AD-A034 447 ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT--ETC F/G 20/4
NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TEST--ETC(U)
DEC 76 G HAIDL

UNCLASSIFIED AGARD-R-652 NL

1 OF 1
ADA034447

END
DATE
FILMED
2 - 77

2 fb.

AGARD-R-652

AGARD

ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

7 RUE ANCELLE 92200 NEUILLY SUR SEINE FRANCE

AGARD REPORT No. 652

on

Non-Linear Effects in Aircraft Ground and Flight Vibration Tests

by

G.Haidl

NORTH ATLANTIC TREATY ORGANIZATION

DISTRIBUTION AND AVAILABILITY
ON BACK COVER

14 AGARD-R-652

NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Report No.652

6 **NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS**

by

10 G.Haidl
Messerschmitt-Bölkow-Blohm GmbH
Unternehmensbereich Flugzeuge
8, München 80, West Germany

11 Dec 76

12 24p.

Paper presented at the 43rd Structures and Materials Panel Meeting, London, September 1976.

400 043
bpg

THE MISSION OF AGARD

The mission of AGARD is to bring together the leading personalities of the NATO nations in the fields of science and technology relating to aerospace for the following purposes:

- Exchanging of scientific and technical information;
- Continuously stimulating advances in the aerospace sciences relevant to strengthening the common defence posture;
- Improving the co-operation among member nations in aerospace research and development;
- Providing scientific and technical advice and assistance to the North Atlantic Military Committee in the field of aerospace research and development;
- Rendering scientific and technical assistance, as requested, to other NATO bodies and to member nations in connection with research and development problems in the aerospace field;
- Providing assistance to member nations for the purpose of increasing their scientific and technical potential;
- Recommending effective ways for the member nations to use their research and development capabilities for the common benefit of the NATO community.

The highest authority within AGARD is the National Delegates Board consisting of officially appointed senior representatives from each member nation. The mission of AGARD is carried out through the Panels which are composed of experts appointed by the National Delegates, the Consultant and Exchange Program and the Aerospace Applications Studies Program. The results of AGARD work are reported to the member nations and the NATO Authorities through the AGARD series of publications of which this is one.

Participation in AGARD activities is by invitation only and is normally limited to citizens of the NATO nations.

The content of this publication has been reproduced directly from material supplied by AGARD or the author.

Published December 1976

ISBN 92-835-1231-7

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London, W1P 1HD

PREFACE

As military aircraft fly with more and more stores, the problem of predicting the critical flutter speed becomes more and more complicated. Apart from the lack of aerodynamic knowledge which makes it almost impossible to predict the unsteady aerodynamic forces, the non-linear behaviour of wing-stores configurations leads to fresh difficulties in the interpretation of ground vibration tests and flight flutter tests.
Mr Haidl's paper helps in the understanding of these difficulties with the support of ground and flight experience on modern aircraft. His contribution will be of great value for all concerned NATO countries.

G.COUPRY
Chairman, Sub-Committee on
Aeroelasticity and Unsteady
Aerodynamics

SUMMARY

Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed to study the effects of friction and backlash with respect to ground resonance test and flight flutter test.

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes the problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non linear system behaviour.

CONTENTS

NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS

by

G.HAIDL

MESSERSCHMITT-BÖLKOW-BLOHM GmbH.
Unternehmensbereich Flugzeuge
8, München 80, - West Germany

PROBLEM SURVEY

There have been many improvements in equipment and test methods for ground resonance tests and flight flutter tests. The determination of the dynamic characteristic of real aircraft structures is still difficult in case of non linear system behaviour.

Some examples taken from previous tests and investigations may help to give a problem survey.

The first example refers to a ground resonance test on a F 104 G "Starfighter" aircraft, described in AGARD Report No. 592, see [Ref. 1]. Two multinationale comparative programs have been performed to define and improve the aerodynamic and elastomechanical basis for the evaluation of aircraft aeroelastic stability. Test results of intensive ground resonance tests indicate the common trend of slightly reducing frequency with increasing amplitude ([Ref. 1], Table 23 and 24). A strong non linear behaviour has been found for a fin torsion, tailplane coplanar rotation mode (r = 4). With increasing amplitude the resonance frequency drops from 12.7 Hz to a minimum of 10.2 Hz but increases to 11.2 Hz with higher amplitudes. Such non linear effects may be caused by backlash, friction, complex actuator stiffness, liquid loads, or engine installation.

An investigation of dry friction effects to an aileron rotation mode of a glider has been performed by O.N.E.R.A. [Ref. 2].

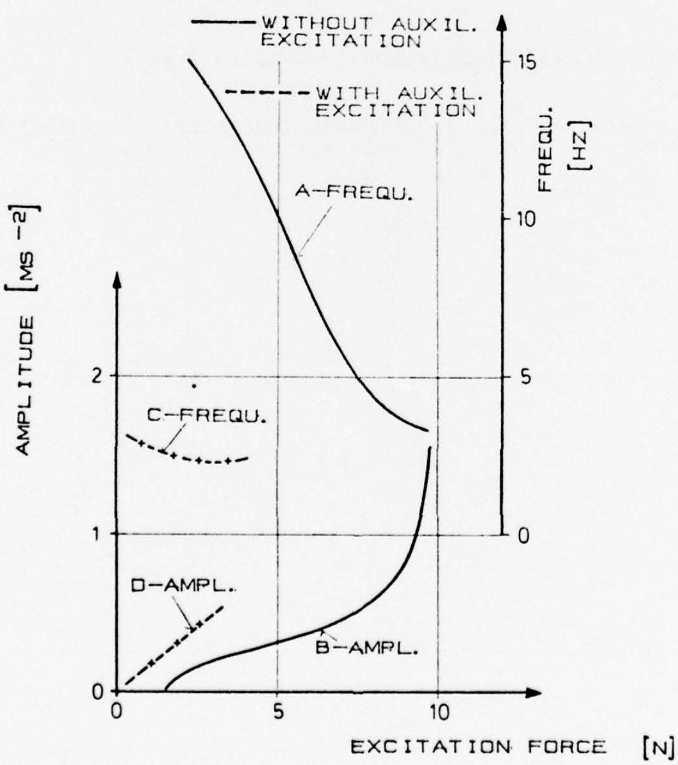

Fig. 1 Influence of an Auxiliary Excitation (60 Hz) on the Aileron Rotation Mode

Fig. 1 shows frequency and amplitude vs excitation force (curve A and B) and with auxiliary excitation at a frequency situated outside the analyzed frequency range (curve C and D). In case of high static friction and lower gliding friction this auxiliary high frequency excitation is a possible way to reduce friction effects.

An investigation on a wing-aileron system with different non linear stiffness characteristics of the aileron has been performed by E. Breitbach, D.F.V.L.R. Göttingen (see [Ref. 3]).

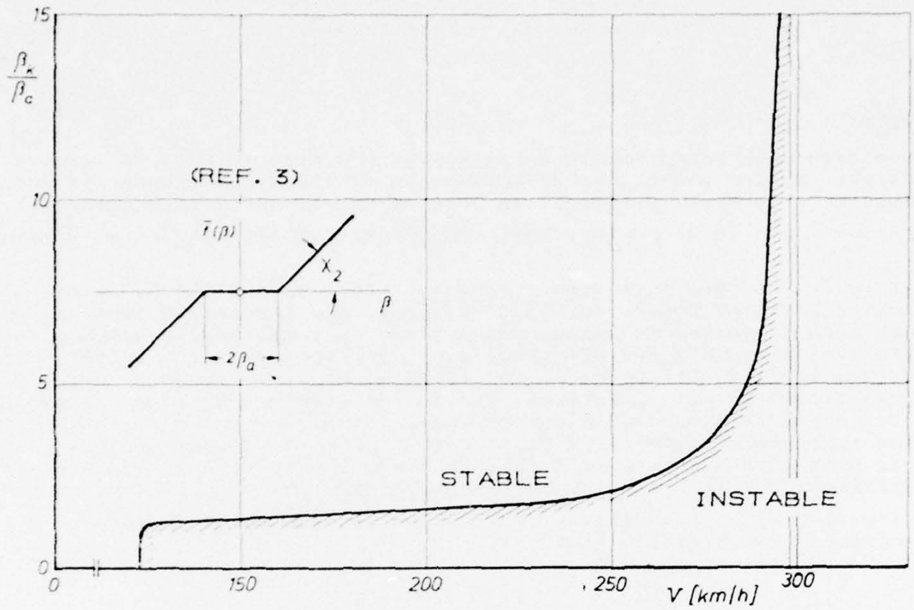

Fig. 2 Effects of Symmetric Backlash to the Wing-Aileron Flutter Stability

In Fig. 2 the considered non linear stiffness characteristic with backlash and the consequences to the flutter stability of this system are shown.

