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A beginners guide to literature in the field of Aeroelasticity

Dr.R.S.Battoo

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ABSTRACT

This document is meant primarily for students (or readers) who may not be familiar with the field of aeroelasticity. The main objective of this paper is to point the reader to some important texts and papers that have been published in the areas which embrace aeroelasticity, using which the reader may gain sufficient knowledge about the subject to make informed decisions. It is hoped that by drawing the readers attention to these salient papers the more interested readers will be able to increase their knowledge on many aspects related to aeroelasticity. This paper is not meant to be exhaustive, rather it is meant to be a preliminary exposition which will assist readers in locating/selecting other relevant references or texts. This paper does not attempt to be an expert guide nor direct the reader to publications in a specific area. What it does attempt to do is hopefully generate interest and illuminate areas related to the field of aeroelasticity which readers can explore to their desire. A modestly comprehensive list of references is included, however it must be emphasized that there are a very extensive number of papers published each year, in all related fields of aeroelasticity. Inclusion of all these would not be appropriate in a paper of this kind. Never-the-less the more interested reader will find sufficient information to utilize the given citations for locating further material.

1. FOREWORD

This paper is divided into four main sections which deal with (1) Review papers in the wider area of Aeroelasticity, (2) Publications that will assist readers to understand the fundamentals of aeroelasticity - theory and practice, (3) A comprehensive list of references for the areas highlighted above and (4) Collectively a list of useful technical Journals, aeroelasticity subject area classifications, a brief note about software with aeroelastic capabilities and a brief note on useful world wide web sites.

Further the paper is divided into several key sections as will be noted from the contents list. After a brief introduction, there is a brief account of the many excellent review papers that discuss developments in the field.

The main emphasis in this paper is given in section 4, which directs the reader to key publications which may be instrumental in providing a sound understanding of the fundamentals of aeroelasticity.

Finally in the summary a quick overview of the authors choice of essential reading is included. At the very least the reader is encouraged to read this section if no other part of the paper.

2. INTRODUCTION

Aeroelasticity covers a wide field and has now-a-days become to be recognized as a multi-disciplinary subject. This was not the case towards the early part of this century (1940's) but has increasingly been the case since the 1960's and to date subjects that were at one time regarded as quite independent from each other have become very closely linked. Subjects such as aerodynamics, structural dynamics, computational fluid dynamics, flight dynamics, stability and control, mechanical vibrations now combine to form close links with each other particularly when it comes to the design of aircraft of the present day.

Aeroelasticity itself has also grown from the early days of first flight by the Wright brothers in December 1903 to the present day of highly maneuverable aircraft and flexible space craft. Hence there are a number of distinct fields that have blossomed and continue to evolve such as static aeroelasticity, dynamic aeroelasticity, stability problems, aerothermoelasticity, aeroservoealsticity, fixed wing aeroelasticity, rotary wing aeroelasticity, effects of passive and active control structures on aeroelasticity, turbo machinery aeroelasticity, aeroelastic tailoring and so on.

This paper is not meant to cover all these fields. The attempt is to give the less familiar reader the direction necessary to be able to understand the fundamentals of aeroelasticity. The papers and books that have been referred to in this paper will provide an excellent grounding in being able to understand the terminology used in aeroelasticity, to be able to understand the primary aspects of the subject and to provide sufficient leads for future research in the general area of aeroelasticity.

Finally it is worth noting that this paper complements the lecture module presented by the author and the lecture notes that go with this lecture module. These lecture notes in themselves will suffice to give a reasonable insight into the subject of aeroelasticity, provide a sound grounding for an introduction to the subject and would be an alternative starting point (to the papers indicated in section 4) for those who have access to these lecture notes.

3. A SURVEY OF REVIEW PAPERS

There have been a number of excellent review papers published since the mid 1940's. The main papers presented have been indicated below and are a must for those wishing to chart the developments in the field of aeroelasticity and related/developing areas. The papers indicated in this section give a detailed picture of how the field of aeroelasticity has developed and its current state to date. The papers also chart the various developments in the general area of aeroelasticity and indicate the development and emergence of new or related topics with the progress of time.

In June 1946 A R Collar [3.1] (then Professor of Aerodynamics at College of Aeronautics at Cranfield) wrote an excellent paper reviewing the current trends and state of the art in a paper entitled *The Expanding Domain of Aeroelasticity.* This is a paper worth reading if only to understand how the field of aeroelasticity developed in forty or so years (from 1903 to the mid 1940's). This was also the paper in which Collar presented his now legendary Collars triangle or "triangle of forces", which was an attempt to illustrate how the field of aeroelasticity could no longer be considered as an isolated subject but had to be treated in relation to other associated subjects. Since then this "triangle of forces" has been added to by several contributors, Done in 1995 [3.7] and Friedmann in 1997 [3.8], to illustrate how the developing region of aeroelasticity has embraced fields which at one time were considered distinct and separate. In [3.8] in particular the triangle has been expanded to a hexahedron to incorporate Controls and Thermal Effects in addition to the well known Elastic, Aerodynamic and Inertia forces.

In 1959 Collar [3.2] presented another paper entitled *Aeroelasticity - Retrospect and Prospect* that prophesied about the future use of computing power and the likely use of large sophisticated models. It must be remembered that in the very early days (as today in introductory classes) two degrees of freedom were utilized to model wing flutter. The mathematical complexity of using more than two (or three) degrees of freedom becomes significant and hence limiting. It was not till the 1960's that calculations were conducted on digital computers and the size of the problems attempted grew.

Since then there have been a number of review papers presented in different journals and at international forums which have covered the wide area of aeroelasticity from experimental analysis to unsteady aerodynamics. Often separate conferences are held for steady and unsteady aerodynamics, computational fluid dynamics, optimization, structures and materials. Aeroelasticity can often feature in each of these, and other, forums.

In 1969 Lowey [3.3] published a paper entitled *Review of rotary-wing V/STOL dynamic and aeroelastic problems*, which dealt admirably with the title subject.

