Theory

by

J. Burnham

LONDON: HER MAJESTY'S STATIONERY OFFICE

1966

THREE SHILLINGS NET

U.D.C. No. 533.6.013.153:551.551:533.6.015.2:533.694.51:533.6.013.47

C.P. No.898
February 1965

MEASUREMENTS OF THE ROLLING RESPONSE OF A FIGHTER AEROPLANE (HUNTER MK.6) TO TURBULENT AIR AND A COMPARISON WITH THEORY

by

J. Burnham

SUMMARY

Measurements of rate of roll and aileron deflection have been made during the landing approach, in turbulent air. These have been used to compute spectral densities of the rate of roll which would have occurred with the ailerons fixed. The results show good agreement with comparable spectra which were calculated theoretically.

Replaces R.A.E. Tech. Report No.65033 - A.R.C.26996

CONTENTS

1 INTRODUCTION

In most cases, the need to provide satisfactory roll control during flight on the landing approach in a turbulent cross-wind dictates the amount of aileron power which must be built into an aeroplane. The advent of highly swept and inertially slender designs has increased the difficulty of satisfying this requirement, for such aircraft have a greater response to a unit side gust than that of the more conventional designs of the past. The way in which more modern types respond to atmospheric turbulence may well differ in character as well as in magnitude from that of the older generation. For example; their dutch roll ratios and dampings may be quite different. Difficulties therefore exist in applying, to these new aircraft, design requirements which derive from experience of older, straight winged, types. Methods must be developed in which the dynamics of the aircraft response are taken into account, and to do this a more fundamental understanding is needed of the rolling response of aircraft to turbulent air.

A starting point is provided by a paper by Zbrozek[1], in which he develops a method for calculating the rolling response of aircraft to stationary random turbulence and applies it in several typical cases. The major part of his paper is concerned with the aircraft response with controls fixed, although the effects of a number of aileron control laws are briefly considered. Following this theoretical work, experimental measurements have been made in order to check the theory and to obtain, if possible, some understanding of the way in which a human pilot controls an aeroplane during flight through turbulent air. The latter work will be the subject of a further report. The present paper is concerned solely with the 'controls fixed' response of the aeroplane, which was a Hawker Hunter F6 (prototype), a photograph of which is given in Fig.1; and with the comparison of the results obtained with those calculated theoretically for a similar aeroplane (type A) in Ref.1.

2 THE FLIGHT EXPERIMENT

Ref.1 gives the spectral density of bank angle arising from unit rms gust velocity. The effects both of lateral gusts and of inequality of vertical gusts across the aircraft's span are taken into account, but so far as the present work is concerned, the effects of the latter are negligible. Aeroplane A of Ref.1 corresponds to that used in the present tests, which were made at a speed of 150 knots. Since flight on the approach is of the greatest interest, and the measurements described here are part of a series in which pilot control actions are being investigated, the test data were obtained on actual approaches from which the aircraft touched down, although for the present purpose it could equally well have been obtained in nominally straight and level flight. The stability derivatives used in Ref.1 correspond to the test aeroplane with flaps up, so that the present data were obtained in this configuration.

The spectral density of rate of roll decays less rapidly with frequency than that of bank angle. In order to achieve greater accuracy at the higher frequencies it was therefore decided that rate of roll would be measured in flight. Aileron angle was also measured and both quantities were continuously recorded. It was not practicable to measure the lateral component of gust velocity directly.

The theoretical results with which the present measurements are compared were calculated under the assumption that the ailerons were fixed. The aileron movements which occurred in flight were found to have too great an effect on the roll rates which were measured for a direct comparison between spectra of the latter and the theoretical results to have much value. However if the frequency response of the aeroplane in roll in response to aileron inputs is known, it is possible (as will be described in Section 3) to compute the spectral density of the rate of roll which would have occurred had the ailerons not moved (hereinafter referred to as the 'uncontrolled rate of roll') from measurements of the spectra and cross spectra of rate of roll and aileron angle. To determine the frequency response in roll, aileron pulses were applied during flight in the test configuration through smooth air at a height of 1000 ft.