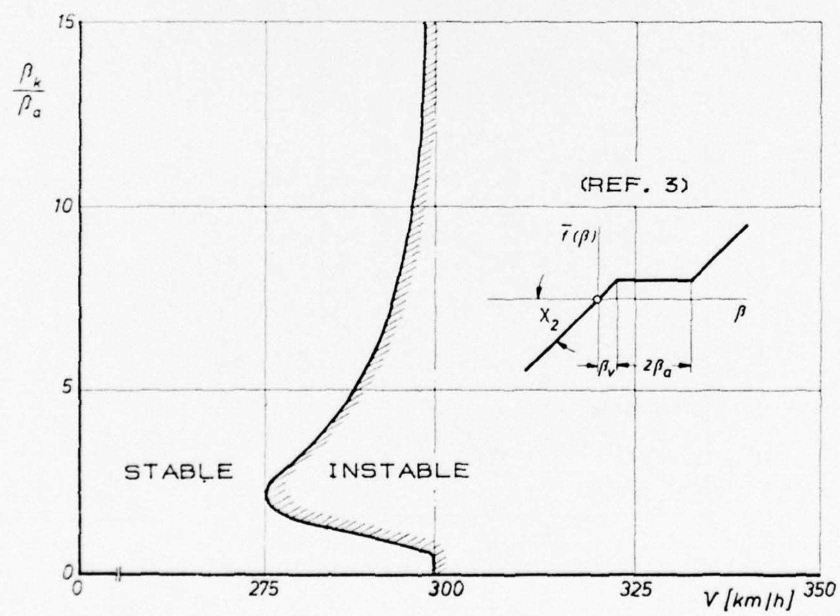

Fig. 3 Effects of Non Symmetric Backlash to the Wing-Aileron Flutter Stability (Preloaded System)

Fig. 3 shows the same parameters for a "preloaded" system or a system with "asymmetric stiffness characteristic".

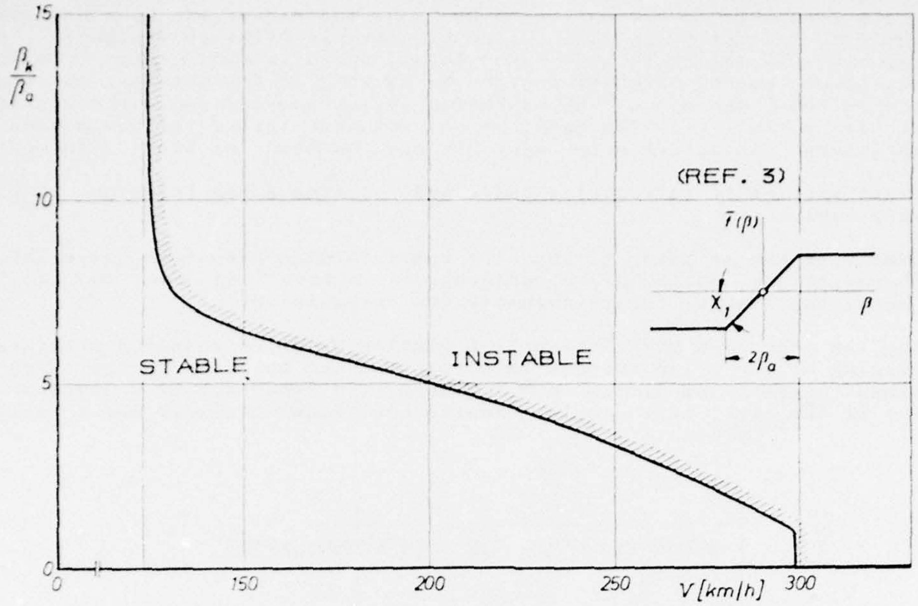

Fig. 4 Effects of Non Linear Stiffness to the Wing-Aileron Flutter Stability

Fig. 4 reveals the most critical behaviour of the system with the shown degressive stiffness characteristic. This flutter behaviour is very dangerous because there is no amplitude limitation after the system reaches the initial amplitudes of the shown stability boundary.

All these examples may illustrate the problems in the ground resonance test to define the amplitude dependent dynamic characteristics of a structure and if possible to find a representative "linearisation" at a reference point close to operational conditions.

The following examples from a recent ground resonance test on an aircraft with sweepable wing and underwing stores may show the limits of this linearisation technique and possible consequences to the test philosophy.

I want to acknowledge the work of Mr. John B.Cox from Mechanical Test Department of BAC-Warton, who has contributed considerably to the A/C test examples which are shown in this paper.

Non Linear Effects in A/C Ground Resonance Test

The non linearities which will be dicussed here are effects of backlash and friction, influencing the dynamic system behaviour. Fig. 5 gives a sketch of the simplified vibration system.

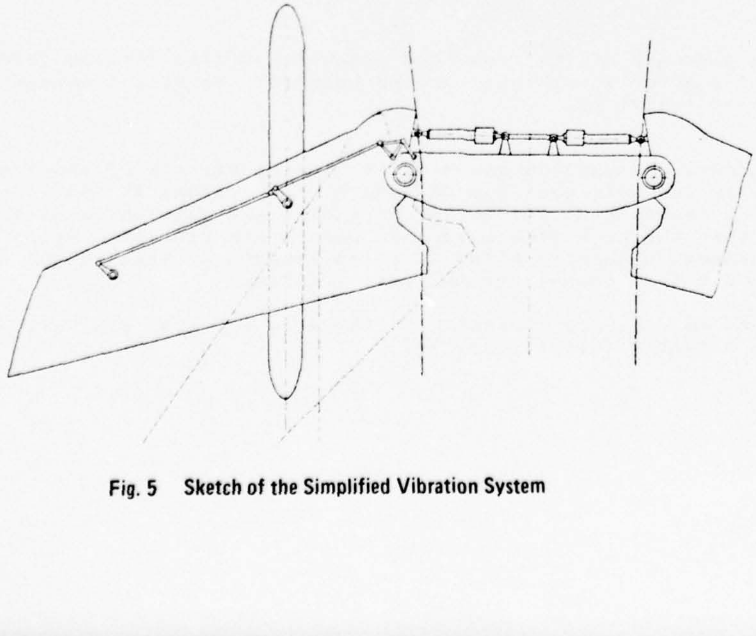

Fig. 5 Sketch of the Simplified Vibration System

The wings are sweepable in teflon coated bearings and are driven by wing sweep actuators. The friction moment in this teflon bearings is relatively high (~2 kNm) because of "shrunk in procedures" and static loads, which is much higher than usual available excitation moments with GRT equipment. As long as the external exciting moments or the internal moments of the vibrating system in wing-yaw direction are below the friction moment, actuator backlash and actuator spring stiffness have no or limited influence. The system properties are changed when the bearing is moving.

The wing slot sealing is introducing additional stiffness and friction, varying with wing sweep angle.

The attachment of the actuator at the wing carry through structure has a lateral deflection characteristic which has an influence on asymmetrical modes whereas for symmetrical modes the lateral forces normally are compensated.