In 1970 Ashley [3.9] presented a review paper simply entitled *Aeroelasticity.*

In 1976 Garrick [3.12] presented a paper entitled *Aeroelasticity-Frontiers and Beyond.*

In 1979 Fleeter [3.11] presented a paper entitled *Aeroelasticity research for Turbomachine applications.*

In 1981 Garrick and Reed [3.14] presented a paper entitled *Historical development of aircraft flutter.*

In 1986 Ashley [3.10] presented a paper entitled *Update to aeroelasticity.*

In 1987 Friedmann [3.4] presented a paper entitled *Recent trends in rotary wing aeroelasticity.*

In 1990 Chopra [3.5] presented a paper entitled *Perspectives in Aero-mechanical Stability of Helicopter Rotors.*

In August 1993 Done [3.7] presented a review paper entitled *Past and future progress in fixed and rotary wing aeroelasticity* which looked at the area of aeroelasticity and described the challenges and developments in the field. The main challenge appears to be in the area of rotary wing aeroelasticity. Largely due to the complex nature of the mechanisms at play and the fluid structure interaction. In this paper Done also discusses and points to other review papers in the field of both fixed wing and rotary wing aeroelasticity. For example the papers by Collar [3.1, 3.2] are cited. Further the review papers by Friedmann [3.4], Chopra [3.5] and Lowey [3.3] are also cited which deal specifically with rotary wing aeroelasticity.

Also in 1993 Noor and Venneri [3.15] were editors to a series of six review articles which were published as a book. These articles covered the areas of (1) Experimental aeroelasticity in wind tunnels (2) Aeroservoelasticity (3) Nonlinear aeroelasticity (4) Aeroelasticity problems in turbomachines (5) Rotary wing aeroelasticity with applications to VSTOL vehicles and (6) Computational aeroelasticity. These are a very comprehensive series of papers which in collaboration are an excellent source of references and are abundantly rich in charting the progress and developments in the above fields.

Recently in June 1997 Friedmann [3.8] presented a review paper that has extended the survey and touches on various topics one of which is rotary wing aeroelasticity. This area is seen to be a major challenge for researchers and practitioners alike. In this paper Friedmann dispels any notion that the field of aeroelasticity is becoming stagnant particularly in the area of research. Although Ashley [3.10] has noted that there have been significant advances made in the area, particularly for fixed wing aeroelasticity, there are still areas in aeroelasticity that require further research. Indeed it is pointed out that the use of adaptive materials is bringing into vogue new and demanding challenges that have a major impact on the design of future generation aerospace vehicles. Further it should be noted that with the passage of time and increasing demands on aircraft requirements the evolving challenges in aeroelasticity are getting increasingly demanding and technically complex.

The papers listed above will provide a detailed insight into the manner in which the field of aeroelasticity has developed, matured and diversified. There is a substantial amount of data and information contained in the papers noted above, hence a selective approach would be in order to gain maximum benefit. Since the emphasis of this paper is not to chart the developments in the field of aeroelasticity but to refer the reader to useful material related to the fundamentals and the theory of aeroelasticity, the above review of survey publications is naturally incomplete. Further details of survey papers can however be found, apart from the papers discussed above, in Dowell et al [1.5] *A modern course in Aeroelasticity.*

Areas of continuing interest to aeroelasticians are Fluid structure interaction, Adaptive materials or smart structures, Non-linear effects, Aeroservoelastic effects, Aerothermoelastic effects, and Aeroelastic tailoring most of which still require considerable research.

4. NOTABLE PUBLICATIONS ON THE FUNDAMENTALS AND THEORY OF AEROELASTICITY

4.1 The Elementary Theory of Aeroelasticity by E.G.Broadbent

Possibly one of the best papers that lays down the foundations of aeroelasticity for the student or structural dynamicist were a series of four papers presented by Broadbent [2.1] (then of RAE Farnbrough) entitled *The Elementary Theory of Aero-Elasticity* in 1954. These are introductory type expositions but contain sufficient detail without any cross referencing (and hence diversions) to other published material. Hence they are self contained and cover the area of (largely fixed wing) aeroelasticity sufficiently well to be of use for all related aspects of aeroelasticity. Broadbent has however indicated further reading, at the end of each paper, should the reader require more detail.

The four articles cover Divergence and Reversal of Control, Wing Flutter, Flutter of Control Surfaces & Tabs and Guiding Principles in Flutter Analysis respectively. These papers are an excellent source of information on the fundamentals of aeroelasticity for the practicing engineer and the more interested reader alike. The emphasis is on the use of presenting the fundamentals together with the explanations of the principles with a number of examples.

Considering these papers were written in 1954, they elude to aircraft of the time and utilize imperial units in the discussions. With a bit of care and effort conversion from imperial units to SI can be readily conducted, for comparisons with more current figures/values. The trends presented however are equally useful although the relation to current aircraft may be more difficult.

The exposition is clearly apt for the time of publication, however the main principles are expounded well and to some level of detail. These four papers form a series and make a very necessary first port of call for any one interested in the area of aeroelasticity particularly with limited experience in it.

4.2 On the teaching of the principles of wing flexure-torsion flutter by Hancock, Wright & Simpson

In 1980 Hancock, Wright & Simpson [2.2] presented a complementary paper to Broadbents papers of 1954 which deals with the teaching and learning of aeroelasticity, and treats the subject of wing flexural torsion flutter to some depth. In particular there is some emphasis in eradicating misconceptions, mis-interpretations and some common anomalies in the area of wing flutter that are formulated in under-graduate teaching of aeroelasticity.

There is also a discussion of Duncans flutter engine. But most important of all the paper presents the mathematical equations of motion for a simple structural system that is subjected to aerodynamic forces. The primary equations of motion for a two degrees of freedom (binary) system are presented and solved for a number of different practical/possible cases.

The paper also discusses the use of graphical techniques for the solution of binary flutter problems. A technique which is both instructive and informative for those wishing to understand the mechanism and solution of flutter equations using fundamental techniques. Graphical representation also has the advantage of illustrating the manner in which certain parameters or criteria, namely aerodynamic derivatives, affect the dynamic system. Graphical representation of the equations of motion and solutions for the equations are presented for nine specific cases in graphical form.