3 THE RESULTS OBTAINED

3.1 The aircraft frequency response in roll to aileron input

Of the time-histories of the roll response to aileron pulse inputs which were obtained, two were selected in which the aircraft returned accurately to wings level flight as the response decayed. Rate of roll and aileron angle were read from these at 1/16 sec intervals and the amplitude ratio and phase difference of the frequency response computed from them by Fourier integration. The results are shown in Fig.2. Also shown are theoretical values obtained, using the same stability derivatives as in Ref.1, from formulae given in Ref.2. The experimental and theoretical amplitude ratios differ by a constant factor, because too low a value of the rolling moment due to aileron deflection derivative (ℓ_ξ) was used in the theoretical calculation. This derivative does not affect the aircraft response to gusts. Other than this, the agreement between measured and theoretical values of amplitude ratio is good. In the case of the difference between the theoretical and measured values for phase, the discrepancies at the lower frequencies are felt to be due to experimental error. The constant difference at the higher frequencies is due to different phase lags in the instrumentation, the amplitude ratios of which were flat to much higher frequencies than are considered here. From the agreement shown in Fig.2 it therefore appears that the stability derivatives used in Ref.1 provides an adequate description of the test aeroplane. The actual values of the roll frequency response to aileron used in computing the spectra of uncontrolled rate of roll are shown in Fig.2.

3.2 The spectral densities of uncontrolled rate of roll

The spectral density of uncontrolled rate of roll, $\phi_{pu}(f)$, may be obtained from the spectral densities of measured rate of roll, $\phi_{pc}(f)$, and aileron angle, $\phi_{\xi}(f)$, their cross spectral density, $\psi_{pc,\xi}(f)$, and the frequency response of rate of roll to aileron deflection, $P_{\xi}(f)$, by using the relation,

$$\phi_{pu}(f) = \phi_{pc}(f) + |P_{\xi}(f)|^2 \phi_{\xi}(f) - 2\,R\{P_{\xi}(f)\,\psi_{pc,\xi}(f)\} \qquad (1)$$

where R denotes 'the real part of'.

The records of rate of roll and aileron angle, for the eight approaches which were made in the configuration appropriate to the present tests, were read at 1/16th sec intervals and this data used to compute the spectral and cross spectral densities of these quantities. These were then used, together with the frequency response described in Section 3.1, to compute the spectral densities of uncontrolled rate of roll. The results obtained are shown in Fig.3 in non-dimensional form as the ratios of the computed spectral densities to the mean squares of the uncontrolled rates of roll for each approach.

4 COMPARISON BETWEEN EXPERIMENT AND THEORY

The theoretical result from Ref.1 appropriate to the test configuration is also shown in Fig.3, replotted as the same non-dimensional spectral density. It will be seen that it agrees well with the experimental results. The discrepancies at the ends of the frequency range covered, where the experimental points have rather larger spectral densities than is predicted by theory, may well be due to the former having been determined from finite samples; this has the effect of spreading the energy from the peak over the whole frequency range.

The spectral density of uncontrolled rate of roll is essentially the product of two factors; the spectral density of the lateral component of the turbulence through which the aircraft flew and its frequency response in roll to this component. Over the range of wavelengths covered by the measurements, it has been fairly well established that the spectrum of atmospheric turbulence at low altitudes has the shape used in Ref.1. The present results can therefore be regarded as showing agreement between the theoretical and experimental shapes of the modulus of the frequency response of the aircraft to lateral gusts. Since the lateral component of the turbulence was not measured directly, it has not been possible to determine the ratio between its rms and that of the uncontrolled rate of roll. However, the data of Ref.1 have been used to compute the rms lateral gust velocities corresponding to the rms uncontrolled rates of roll. These values correspond well with the pilots descriptions of the turbulence; the values being between 2 and 5 feet per second and the descriptions of the turbulence ranging from light to moderate.