Considering the store yaw mode, there is a similar friction coupling mechanism in the teflon bearing of the pylon spigot. This friction and backlash in the pylon sweep drive rod mechanism generates similar non linear system behaviour as discussed before. The attachment of the store to the pylon creates additional backlash and friction effects.

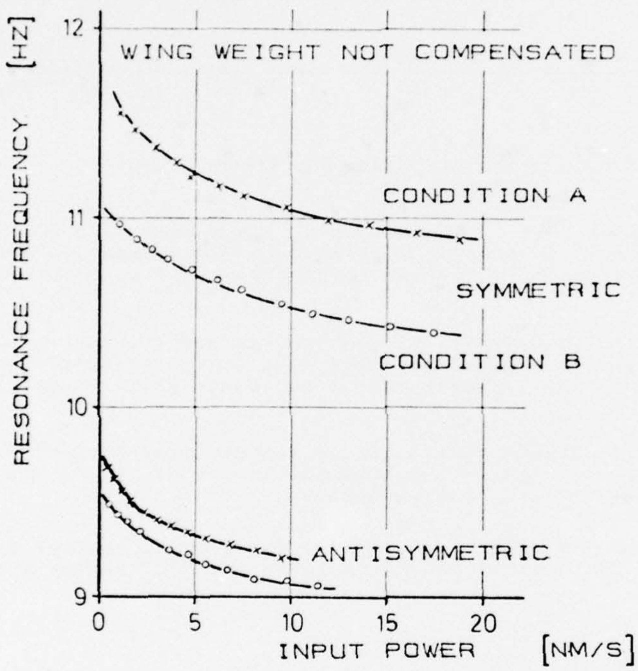

Fig. 6 Effect of Input Power on Resonance Frequency for Wing Yaw-Mode

Fig. 6 shows measured decrease of the resonance frequencies with forcing level for the wing yaw mode (curve A). After a back and forward sweep of the wing a change in frequencies have been found (curve B).

This trend of frequency decrease is given by increasing effects of short movements in the bearing, changing the stiffness and damping of the system. It should be mentioned here, that the friction coefficient for teflon in static and gliding condition is about the same. That means that the part time movements during one vibration cycle are limited for durating system moments higher than the friction moment. By this reason an auxiliary excitation as mentioned before cannot "break" this friction.

Effects of a preload in wing aft direction to the wing yaw mode can be seen in the time histories of the actuator forces, Fig. 7a.

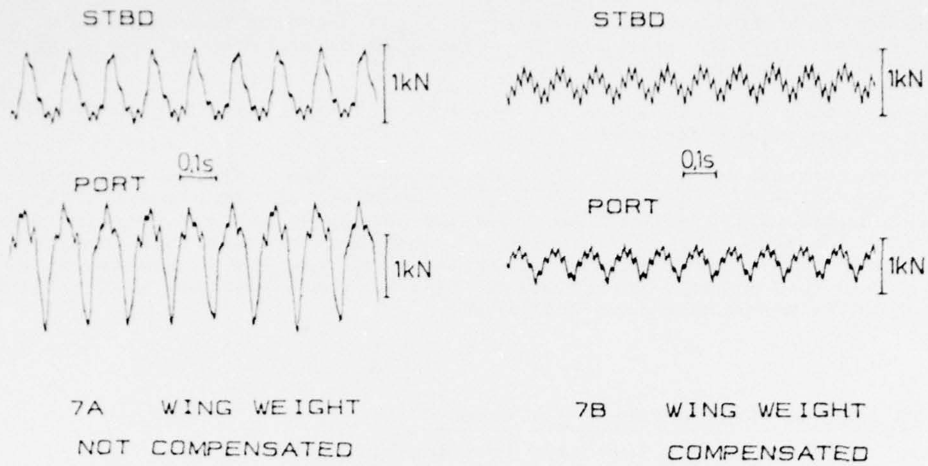

Fig. 7 Time History of the Actuator Force
Wing Yaw Mode Excited with ~90 N on Outboard Pylon Station

With compensated preload (wing suspended) the resonance amplitudes with nearly the same excitation moment are reduced as shown in Fig. 7b. This non expected behaviour can be explained by reduced gliding effects with preload.

The non symmetric stiffnes characteristic is indicated in the wave form of the port actuator force in Fig. 7a. The energy consuming relativ movements in the wing pivot bearing (friction coupling) therefore seem to be limited to the wing forward oscillation cycle.

In the symmetric case without preload there are gliding effects in both directions causing higher system damping and reduced amplitudes, see Fig. 7b.

More severe effects of friction and backlash have been found for the store modes.

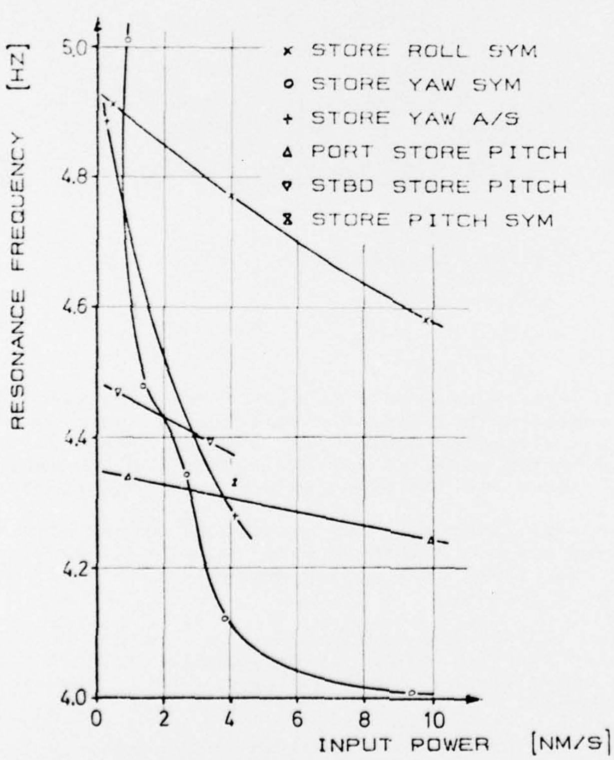

Fig. 8 Vibration in Frequency of Low Frequency Modes

Fig. 8 shows the variation in frequency vs input power of the store roll, yaw and pitch mode. A very important aspect is the strong frequency drop of the yaw mode crossing the frequency of the pitch mode.

In addition frequency differences between left and right side for store pitch mode are indicated (asymmetrical behaviour).

These effects of backlash, friction, mode-asymmetry and different mode coupling illuminate the problems in interpretation and comparison of GRT results with vibration-calculations. In calculations the free pylon yaw condition and the friction fixed condition can be considered. The test results are somewhere between this boundary conditions. In order to get a better understanding of system behaviour and an assessment of consequences to ground test parameters and flight flutter tests separate studies with a simplified dynamically model have been performed.

MODEL STUDIES WITH NON LINEAR "STORE YAW MODEL"

The vibration system wing-pylon-store is illustrated in Fig. 9.