This is a useful paper for those wishing to teach the subject or those requiring a greater depth of knowledge into the subject of wing flutter. This really is an excellent paper that no eager student should ignore either. The reader is cautioned that there are a few minor typographic errors in this paper. Hence prior to adopting any of the equations the reader would be advised to verify the equations presented. This by no means detracts from the fact that this is an excellent paper and if used with thoroughness can prove to be extremely useful.

Together, the papers by Broadbent [2.1] and Hancock, Wright & Simpson [2.2] will give the reader sufficient insight into flutter, divergence and control reversal from a mathematical stand point and also from a design and application stand point.

4.3 The fundamentals of flutter by Duncan

In 1948 Duncan [2.3] (then Professor of aerodynamics at the College of Aeronautics at Cranfield) presented a paper aimed, as he put it, at the non-expert. This paper was entitled *The fundamentals of flutter*, and was substantially the same as a paper of the same title presented in January and February 1945, which appeared in Aircraft Engineering. The paper is divided into two parts although it fits nicely into three categories. Part I is entirely non-mathematical and is meant to present a rational and easily understood account of flutter. This will appeal to non-expert readers and those who do not wish to be distracted, or diverted, by mathematical developments. In the second part of the paper an elementary account of the theory of flutter is given, accompanied with sufficient mathematical detail. However much of the mathematical details are contained in the three accompanying appendices. Part II will appeal to those who want a more detailed insight into the equations employed for the analysis of flutter.

This is a very useful paper, even today, since it discusses the fundamental principles and physics of flutter in an easy and understandable manner. The descriptive section (Part I) focuses on the Phenomena of flutter, Causation of flutter, Prevention of flutter, Critical flutter speeds and other related topics. There is also a discussion of Wing Divergence and the, famous, Flutter Engine that has been referred to by other researchers.

The Flutter Engine (sometimes also referred to as Duncans Flutter Engine) was used to demonstrate how variations in pitch and flexural stiffness could be employed, and altered, to demonstrate the on set of flutter.

In Part II the mathematical description is initiated with a single degree of freedom case and developed for a two degrees of freedom system to yield the binary flutter equations. The properties required of a system for flutter to occur are discussed. The paper also discusses the Rouths test function. Rouths test function was a technique used (during the 1940's to 1950's) for binary flutter problems, to establish if the system would be stable or unstable. This criteria is not used today since it relates to a binary flutter system and is not suitable for systems with more than two degrees of freedom.

4.4 An introduction to the theory of aeroelasticity by Y.C.Fung

An introduction to the theory of aeroelasticity by Y.C.Fung [1.2] (published in 1955) is a book that deals with the subject of aeroelasticity quite adequately. The book is also available in student edition. Hence this is a book well worth perusing for those who do not want the mathematical detail presented by Bishplinghoff, Ashley and Halfman [1.3] (see below). The book certainly contains a very readable and interesting introduction which in itself is quite enlightening.

There is an interesting exposition on aeroelastic effects in fields other than aeronautical engineering, which make interesting reading and will give the reader a wider picture of aeroelasticity often not afforded by specialist texts. In particular the cases of galloping electricity cables and the notorious Tacoma Narrows Bridge are covered to some depth. Equally the text deals with the salient parts of aeroelasticity in sufficient detail to be of use to the student and practicing engineer alike.

4.5 Introduction to the study of aircraft vibration and flutter by Scanlan & Rosenbaum

Scanlan & Rosenbaum's [1.1] *Introduction to the study of aircraft vibration and flutter* was printed in 1962 by The Macmillan Company totaling some 428 pages. This book treats the problem of vibrations first and lays down the fundamental principles for the analysis of simple dynamic systems. For a treatise on the first principles and fundamental details this is an excellent guide. Aircraft wings are treated as beams which are analytically treated via several methods of solution.

Having developed the basics and the theory of dynamics of beam like structures the text then develops flutter theory first in two then in three dimensions. The book also deals with the problem of flutter and details the main aspects and parameters that require consideration. A chapter on instrumentation and testing is also included, however although the principles are still the same the equipment now-a-days is significantly different.

A book to be recommended to the student without much vibration/structural dynamics experience. However it is equally useful if not essential for those with experience in this area but who require a fresh look at the subject or require some revision. Certainly a book not to be overlooked. Despite the fact that a large part of the book does not deal with flutter, the contents are all necessary and complimentary to the study of aeroelastic analysis.

4.6 Aeroelasticity by Bishplinghoff, Ashley & Halfman

Aeroelasticity (published in 1955) by Bishplinghoff, Ashley & Halfman [1.3] is a classic text featured on many courses related to the subject. Talk to anybody about aeroelasticity and one of the first books to be mentioned will be *Aeroelasticity* by Bishplinghoff, Ashley & Halfman. There is little doubt that this book is *the* book on the subject of aeroelasticity, although now out of print and unavailable in good book stores.

This is a classical text book which deals with the subject of aeroelasticity, from the American method of approach, to some great depth. It should be noted that this book is not for the novice nor is it the ideal starting point for those contemplating to start the study of the subject. It is however a favorite text book of senior research students and practicing engineers alike. A classic text book which contains a host of classical material and references and an essential piece for reference on aeroelasticity.

4.7 AGARD Manual on Aeroelasticity Vol I-VII circa 1965

Advisory group for Aeronautics Research & Development. These manuals [2.4] contain an excellent series of articles and are a valuable source of knowledge on all aspects of aeroelasticity. AGARD Manual on Aeroelasticity publication began in 1959 with continual updating.