5 CONCLUSIONS

Spectral densities of the rate of roll which would have occurred if the ailerons had not been moved have been computed from flight measurements in turbulent air and were found to be in good agreement with similar spectra calculated theoretically in Ref.1. A detailed experimental verification of this theory must await more detailed measurements, which would include direct measurements (which were not possible in the present case) of the turbulence through which the aircraft flew.

REFERENCES

No.	Author	Title, etc.
1	J.K. Zbrozek	Theoretical Study of the rolling response of aircraft to turbulent air. A.R.C. R. & M. 3423, April 1961
2	J.K. Zbrozek	On the extraction of stability derivatives from full scale flight data. A.R.C. 20276 April 1958

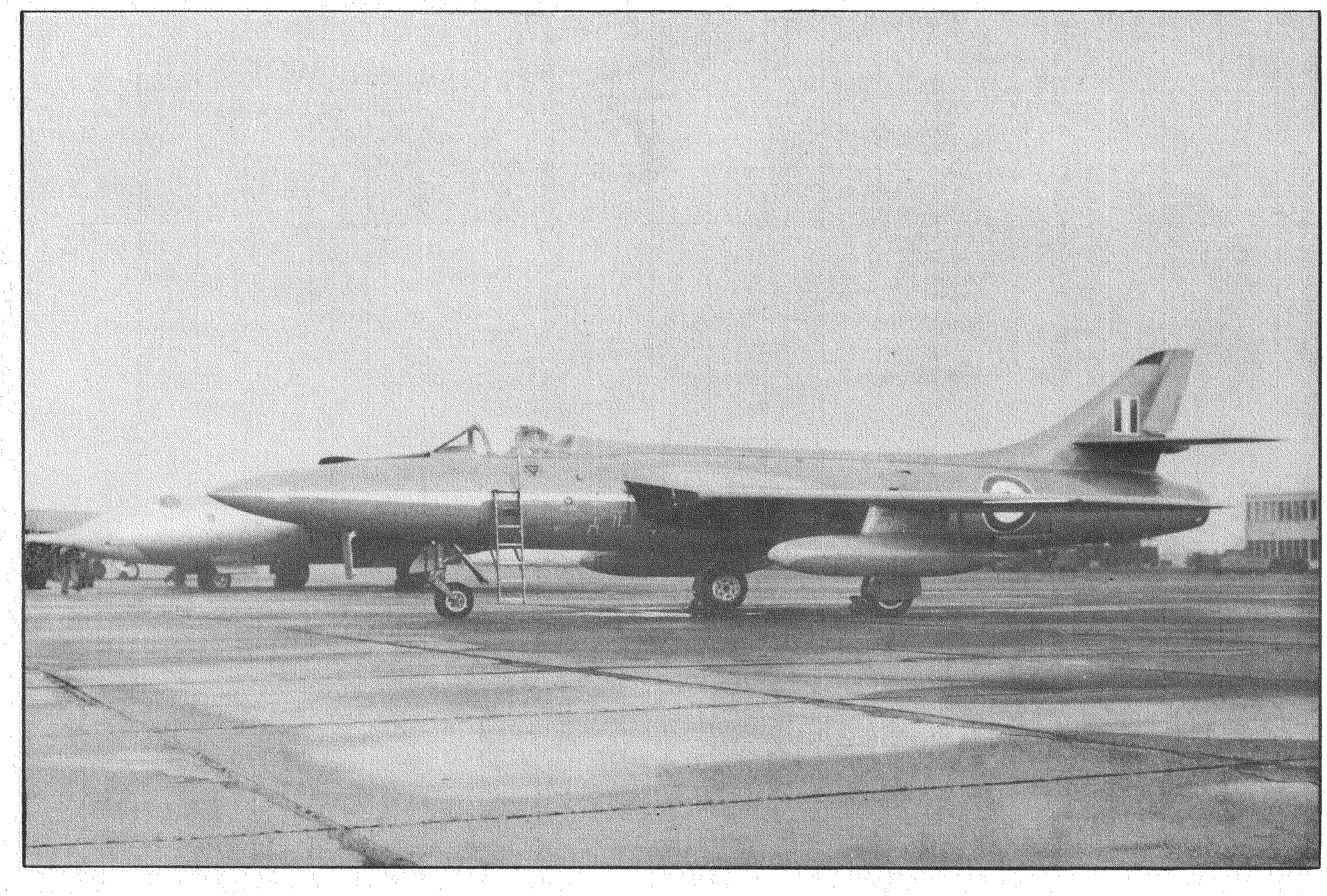

Fig.1 The test aeroplane

$$\text{THEORY}: \frac{\hat{p}}{\xi} = 77\ 5\ \frac{\iota\omega\left((\iota\omega)^2 \mp 0\ 8\ \iota\omega + 15{\cdot}4\right)}{0\ 92\left(\iota\omega + 0{\cdot}1012\right)\left(\iota\omega + 4\ 435\right)\left((\iota\omega)^2 + 1{\cdot}244\ \iota\omega + 30\ 6\right)}$$