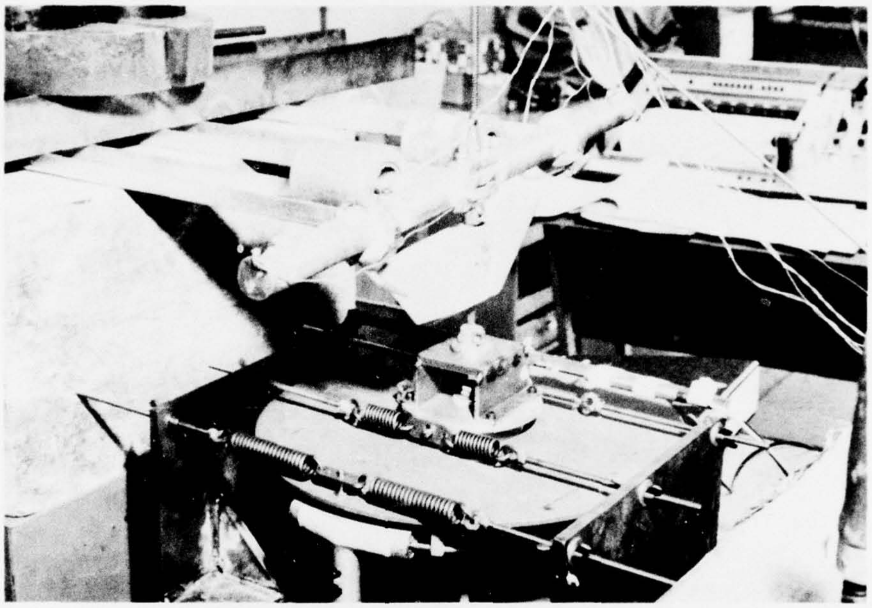

Fig. 9 Total View of the Model

The store and the pylon were taken from a flutter model. The pylon beam is attached to a small aluminum disc coated with teflon (friction damper part 1). This disc rests on a polished plate of steel (friction damper part 2). The plate is attached to a moving disc. which is held by two parallel springs simulating the wing - wing pivot stiffness. The C.G. of the store and the pylon axis are in the rotation axis of the system.

Parallel to this two springs there are four springs on damper part 1, which are simulating the pylon sweep drive rod stiffness with and without backlash in the connection to damper part 1. The amount of friction moment can be varied by balancing part of the store weight by a spring.

The model was excited by two electrodynamical exciters acting on the store. Pick-ups fitted on front and rear store position, on damper part 1 and 2 (absolute motion) and between damper part 1 and 2 (relative motion) were used to measure the motion in different points of the system.

Time histories with harmonic excitation (amplitude resonance) and decay curves after switching off the excitation illustrates the behaviour of the system "without backlash" and different excitation moments.

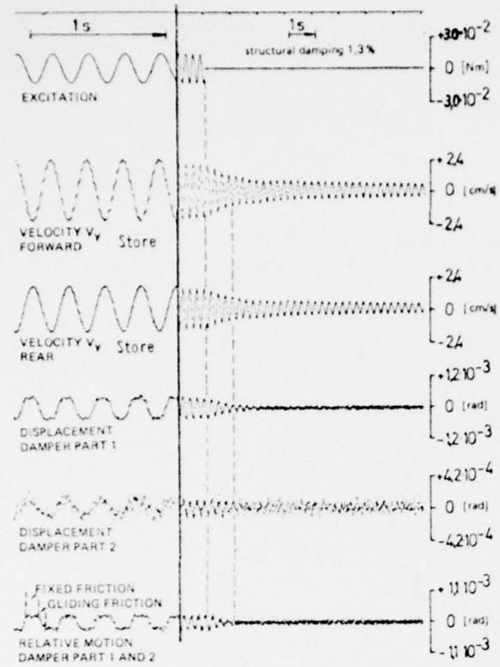

Fig. 10 Time Histories

Friction Moment: 7,6 10^{-2} Nm
Excitation: 1,37 10^{-2} Nm
Resonance Frequency: 3,80 Hz

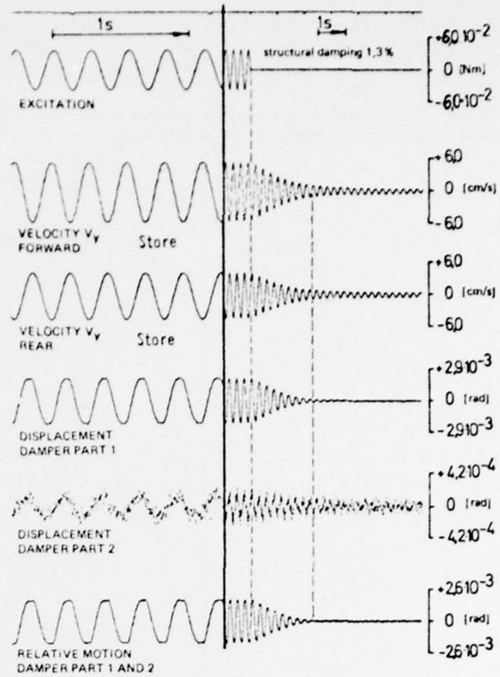

Fig. 11 Time Histories

Friction Moment: 7,6 10^{-2} Nm
Excitation: 3,67 10^{-2} Nm
Resonance Frequency: 3,62 Hz

The trace of the relative motion in Fig. 10 demonstrates the part time movements in the friction coupling during a vibration cycle. As long as there is a relative motion, the decay curves show the effects of gliding friction together with structural damping.

After the relative motion is stopped the decay curve shows the structural damping only.

Fig. 11 and Fig. 12 illustrate the change in the decay curves for increasing excitation moments and the same friction moment.

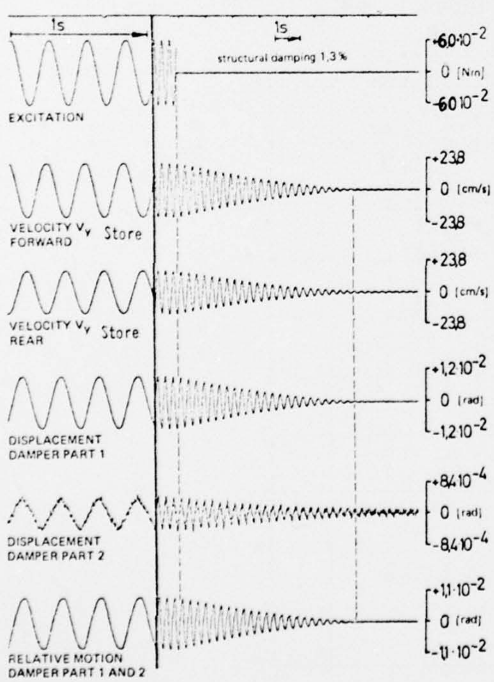

Fig. 12 Time Histories

Friction Moment: 7,6 10^{-2} Nm
Excitation: 6,11 10^{-2} Nm
Resonance Frequency: 3,54 Hz

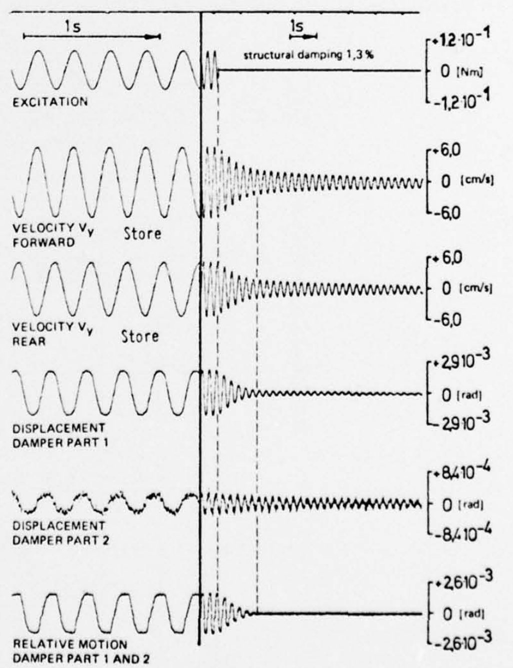

Fig. 13 Time Histories

Friction Moment: 1,6 10^{-1} Nm
Excitation: 7,34 10^{-2} Nm
Resonance Frequency: 3,72 Hz

The time history in Fig. 13 shows a case with higher friction moment. Similar measurements with backlash in the spring attachment of damper part 1 indicated a relatively rapid stop of the relative movement in a position somewhere within the backlash range.

In Fig. 14 the amplitude dependent effects of a constant friction moment to the apparent system damping are shown.