4.8 Aerodynamic flutter by I.E.Garrick

Another classic collection of papers edited by I.E.Garrick [2.11] (of NASA Langley Research Centre) was published under the title *Aerodynamic flutter*. This is a volume of selected AIAA papers that relate to aerodynamic flutter that have been selected by Garrick to represent some excellent papers written by eminent researchers of the time. The papers span the era 1920 to 1966 and are excellent papers for those readers who wish to get to grips with the fundamentals of flutter. It must also be noted that a number of papers presented during this period had the advantage of dealing with the subject to length and in its entirety. Currently since the subject has become rather more explored and consequently more detail is available, there is a lack of completeness in any one paper. One has to scour a number of papers before a detailed impression of an aspect can be gleaned. Thus these early papers are a valuable source of fundamental knowledge and techniques.

4.9 A modern course in aeroelasticity by Dowell, Curtis Jr, Scanlan and Sisto.

In 1995 *A modern course in aeroelasticity* by Dowell et al [1.5] was issued in its Third Revised and Enlarged edition format. This is the most recent of publications that deals with a number of related topics and areas of interest in the recent past. Subjects such as turbomachinery, blade flutter and aeroservoelasticity are given considerable coverage. The second edition of this book was published in 1989 with a useful source of then current papers in areas under investigation. It covered the topics of Static Aeroelasticity, Dynamic Aeroelasticity, Nonsteady aerodynamics of lifting and non-lifting surfaces, Stall flutter, Aeroelastic problems of civil engineering structures, Aeroelasticity in turbomachines and Unsteady transonic aerodynamics & aeroelasticity.

4.10 Rotary wing aeroelasticity and structural dynamics by Bielawa.

Richard Bielawa's [1.7] *Rotary wing aeroelasticity and structural dynamics*. This book is one of a number of texts published in the AIAA Education Series which deals with the title subject in detail. The book covers the fundamental concepts of structural dynamics and aeroelasticity for not only the conventional rotary wing aircraft but also for the tilt-rotor and tilt-wing aircraft which are more recent arrivals on the scene. The books also contains relevant examples to reinforce the theory. In total their are a total of fourteen chapters, four appendices and a comprehensive bibliography totaling 562 pages in length.

The topics covered in this book are basic analysis tools, rotating beams, gyroscopic phenomena, drive system procedures, fuselage vibrations, methods for controlling vibrations, dynamics test procedures, stability analysis, mechanical and aeromechanical instabilities of rotors and rotor-pylon assemblies, unsteady aerodynamics and flutter of rotors, analysis of non-linear systems and model testing. The author brings together his extensive experience as a practicing engineer and researcher into this excellent book aimed at rotary wing aeroelasticity as is obvious from the title.

4.11 Certification documents.

Certification authorities require that aerospace vehicles are designed and built to strictly controlled criteria. For military aircraft the criteria employed is given in a defense standard document **DEF STAN 00-970 500 Vol 1-12**. DEF STAN relates to Ministry of Defense requirements for Military Aircraft, Chapter 500 relates to Aeroelasticity and Vols 1-12 contents are as follows : -

Vol 1 Aeroelasticity Introduction
Vol 2 Lifting surface flutter
Vol 3 Flutter of trailing edge control surfaces (ailerons, elevators and rudders)
Vol 4 Tab flutter
Vol 5 Model testing in wind tunnels
Vol 6 Stiffness tests
Vol 7 Hydraulic actuator impedance
Vol 8 Still air ground vibration tests
Vol 9 Flight flutter tests
Vol 10 Flutter clearance programme
Vol 11 Design criteria for mass balancing of trailing edge control surfaces

Vol 12 Finite element aeroelastic analysis

As seen form the above these papers cover all the possible cases of interest for certification purposes and are used largely in the UK.

For commercial, or civil, aircraft the Joint Airworthiness Regulations (JARs) are used in Europe, the Federal Airworthiness Requirements (FARs) constituted by the United States Federal Aviation Administration are used in the USA and Lufttuchtigkeitsforderungen Fur Segelflugzeuge und Motorsegler (LFSM) are used in Germany. Other countries may also have their own certification requirements, although the JARs and FARs are increasingly being adopted as standard regulatory documents. Further the British Civil Airworthiness Requirements (BCAR) may also be invoked for certian classes of aircraft and the document that deals with aeroelasticity is given in Sub-section K3-Structures (Issued 1st October 1969).

The relevant airworthiness requirements concerning aeroelastic characteristics are contained in the ducuments indicated below :-

Civil Aircraft

- Civil Aircraft - Small Aircraft FAR 23, JAR 23
- Civil Aircraft - Large Aircraft FAR 25, JAR 25
- Civil Aircraft - Sailplanes LFSM, JAR 22

Military Aircraft

- Military Aircraft - MIL-A-8870 (ASG) Applicable to the United States Air Force and United States Navy.
- Military Aircraft - MIL-A-8870 A (USAF) Applicable to the United States Air Force.
- Military Aircraft - DEF STAN 00-970 500 Applicable to the RAF (UK).

4.12 Conference Proceedings

Another very useful source of publications are the relevant conferences in the areas of Aeroelasticity and Structural Dynamics [7.5-7.8]. Of the more important is the bi-annual international forum held under the title *International Forum on Aeroelasticity & Structural Dynamics* last held in June 1997. Of similar importance is the ICAS conference which is also a bi-annual forum to be held next in January 1998.

Other important conferences are organized by the American Institute of Aeronautics and Astronautics (AIAA), the American Society of Mechanical Engineers (ASME), the Royal Aeronautical Society (RAeS), Advisory Group for Aerospace Research and Development (AGARD), (ESDU), Confederation of European Aerospace Societies (CEAS) and similar national aerospace and aeronautics organizations.

If the reader is interested in research or current publications then these proceedings are a valuable source of information. It was noted by Friedmann [3.8] that since 1986 there have been 40-90 papers presented per annum. This gives something in the region of 450 to 1000 papers available on the subject, in the last eleven years alone. Indicating the growing nature of the field and the numerous references available.