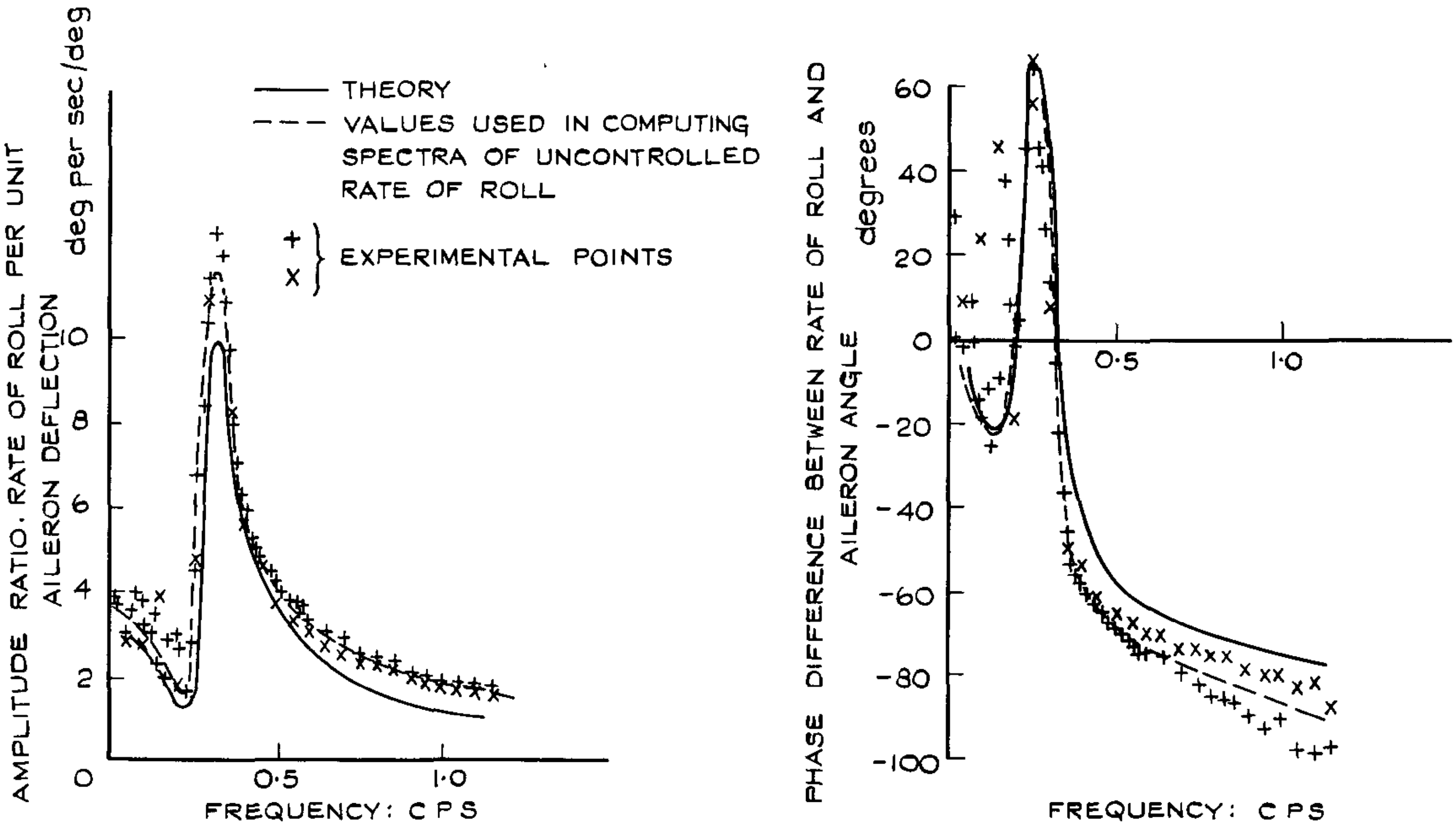

FIG. 2 MEASURED AND THEORETICAL FREQUENCY RESPONSES TO AILERON INPUT IN THE TEST CONFIGURATION

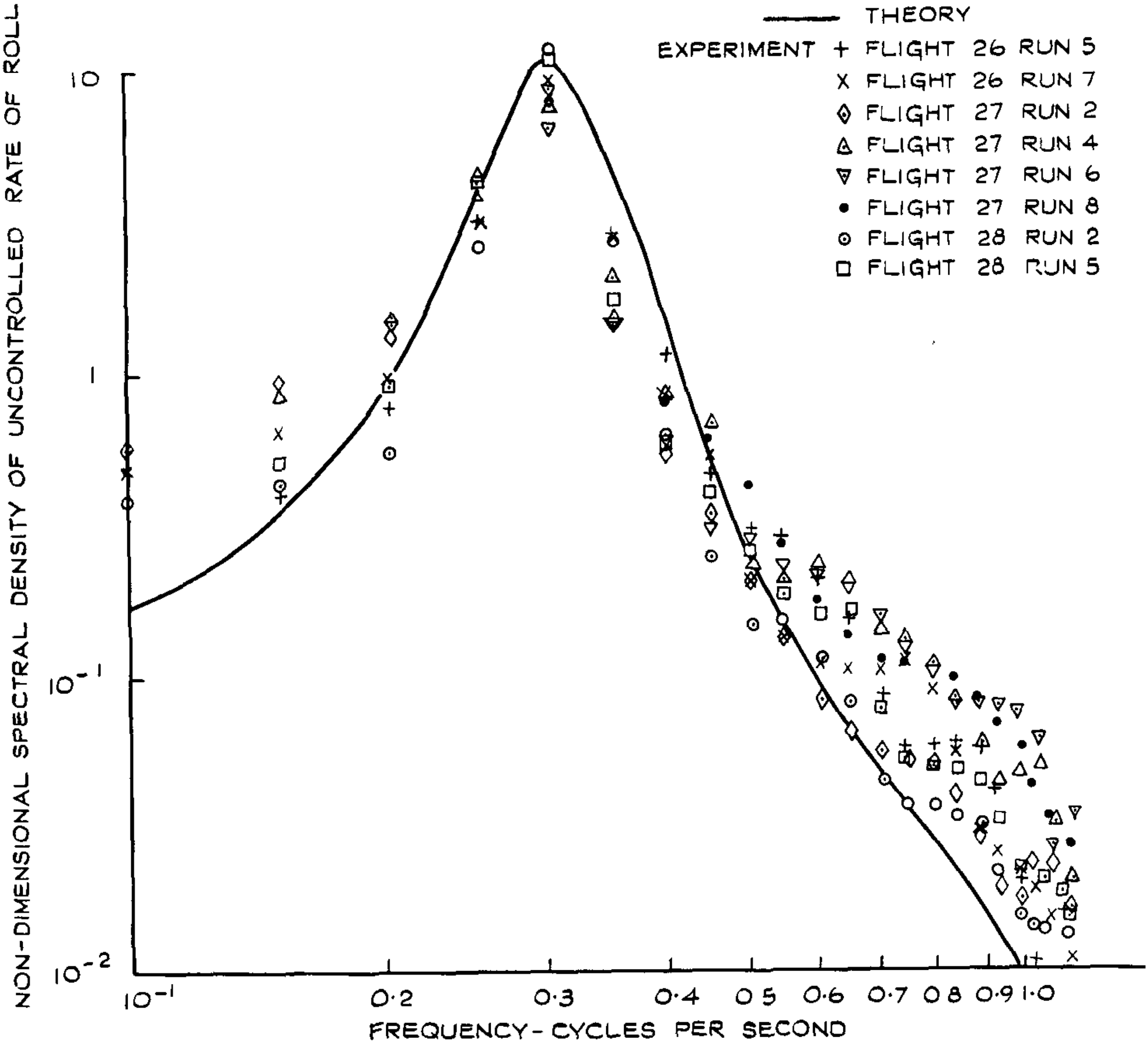

FIG 3 MEASURED AND THEORETICAL NON-DIMENSIONAL SPECTRAL DENSITIES OF UNCONTROLLED RATE OF ROLL

*Printed in England for Her Majesty's Stationery Office by
the Royal Aircraft Establishment, Farnborough. Dd.125875.K.4.*

A.R.C. C.P. No.898
Burnham, J.
MEASUREMENTS OF THE ROLLING RESPONSE OF A FIGHTER AEROPLANE (HUNTER MK.6) TO TURBULENT AIR AND A COMPARISON WITH THEORY.

533.6.013.153 :
551.551 :
533.6.015.2 :
533.694.51 :
533.6.013.47

February, 1965

Measurements of rate of roll and aileron deflection have been made during the landing approach, in turbulent air. These have been used to compute spectral densities of the rate of roll which would have occurred with the ailerons fixed. The results show good agreement with comparable spectra which were calculated theoretically.