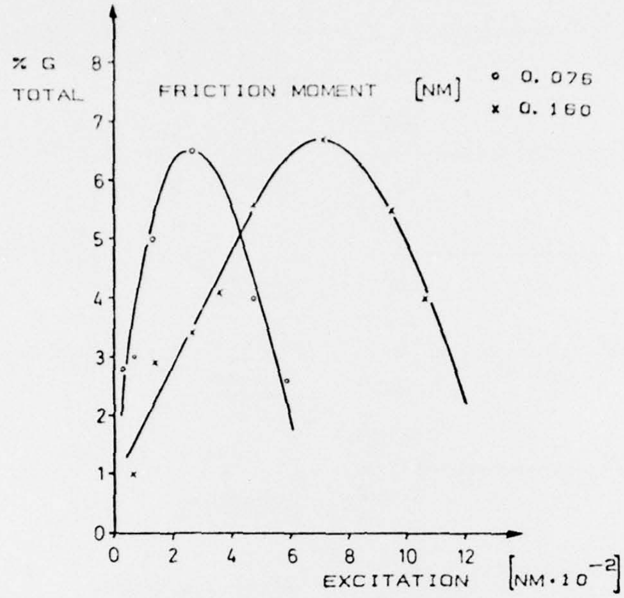

Fig. 14 Apparent Damping vs Exciter Moment (g = 1,3 % Structural Damping Included)

With increasing amplitudes the damping reaches a maximum and decreases. This behaviour demonstrates the misleading effects upon the system damping expressed in % g and it demonstrates the reason, why friction damper are not allowed to suppress flutter.

An analytical approach of this system behaviour with the so called method of "Harmonic Linearisation" was performed. An example of the calculated resonance amplitudes and frequencies compared to test results are shown in Fig. 15.

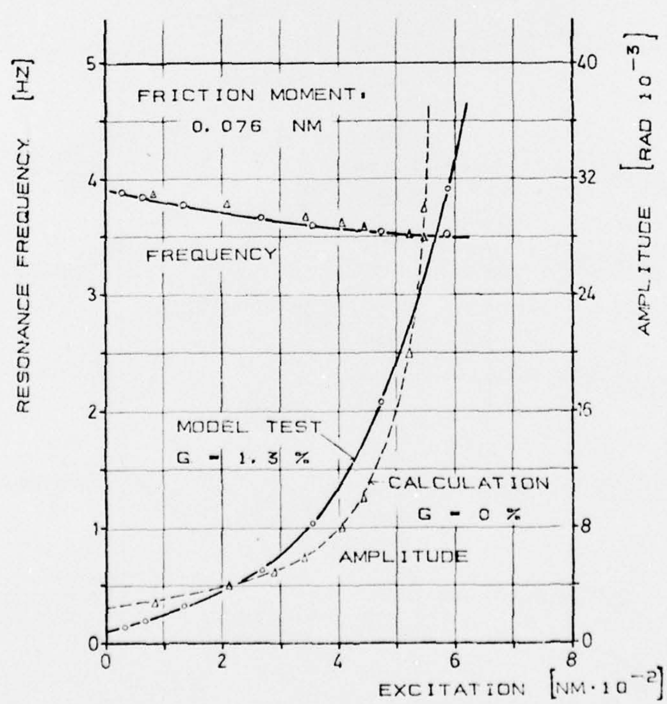

Fig. 15 Resonance Amplitude and -Frequency vs Excitermoment

The actual amount of backlash and friction of such a system can be determined by quasi static measurement of the "hysteresis diagram", see Fig. 16.

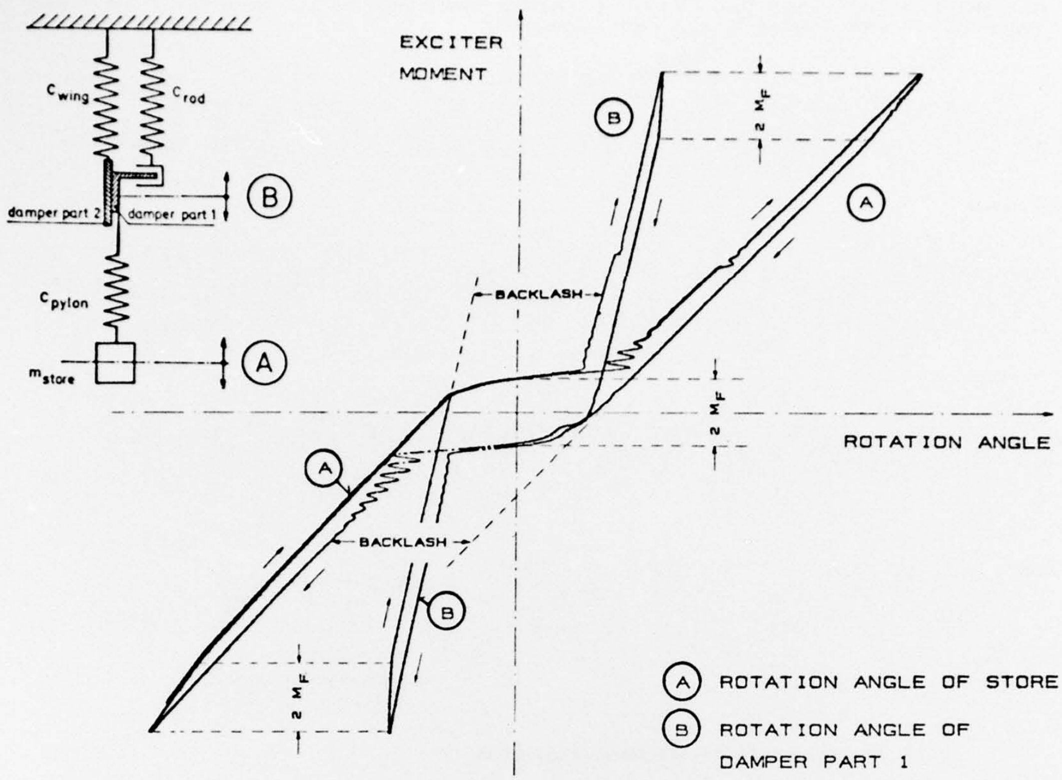

Fig. 16 Hysteresis Diagram

This stiffness characteristic is measured with an exciter moment acting on the store (frequency 0.02 Hz). The diagram of store rotation (curve A) and rotation of damper part 1 (curve B) reveals the amount of backlash and friction of the actual system.

Effects of Friction and Backlash to Data Analysis of Flight Flutter Tests

Different excitations have been used in the model test in order to study the effects to the data analysis with different methods [Ref. 5, 6] .

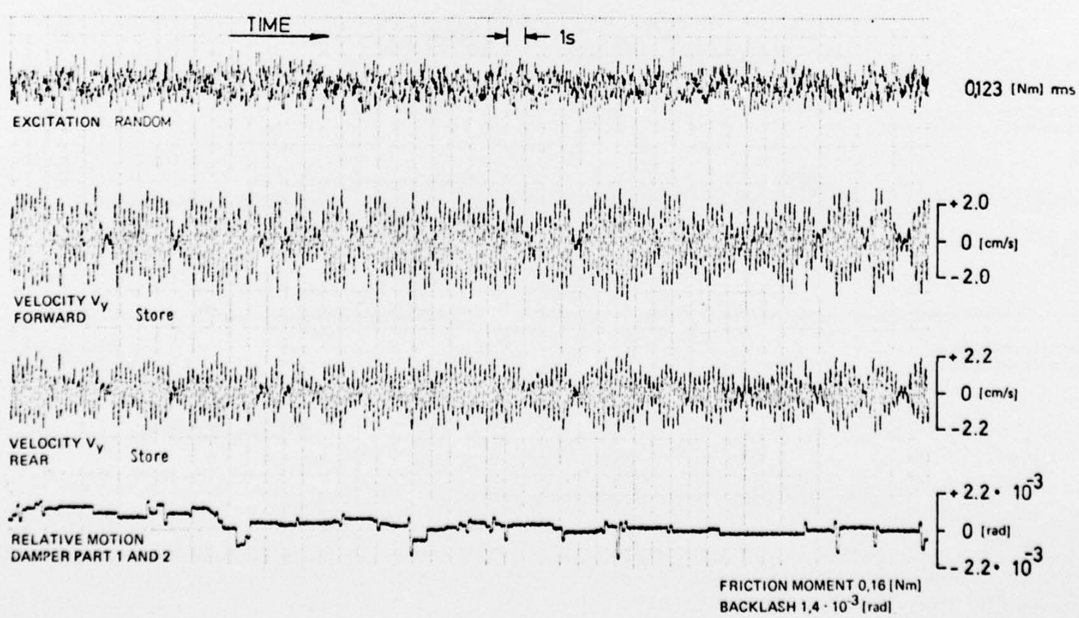

Fig. 17 Time History of a Test with Random Excitation

Fig. 17 is a time history of a test with random excitation which shows the random excitation signal, the lateral response V_y at forward and rear store and the relative movement in the friction coupling. The model has a backlash of 0,1 mm ($1,4 \cdot 10^{-3}$ rad) in the attachment of the "pylon sweep rod" springs.