5. SOFTWARE APPLICATIONS WITH AEROELASTICITY CAPABILITIES

During the early stages of aeroelastic expansion calculations were first carried out by hand. Hence it was only possible to include two or at most three degrees of freedom before the problem became too cumbersome or large to handle in this manner. During that period techniques such as the Routh [2.3] criteria were developed which were useful for these two degree of freedom cases. As the computer age took off the number of degrees of freedom that could be included increased rapidly. With the first computers space restrictions were the predominant limiting factors since the analysis requires the solution of simultaneous equations which are often represented as matrix equations. The more the degrees of freedom the larger the matrix hence greater the computing power required. Today computers have become sufficiently powerful such that most aeroelastic problems are solved with their aid.

During early developments hand calculations with the use of powerful calculators were the norm. Since the analysis of aeroelastic problems was a specialized area of interest, largely to people in the aeronautical field, these specialist groups had there own methods of solution. This was particularly true for aircraft manufactures and designers who developed their own software programs which assisted them in the solution of problems specific to their particular designs and configurations. Inevitably aircraft manufacturers who designed and built military aircraft had slightly different requirements and hence tools as compared with civil aircraft designers. The theory and principles of course remain the same. The is borne out to this day, in as much as the current practices in industry demonstrate that companies have their own in-house codes which have evolved over many years. To such an extent that different sectors of the same company may, and often do, have different software and methodologies for conducting, largely similar, aeroelastic calculations.

With the phenomenal increase in computing power there have been a number of software development projects that have been responsible solely for the generation of software tools. In the aeronautical area one of the most popular software packages is NASTRAN, which has many capabilities one of which is an aeroelastic capability. It ought to be mentioned in passing that NASTRAN has had a rich and varied history and is today marketed by several organizations. For example MSC/NASTRAN, UAI/NASTRAN, CSA/NASTRAN to name but a few. MSC/NASTRAN is considered to be the more widely used although the other applications also claim their converts and advantages. There exists an Aeroelasticity manual [1.14] for use with MSC/NASTRAN which details the theory and the manner of application of problems for aeroelastic purposes. CSA/NASTRAN can be used on a personal computer and has been successfully used for small aeroelastic problems.

There are of course other applications that have aeroelastic capabilities such as ASTROS, LAGRANGE, ECLIPSE to name but a few. Some of these applications are commercially available while others are specific to the company which in turn may have developed the software. As noted above specialist algorithms have also been developed by researchers and manufacturers of aircraft which are specific to the needs of their products and requirements.

Binary flutter calculations are rarely used these days since the existence of Finite Element based software tools like those mentioned above, have made aeroelastic analysis relatively easy. Instead problems of aircraft aeroelasticity are now readily modeled using these tools. There is however a great danger in using these tools without having the knowledge of the fundamentals of aeroelasticity. These packages, many of them large and sometimes difficult to use, may detract from the problem at hand, that of solving say a flutter problem. Thus the non-expert reader is cautioned to gain some prior knowledge about aeroelasticity, see Section 4, before using software tools which offer aeroelastic capabilities.

6. JOURNALS AND RELEVANT AEROELASTICITY PUBLICATIONS

Another very useful source of literature are the technical journals, although these become useful once one is more familiar with the filed of aeroelasticity. Indeed it should be noted that there is no one journal specifically devoted to aeroelasticity. Further as aeroelasticity is such a multidiciplinary field one will find publications in a wide variety of technical journals. The main ones, that are likely to contain relevant material, are listed below :-

- The Royal Aeronautical Journal
- The Journal of Aircraft
- The Journal of Aeronautical Sciences
- International Journal of Control
- The Journal of Sound and Vibration
- Journal of Fluids and Structures
- International Journal of Solids and Structures
- The Journal of American Helicopter Society
- AHS (American Helicopter Society) Journal
- AIAA (American Institute of Aeronautics and Astronautics) Journal
- ASME (American Society for Mechanical Engineers) Transactions, Journal of Applied Mechanics
- ASCE (American Society for Civil Engineers) Transactions, Engineering Mechanics Division
- Composite and Structures
- AGARD papers
- Vertica
- Shock and Vibration Digest
- Journal of Mechanical Engineering Science
- Chinese Journal of Aeronautics
- The Journal of Aeronautical Society of India
- The Japan Society for Aeronautical and Space Sciences
- Progress in Aerospace Sciences

- Journal of Reinforced Plastics and Composites
- ICAS conference transactions
- International Forum on Aeroelasticity and Structural Dynamics Proceedings

7. USEFUL WORLD WIDE WEB SITES

In todays age of networked computing and the global village environment one must not ignore the very powerful resource offered by the internet. Indeed there are a number of excellent sites that can be visited which hold a myriad of information related to aeronautics and astronautics and hence aeroelasticity. Some of the more famous (or popular sites) are indicated below. New sites and locations are constantly appearing but the sites recorded here will suffice as a start. It ought to be noted that the list below is neither exhaustive nor representative of aeroelastic activities being conducted in the arena.

NASA home page
http://www.nasa.gov/NASA_homepage.html

NASA Dryden
http://www.dfrc.nasa.gov/dryden.html

NASA Langley
http://www.larc.nasa.gov/langley.html

AIAA home page
http://www.aiaa.org/

DLR Gottingen Institute of Aeroelasticity
http://www.dlr.de/

European Space Agency (ESA) home page
http://www.esrin.esa.it/

Federal Airwirthiness Authorities (FAA) home page
http://www.faa.gov/

University of Maryland Centre for Rotorcraft Education and Research
http://www.enae.umd.edu/CRER

Aerospace agencies (from Cranfield University)
http://www.cranfield.ac.uk/cils/library/subjects/agencies.html

CSA/NASTRAN Home Page
http://www.csar.com/

MSC/NASTRAN Home Page
http://www.macsch.com/

8. A BRIEF WORD ON LITERATURE SEARCHES

As noted above the present paper is meant for the non-expert reader, however it may be worth remarking in passing that searching for literature in the field of aeroelasticity can be somewhat of a specialist task. Thus no attempt will be made here to address this very important aspect, particularly for the researcher. Instead the reader is directed to the documents supplied by relevant library services (e.g. Cranfield University Library) which deal with this matter adequately and in expert fashion. Searches can be conducted using a variety of tools and techniques together with numerous search facilities. This in itself is a specialist topic and can not be done justice in a paper of the present kind.