A.R.C. C.P. No.898
Burnham, J.
MEASUREMENTS OF THE ROLLING RESPONSE OF A FIGHTER AEROPLANE (HUNTER MK.6) TO TURBULENT AIR AND A COMPARISON WITH THEORY.

533.6.013.153:
551.551 :
533.6.015.2 :
533.694.51 :
533.6.013.47

February, 1965

Measurements of rate of roll and aileron deflection have been made during the landing approach, in turbulent air. These have been used to compute spectral densities of the rate of roll which would have occurred with the ailerons fixed. The results show good agreement with comparable spectra which were calculated theoretically.

A.R.C. C.P. No.898
Burnham, J.
MEASUREMENTS OF THE ROLLING RESPONSE OF A FIGHTER AEROPLANE (HUNTER MK.6) TO TURBULENT AIR AND A COMPARISON WITH THEORY.

533.6.013.153 :
551.551 :
533.6.015.2 :
533.694.51 :
533.6.013.47

February, 1965

Measurements of rate of roll and aileron deflections have been made during the landing approach, in turbulent air. These have been used to compute spectral densities of the rate of roll which would have occurred with the ailerons fixed. The results show good agreement with comparable spectra which were calculated theoretically.

DETACHABLE ABSTRACT CARDS

C.P. No. 898

Published by
HER MAJESTY'S STATIONERY OFFICE

To be purchased from
49 High Holborn, London W.C.1
423 Oxford Street, London W.1
13A Castle Street, Edinburgh 2
109 St Mary Street, Cardiff
Brazennose Street, Manchester 2
50 Fairfax Street, Bristol 1
35 Smallbrook, Ringway, Birmingham 5
80 Chichester Street, Belfast 1
or through any bookseller

C.P. No. 898

S.O. CODE No. 23-9016-98