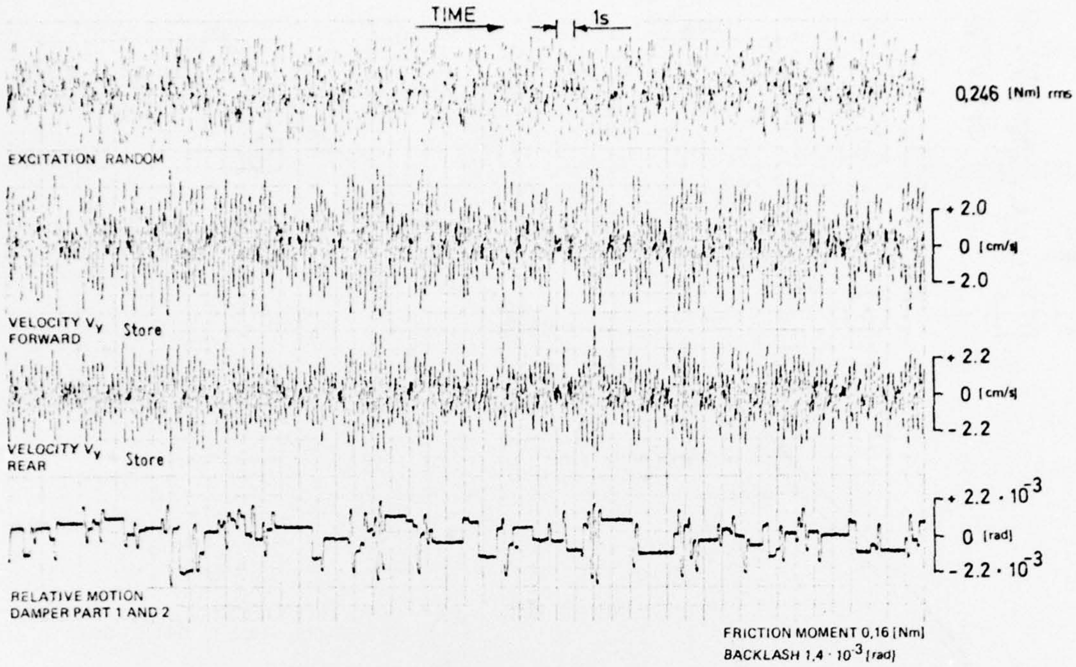

Fig. 18 Time History of a Test with Random Excitation

Fig. 18 shows the increase of relative movements in the friction coupling with increasing excitation, affecting the system damping and resonance frequency.

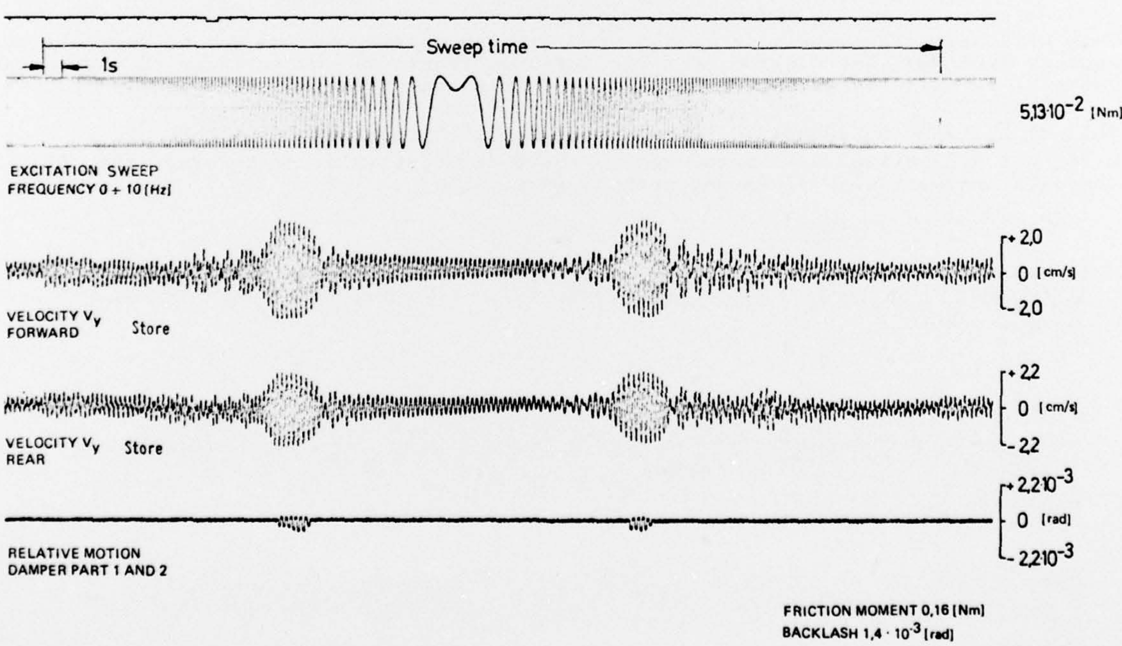

Fig. 19 Time History of a Test with Sweep Excitation

Fig. 19 illustrates the dynamic response of the system to a frequency sweep input. Relative motions in the friction coupling appear, when the excitation frequency is running through the system resonance.

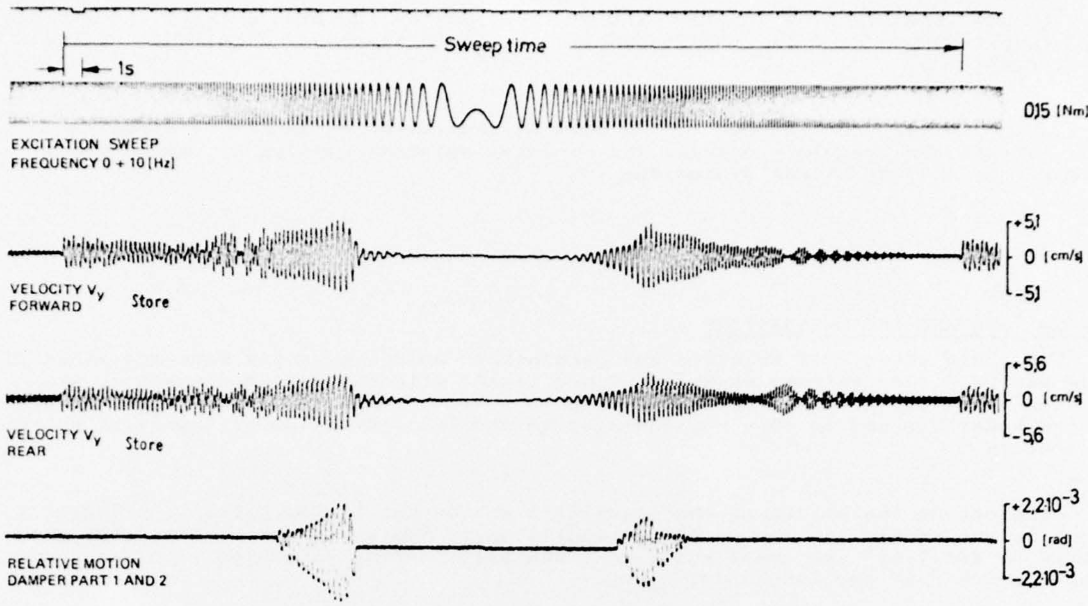

Fig. 20 Time History of a Test with Sweep Excitation

Fig. 20 shows the dynamic response of the same system excited with higher force level. There are considerable time variant effects to the system damping and resonance frequency.