9. AEROELASTICITY SUBJECT AREA CLASSIFICATIONS

From the discussions conducted thus far one will recognize that there are presently a variety of areas into which the larger field of aeroelasticity can be classified. This is particularly true when it comes to research, when it is often necessary to deal with a narrow rather than general field. To this end following is a rudimentary list of possible topic areas and subject subdivisions that the new reader may find useful, particularly if a literature search is to be conducted. The topic areas listed may assist in narrowing down the field or direct the reader to more specific topics.

Aeroservoelasticity

Aerothermoelasticity

Adaptive structures (smart structures)

Aeroelastic tailoring

Flexible wings aeroelastic studies

Static aeroelasticity

Dynamic Aeroelasticity

Fixed wing aeroelasticity

Rotary wing aeroelasticity

Buzz and Buffet

Unsteady aerodynamics

Static Aeroelasticity

Wing (Torsional) Divergence
Wing Divergence (Forward Swept, Unswept, Swept Back wings)

Control Surface (Aileron, Elevator, Rudder, Tab) Divergence
Control Surface (Aileron, Elevator, Rudder, Tab) Reversal

Fuselage divergence

Aeroelasticity General (Static and Dynamic Aeroelasticity)

Aeroelasticity as related to aircraft structures (civil, military)
Aeroelasticity as related to aerospace structures
Aeroelasticity as related to non aircraft structures (e.g. Bridges, Electricity Cables etc)
Aeroelasticity as related to turbo machinery
Aeroelasticity as related to nuclear structures
Aeroelasticity as related to pipe/flow structures
Aeroelasticity as related to civil engineering structures
Aeroelasticity as related to rotary aircraft wings
Aeroelasticity as related to Helicopters
Aeroelasticity as related Helicopter main rotor flutter
Aeroelasticity as related Helicopter tail rotor flutter

Flutter

Subsonic flutter
Supersonic flutter
Transonic flutter
Subsonic, Supersonic, Transonic, Wing flutter
Subsonic, Supersonic, Transonic, Tail flutter
Control Surface (Aileron, Elevator, Rudder, Tab) Flutter

Flutter of airplanes
Flutter of airplanes at high angles of attack
Flutter of airplanes with delta wings
Flutter of airplanes with high aspect ratio wings
Flutter of airplanes with composite wings
Flutter of airplanes with flexible wings

Flutter of main lifting surfaces
Flutter of secondary control surfaces
Flutter of turbo machinery blades
Flutter of (helicopters) rotary aircraft wings
Flutter of wings, fore-planes, tail planes
Flutter of military, commercial aircraft

Store flutter

Subsonic, Supersonic, Transonic store flutter

Flutter of under wing, tip mounted, multiple wing mounted, with varying aerodynamic profiles stores

Binary Flutter

Binary Flutter solution of equations using graphical, analytical, imperical techniques, using hand calculations

Ternary Flutter

Solution techniques
Possible practical cases of ternary flutter
Modes to be used for ternary flutter

Effects of following parameters on Flutter, Divergence and Control Reversal

Effects of sweep (forward)
Effects of (no sweep); i.e. flutter of straight wings
Effects of sweep (back)
Effect of flexural axis
Effect of aerodynamic axis
Effect of inertia axis
Effect of aspect ratio
Effect of thickness ratio
Effect of taper ratio
Effect of slenderness ratio
Effect of camber
Effect of anhedral
Effect of dihedral
Effect of wash out
Effect of wash in
Effect of torsional stiffness
Effect of flexural stiffness

10. SUMMARY

In summary it is worth noting that in this preliminary paper a modest number of publications have been cited for a paper of a preliminary nature.

For the beginner or non-expert reader who wants to understand the fundamentals and elementary theory of aeroelasticity, the reader would be well placed to study Broadbent's papers [2.1] (of 1954) *The Elementary Theory of Aero-Elasticity* followed by Hancock, Wright and Simpson's paper [2.2] (of 1985) *On the teaching of the principles of flexural-torsional flutter* with perhaps a perusal of Duncan's paper [2.3] (of 1948) *The Fundamentals of Flutter.* These three papers studied, in the given order, will suitably equip most non-experts and make them adequately familiar with the elementary theory and the fundamentals of aeroelasticity.

For the more interested reader or advanced student (having studied the above papers) one may wish to peruse the several excellent books in the field. The fundamentals with sufficient details can be gleaned from Scanlan and Rosenbaum's [1.1] *Introduction to the study of Aircraft Vibrations and Flutter*, Y.C.Fung's [1.2] *An introduction to Aeroelasticity* and for a more comprehensive exposition see Bishplinghoff, Ashley and Halfman's [1.3] *Aeroelasticity*. More recent developments and applications can be studied in Dowell et al's *A modern course in aeroelasticity* and Bielawa's *Rotary Wing Aeroelasticity and Structural Dynamics.*

The researcher would benefit from the note made in the second paragraph above. Perusal of the items in paragraph three would serve to provide more detailed and comprehensive information. But the main source of information/data will largely be attained from the numerous technical publications available in the open literature. See Section 6 above for a list of useful technical journals.

The more advanced researcher would be unlikely to benefit immensely from this note since their knowledge would far surpass the modest deliberations presented herein.

In conclusion aeroelasticity is a challenging and demanding field but equally it is a highly interesting field, which the more it is studied the more affinity one will gain for it.

11. REFERENCES

The following is a broad list of categories into which the references cited in this paper have been ordered.

1. AEROELASTICITY - (TEXT) BOOKS.

2. AEROELASTICITY - CLASSIC REFERENCES.

3. AEROELASTICITY - REVIEW PAPERS.

4. AEROELASTICITY - (TEXT) BOOKS.

5. AEROELASTICITY - GENERAL REFERENCES.

6. AEROELASTICITY - REFERENCES - SMART STRUCTURES.

7. AEROELASTICITY - ADDITIONAL PAPERS.

8. DIVERGENCE.

9. FLUTTER.

10. AEROSERVOELASTICITY.

11. ROTARY WING AEROELASTICITY.

12. AEROELASTIC TAILORING.

1. AEROELASTICITY -(TEXT) BOOKS.

[1.1] R.H.SCANLAN and R.ROSENBAUM. Introduction to the study of aircraft vibration and flutter. Published by the Macmillan Company, 1951.