In a flight flutter test with artificial frequency sweep excitation and superimposed random excitation there is a combination of the shown behaviour for random and sweep excitation.

A mix of different effects of the friction moment and different resonance frequencies in the response signal are the consequence.

Digital data analysis *with statistical methods is based on the assumption* of a linear system. Changing resonance frequencies with amplitude will produce an apparent damping, which is not existent in the system. As shown before in Fig. 14, a friction moment is introducing similar misleading effects of apparent damping.

Fig. 21 is an example of data analysis of a random excited model test with "backlash".

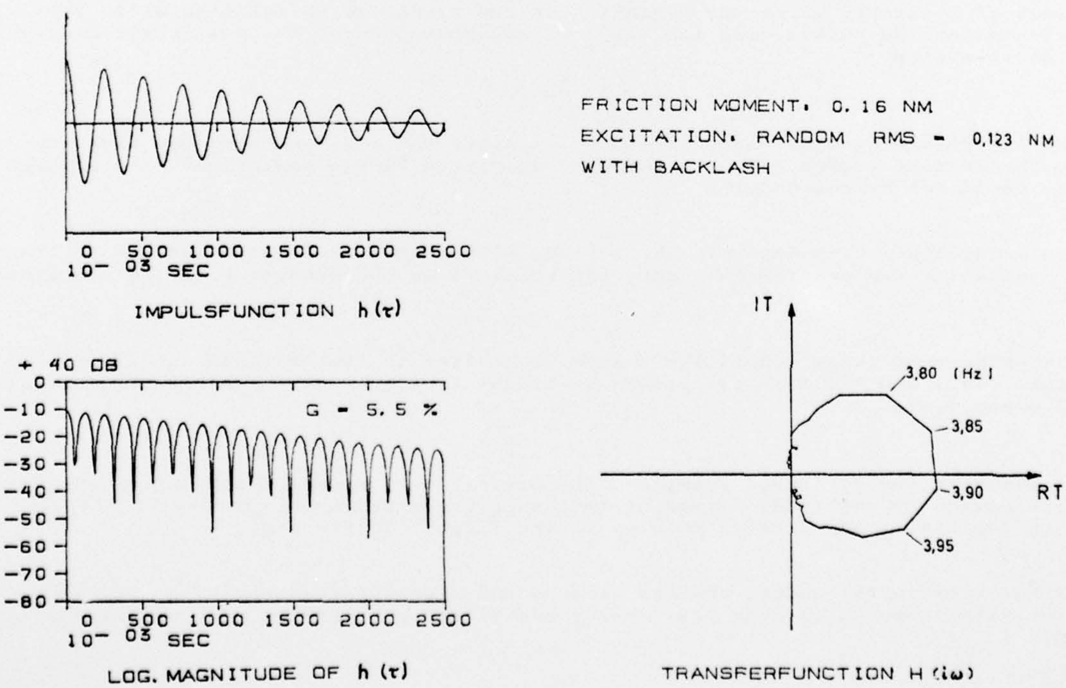

Fig. 21 Frequency and Damping Analysis of Random Excited Model Data

It shows the computed complex plot of the transfer function H ($i\omega$) and after a "Fast Fourier Transform" the impuls function $h_{(\tau)}$ and the "log. magnitude" of the impulsfunction.

In the impulsfunction there is no more an indication of amplitude dependent friction effects and frequency change. The analyzed apparent damping is considerably higher than the structural system damping.

CONCLUSIONS AND RECOMMENDATIONS

The shown effects of friction and backlash to an A/C wing yaw mode and store yaw mode may be rather extreme examples of non linear effects. But the intent of the studies is to provide information leading to a better understanding of non linear system behaviour and to show consequences in the identification of important system parameters.

Considering the stiffness characteristic of the non linear "store yaw model" as shown before in Fig. 16 the boundary conditions of the system are defined by pylon "fixed by friction" for small amplitudes and pylon spring in series with the spring "sweep drive rod" for large amplitudes.

Between these small and large amplitude boundary conditions a decreasing and increasing effective stiffness with amplitude is caused by the amount of friction and backlash. The minimum of the effective stiffness is a further important condition in respect to parameter variation in the "linear" calculation. This minimum effective stiffness is strongly dependent on change in friction and backlash. Without friction moment, the effective stiffness within the backlash range would be zero. In order to have a representative variation, differences within the production line and wear effects must be covered.

Asymmetries in the stiffness characteristic caused by preload give a change in effective stiffness compared to the symmetric case.

Vibration measurements somewhere within the backlash range cannot be used to assess the range of necessary parameter variation in the vibration calculation or to verify the calculation. In such a case the separate determination of the hysteresis diagram is a valuable step.

The Aircraft Ground Resonance Test in the store yaw mode and wing yaw mode has shown, that a test approach to the boundary condition "large amplitude" as discussed before, could not be reached.

The model tests with harmonic excitation, with random excitation and with frequency sweep excitation can provide necessary informations on the behaviour of the non linear system.

The effects of these non linear system properties to test methods used in ground resonance tests and the data evaluation in flight flutter tests have been demonstrated in the model tests.

As shown in the different examples, the non existent apparent damping in the data analysis caused by amplitude dependent resonance frequencies and misleading effects friction depicts a very serious problem in the flight flutter test.

Asymmetries in the modes, preload effects and crossing frequencies of the store yaw mode with store pitch mode are causing additional problems in mode separation and damping.

An essential step with respect to flutter stability or fatigue is to determine whether or not these non linear features are important in the flutter behaviour of the A/C. Following aspects have to be considered:

- modes relevant for flutter
- modes coupling with relevant flutter modes
- asymmetries in modes affecting the flutter speed
- effects of apparent damping in the data analysis

Recommendations to achieve a representative flutter clearance in case of severe non linearities are:

- careful parameter identification in static tests
- calculations with corresponding parameter variations
- wind tunnel tests to find out the influence of asymmetries and non linear features to flutter
- non linear analytical investigations
- ground resonance tests and flight flutter tests with a modified test airplane (reduced damping and backlash) to cover the worst condition.

REFERENCES

[1] KÜSSNER, H.G. — A Comparison of Methods used in Flutter Research
AGARD-Report No. 592

[2] DAT, R. — Structural Vibration Tests Methods Implemented at O.N.E.R.A.
Publication No. 1975-1

[3] BREITBACH, E. — Flattersimulation des Flugzeuges mit Hilfe des elektronischen Analogrechners unter besonderer Berücksichtigung struktureller Nichtlinearitäten
DFVLR - Institut für Aeroelastik, Göttingen Bericht DLR-FB 73-30

[4] SCHOEN, B. — Assessment of the Influence of Friction Backlash and Asymmetries on the Dynamical Behaviour of an A/C with Wing Mounted Stores
MBB Report No. STR-P-0030

[5] POTTER, D.K., LOTZE, A. — Inflight Flutter Identification of the MRCA
42nd Meeting of the Structures and Materials Panel of AGARD
Ottawa/Canada, 4-9 April 1976

[6] HOUBOLT, John C. — Subcritical Flutter Testing and System Identification
National Aeronautics and Space Administration Report No. 219

[7] George C. Marshall Space Flight Test Center
MFSC Vibration Manual

[8] MIL Spec - MIL-A-008870 A (USAF)
Military Specification
Airplane Strength and Rigidity -
Flutter, Divergence, and other Aeroelastic Instabilities

15

REPORT DOCUMENTATION PAGE

1. Recipient's Reference	2. Originator's Reference	3. Further Reference	4. Security Classification of Document
	AGARD-R-652	ISBN 92-835-1231-7	UNCLASSIFIED

5. Originator	Advisory Group for Aerospace Research and Development North Atlantic Treaty Organization 7 rue Ancelle, 92200 Neuilly sur Seine, France
6. Title	NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS
7. Presented at	the 43rd Structures and Materials Panel Meeting, London, September 1976.