[1.2] Y.C.FUNG. An introduction to the theory of aeroelasticity. John Wiley & Sons, Inc, New York, 1955.

[1.3] Raymond.L.BISPLINGHOFF, Holt.ASHLEY and Robert.L.HALFMAN. Aeroelasticity. Addison-Wesley Publishing Co, Inc, Cambridge, Mass, 1955.

[1.4] R.L.BISHPLINGHOF and H.ASHLEY. Principles of Aeroelasticity. Published by John Wiley & Sons, 1962.

[1.5] E.H.DOWELL, C.H.CURTIS Jr, R.H.SCANLAN and F.SISTO. A modern course in aeroelasticity. Kulwer Academic Publishers, The Netherlands, 3rd revised edition, 1995.

[1.6] E.H.DOWELL and M.ILGAMOV. Studies in Nonlinear Aeroelasticity. Published by Springer-Verlag, New York, 1988.

[1.7] Richard.L.BIELAWA. Rotary wing structural dynamics and aeroelasticity. AIAA Education series, 1992.

[1.8] E.H.DOWELL. Aeroelasticity of plates and shells. Leyden: Noordoff International , 1975.

[1.9] Robert.Alexander.FRAZER Elementary matrices and some applications to dynamics and differential equations. 1946.

[1.10] R.A.FRAZER and DUNCAN. The flutter of aeroplane wings. 1928.

[1.11] W.JOHNSON. Helicopter Theory. Princeton University Press, 1980.

[1.12] H.TEMPELTON. Massbalancing of aircraft control surfaces. Chapman & Hall Ltd, London, 1954.

[1.13] Norman.H.ABRAMSON. An introduction to the dynamics of airplanes. 1958.

[1.14] William.R.RODDEN and Erwin.H.JOHNSON. MSC/NASTRAN Aeroelasticity analysis Users Guide. Version 68. The Macneal-Schwendler Corporation, Los Angeles, USA.

[1.15] Darrol.STINTON. The anatomy of the aeroplane. G.T.Foulis & Co Ltd, 1966.

Non English texts

[1.16] H.W.FORSCHING. Grundlagen der Aeroelsatik *"Fundamentals of Aeroelasticity"*. (In German). Springer-Verleg ISBN 3-540-06540-7 New York, 1974.

[1.17] A.PETRE. Theory of Aeroelasticity. Vol I Statics, Vol II Dynamics. (In Romanian). Publishing House of the Academy of the Socialist Republic of Romania, Bucharest, 1966.

2. CLASSIC REFERENCES - AEROELASTICITY

[2.1] E.G.BROADBENT. The elementary theory of aero-elasticity. Aircraft Engineering, March/April//May/June 1954.

[2.2] G.J.HANCOCK, and J.R.WRIGHT, and A.SIMPSON. On the teaching of the principles of wing flexure-torsion flutter. The Aeronautical Journal, October 1985.

[2.3] W.J.DUNCAN. The fundamentals of flutter. Published as article R.A.E Report No Aero 1920; Reports and Memoranda No. 2417. November 1948; and also in Aircraft Engineering, January and February 1945.

[2.4] AGARD Manual on Aeroelasticity, Vols I-VII. Published by AGARD (circa 1965).

[2.5] A.W.BABISTER. Flutter and Divergence of sweptback and sweptforward wings. College of Aeronautics, Report No. 39, June 1950.

[2.6] A.R.COLLAR. Aeroelastic problems at high speed. The Journal of the Royal Aeronautical Society, January 1947, Vol 51, No 433.

[2.7] R.A.FRAZER and DUNCAN. The flutter of aeroplane tails. 1930, ARC/R&M 1237.

[2.8] R.A.FRAZER. The flutter of aeroplane wings. The Journal of the Royal Aeronautical Society, June 1929, Vol XXXIII, No 22, pp 407-

[2.9] R.A.FRAZER and W.J.DUNCAN. Main lifting surface flutter. ARC R& M 1155, 1928.

[2.10] H.ROXBEE-COX and A.G.PUGSLEY. Theory of loss of lateral control due to wing twisting. Br ARC R& M 1506, October 1932.

[2.10] H.REISSNER. Neuere probleme aus der Flugzeugstatik. Z. fur Flugtechnik und Motorluftschiffahrt, Vol 17, No 7, April 1926.

[2.11] I.E.GARRICK. Aerodynamic flutter. AIAA

[2.12] (Ed) P.P.FRIEDMANN & J.C.I.CHANG. Aeroelasticity and fluid structure interaction problems. AD-Vol. 44. ASME 1994. ISBN 0-7918-1453-X

[2.13] C.R.FREBERG and E.N.KEMLER. Aircraft vibration and flutter. Published by the John Wiley & Sons, 1944.

[2.14] S.J.LORING. General approach to the flutter problem. SAE Transactions, August 1941, pp 345-355.

[2.15] B.LOCKSPEISER. A simple approach to the wing flutter problem. The Journal of the Royal Aeronautical Society, June 1929, Vol XXXIII, No 22, pp 783-792.

[2.15] Marthinus.C.van SCHOOR and Andreas.H.von FLOTOW. Aeroelastic characteristics of a highly flexible aircraft. Journal of Aircraft, October 1990, Vol 27, No 10, pp 901-908.

3. AEROELASTICITY REVIEW PAPERS

[3.1] A.R.COLLAR. The expanding domain of aeroelasticity. The Journal of the Royal Aeronautical Society, June 1946, Vol 50, pp 613-636.

[3.2] A.R.COLLAR. Aeroelasticity - retrospect and Prospect. The Journal of the Royal Aeronautical Society, January 1959, Vol 63, pp 1-15.