8. Author(s)	9. Date
G.Haidl	December 1976

10. Author's Address	11. Pages
Messerschmitt-Bölkow-Blohm GmbH Unternehmensbereich Flugzeuge 8, München 80, West Germany	22

12. Distribution Statement	This document is distributed in accordance with AGARD policies and regulations, which are outlined on the Outside Back Covers of all AGARD publications.

13. Keywords/Descriptors		
	Vibration tests	Aerodynamic configurations
	Aerodynamic forces	External stores
	Unsteady flow	Aerodynamic stability
	Aircraft	Flutter

14. Abstract

Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed, to study the effects of friction and backlash with respect to ground resonance test and flight flutter test.

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes and problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non linear system behaviour.

AGARD Report No.652 Advisory Group for Aerospace Research and Development, NATO NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS G.Haidl Published December 1976 22 pages Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed, to study the effects of friction and backlash with respect to ground resonance test and flight flutter test. P.T.O.	AGARD-R-652 Vibration tests Aerodynamic forces Unsteady flow Aircraft Aerodynamic configurations External stores Aerodynamic stability Flutter
AGARD Report No.652 Advisory Group for Aerospace Research and Development, NATO NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS G.Haidl Published December 1976 22 pages Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed, to study the effects of friction and backlash with respect to ground resonance test and flight flutter test. P.T.O.	AGARD-R652 Vibration tests Aerodynamic forces Unsteady flow Aircraft Aerodynamic configurations External stores Aerodynamic stability Flutter
AGARD Report No.652 Advisory Group for Aerospace Research and Development, NATO NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS G.Haidl Published December 1976 22 pages Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed, to study the effects of friction and backlash with respect to ground resonance test and flight flutter test. P.T.O.	AGARD-R-652 Vibration tests Aerodynamic forces Unsteady flow Aircraft Aerodynamic configurations External stores Aerodynamic stability Flutter
AGARD Report No.652 Advisory Group for Aerospace Research and Development, NATO NON-LINEAR EFFECTS IN AIRCRAFT GROUND AND FLIGHT VIBRATION TESTS G.Haidl Published December 1976 22 pages Examples of non-linear vibration behaviour in ground resonance tests of an aircraft are shown. Model tests for a simplified system with non-linear properties have been performed, to study the effects of friction and backlash with respect to ground resonance test and flight flutter test. P.T.O.	AGARD-R-652 Vibration tests Aerodynamic forces Unsteady flow Aircraft Aerodynamic configurations External stores Aerodynamic stability Flutter

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes the problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non-linear system behaviour.

Paper presented at the 43rd Structures and Materials Panel Meeting, London, September 1976.

ISBN 92-835-1231-7

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes the problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non-linear system behaviour.

Paper presented at the 43rd Structures and Materials Panel Meeting, London, September 1976.

ISBN 92-835-1231-7

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes the problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non-linear system behaviour.

Paper presented at the 43rd Structures and Materials Panel Meeting, London, September 1976.

ISBN 92-835-1231-7

With symmetric and asymmetric non-linear stiffness characteristics effects of amplitude dependent frequencies, mode coupling, mode asymmetries and the consequences in parameter identification in vibration tests are pointed out and discussed.

In case of flutter critical modes the problems of apparent damping caused by non-linear system properties are shown and recommendations are given to reach a representative flutter clearance with respect to this non-linear system behaviour.

Paper presented at the 43rd Structures and Materials Panel Meeting, London, September 1976.

ISBN 92-835-1231-7

AGARD

NATO OTAN

7 RUE ANCELLE · 92200 NEUILLY-SUR-SEINE

FRANCE

Telephone 745.08.10 · Telex 610176

DISTRIBUTION OF UNCLASSIFIED AGARD PUBLICATIONS

AGARD does NOT hold stocks of AGARD publications at the above address for general distribution. Initial distribution of AGARD publications is made to AGARD Member Nations through the following National Distribution Centres. Further copies are sometimes available from these Centres, but if not may be purchased in Microfiche or Photocopy form from the Purchase Agencies listed below.

NATIONAL DISTRIBUTION CENTRES

BELGIUM
Coordonnateur AGARD – VSL
Etat-Major de la Force Aérienne
Caserne Prince Baudouin
Place Dailly, 1030 Bruxelles

CANADA
Defence Scientific Information Service
Department of National Defence
Ottawa, Ontario K1A OZ2

DENMARK
Danish Defence Research Board
Østerbrogades Kaserne
Copenhagen Ø

FRANCE
O.N.E.R.A. (Direction)
29 Avenue de la Division Leclerc
92 Châtillon sous Bagneux

GERMANY
Zentralstelle für Luft- und Raumfahrt-
dokumentation und -information
Postfach 860880
D-8 München 86

GREECE
Hellenic Armed Forces Command
D Branch, Athens

ICELAND
Director of Aviation
c/o Flugrad
Reykjavik

ITALY
Aeronautica Militare
Ufficio del Delegato Nazionale all'AGARD
3, Piazzale Adenauer
Roma/EUR

LUXEMBOURG
See Belgium

NETHERLANDS
Netherlands Delegation to AGARD
National Aerospace Laboratory, NLR
P.O. Box 126
Delft

NORWAY
Norwegian Defence Research Establishment
Main Library
P.O. Box 25
N-2007 Kjeller

PORTUGAL
Direccao do Servico de Material
da Forca Aerea
Rua de Escola Politecnica 42
Lisboa
Attn: AGARD National Delegate

TURKEY
Department of Research and Development (ARGE)
Ministry of National Defence, Ankara

UNITED KINGDOM
Defence Research Information Centre
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RE

UNITED STATES
National Aeronautics and Space Administration (NASA),
Langley Field, Virginia 23365
Attn: Report Distribution and Storage Unit

THE UNITED STATES NATIONAL DISTRIBUTION CENTRE (NASA) DOES NOT HOLD STOCKS OF AGARD PUBLICATIONS, AND APPLICATIONS FOR COPIES SHOULD BE MADE DIRECT TO THE NATIONAL TECHNICAL INFORMATION SERVICE (NTIS) AT THE ADDRESS BELOW.

PURCHASE AGENCIES

Microfiche or Photocopy
National Technical
Information Service (NTIS)
5285 Port Royal Road
Springfield
Virginia 22151, USA

Microfiche
Space Documentation Service
European Space Agency
10, rue Mario Nikis
75015 Paris, France

Microfiche
Technology Reports
Centre (DTI)
Station Square House
St. Mary Cray
Orpington, Kent BR5 3RF
England

Requests for microfiche or photocopies of AGARD documents should include the AGARD serial number, title, author or editor, and publication date. Requests to NTIS should include the NASA accession report number. Full bibliographical references and abstracts of AGARD publications are given in the following journals:

Scientific and Technical Aerospace Reports (STAR),
published by NASA Scientific and Technical
Information Facility
Post Office Box 8757
Baltimore/Washington International Airport
Maryland 21240, USA

Government Reports Announcements (GRA),
published by the National Technical
Information Services, Springfield
Virginia 22151, USA

Printed by Technical Editing and Reproduction Ltd
Harford House, 7–9 Charlotte St, London W1P 1HD

ISBN 92-835-1231-7