[3.3] R.G.LOEWY. Review of rotary wing V/STOL dynamic and aeroelastic problems. Journal of the American Helicopter Society, July 1969, pp 2-23.

[3.4] P.P.FRIEDMANN. Recent trends in rotary wing aeroelasticity, Vertica, Vol 11, No 1/2, 1987, pp 139-170.

[3.5] I.CHOPRA. Perspectives in aero-mechanical stability of helicopter rotors, Vertica, Vol 14, No 4, 1990, pp 457-508

[3.6] H.ZIMMERMANN. The aeroelastic challenge of the Airbus family - Review and Prospects. . International Forum of aeroelasticity and structural dynamics. 3-5 June 1991, Aachen, pp 1-11.

[3.7] G.T.S.DONE. Past and future progress in fixed wing and rotary wing aeroelasticity. International Forum of aeroelasticity and structural dynamics. August 1995, Manchester, pp 23.1-23.13.

[3.8] P.P.FRIEDMANN. The renaissance of aeroelasticity and its future. International Forum of aeroelasticity and structural dynamics. June 1997 Rome.

[3.9] H.ASHELY. Aeroelasticity, Applied Mechanics review, Vol. 23, February 1970, pp 119-129.

[3.10] H.ASHLEY. Update to aeroelasticity, Applied Mechanics update, C.R.Steele and G.S.Springer Eds., New York, ASME, 1986, pp 117-125.

[3.11] S.FLEETER. Aeroelasticity research for turbomachine applications, Journal of Aircraft, Vol 16, 1979, pp 330-338.

[3.12] I.E.GARRICK. Aeroelasticity - Frontiers and Beyond, Journal of Aircraft, Vol 13, No 9, September 1976, pp 641-657.

[3.13] H.N.ABRAMSON. Hydroelasticity: A review of Hydrofoil Flutter. Applied Mechanics Reviews, February 1969.

[3.14] I.E.GARRICK and W.H.REED. Historical development of aircraft flutter, Journal of Aircraft, Vol 18, No 11, November 1981, pp 897-912.

[3.15] A.K.NOOR and S.L.VENNERI (Eds.). Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993.

[3.16] O.O.BENDIKSEN. Aeroelastic problems in turbomachines, Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 3, pp 241-297.

[3.17] R.H.RICKETTS. Experimental aeroelasticity in wind tunnels-history, status and future in brief. Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 2, pp 151-177.

[3.18] E.H.DOWELL. Nonlinear aeroelasticity. Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 4, pp 213-239.

[3.19] J.W.EDWARDS. Computational aeroelasticity. Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 7, pp 393-436.

[3.20] P.P.FRIEDMANN and D.A.HODGES. Rotary wing aeroelasticity with application to VSTOL vehicles. Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 6, pp 299-391.

[3.21] T.M.HARRIS, T.E.NOLL, T.J.HERTZ and W.A.SOTOMAYER. A review of aeroelastic research at the flight dynamics laboratory. Presented at the second international symposium on aeroelasticity and structural dynamics. Aachen, Germany, 1-3 April 1985.

[3.22] G.COUPRY. Aeroelasticity today and tomorrow. ICAS-86-0.2. ICAS and AIAA 1986.

[3.23] G.REICHERT and H.STREHLOW. Survey of active and passive means to reduce rotorcraft vibrations. International symposium on aeroelasticity, Nurnberg, Germany. 5-7 October 1981.

4. AEROELASTICITY PAPERS REVIEWING RESEARCH ACTIVITIES AT KEY ESTABLISHMENTS

[4.1] W.H.REED. III. Aeroelasticity matters: Some reflections on two decades of testing in the NASA Langley transonic dynamics tunnel. International symposium on aeroelasticity, Nuremberg, Germany. 5-7 October 1981.

[4.2] H.HONLINGER and M.STEININGER. Survey of aeroelastic wind tunnel and flight testing methods. International symposium on aeroelasticity, Nurnberg, Germany. 5-7 October 1981.

[4.3] D.K.POTTER. Flight flutter and vibration testing. C16/76. Presented at symposium on The Interpretation of complex signals from mechanical systems. Page 9-16. IMechE 1976.

[4.4] Anon. Report on Italian activities in Aeroelasticity. Presented at the 53rd AGARD Structures and Materials Panel - Noordwijkerhout, Netherlands. Fall 1981.

[4.5] R.DESTUYNDER. Recent developments in wing with stores flutter suppression. International symposium on aeroelasticity, Nurnberg, Germany. 5-7 October 1981.

[4.6] Otto SENSBURG. Thirty years of Structural Dynamic investigations at MBB-UF, MBB publication, S-PUB-399, May 1990.

5. GENERAL REFERENCES - AEROELASTICITY

[5.1] H.FORSCHING. New ultra high capacity aircraft (UHCA) - challenges and problems from an aeroelastic point of view. DLR - Institute of Aeroelasticity, Gottingen, Germany.

[5.2] R.A.ORMISTON. Investigations of hingeless rotor stability. DGLR, International symposium on aeroelasticity, Nuremberg, Germany. 7 October 1981.

[5.3] A.R.COLLAR and A.SIMPSON. Matrices and Engineering Dynamics: Programs. Ellis-Horwood.

[5.4] O.BARTSCH and O.SENSBURG. Ultimate factor for structural design of modern fighters. Presented at the 61st AGARD Structures and Materials Panel - Athens/Greece. 28 September - 3 October 1986.

[5.5] G.SCHNEIDER and H.GODEL. Aeroelastic considerations for automatic structural design procedures. International symposium on aeroelasticity, Numberg, Germany. 5-7 October 1981.

[5.6] J.BECKER and A.GRAVELLE. Some results of experimental and analytical buffeting investigations on a delta wing. Second international symposium on aeroelasticity and structural dynamics at Aachen, Germany. 1-3 April 1985.

[5.7] E.G.BROADBENT. Aeroelastic problems in connection with High Speed Flight. Journal of the Royal Aeronautical Society. July 1956, Vol 60, No 547.

[5.8] V.CARD. A review of measured gust responses in the light of modern analysis methods. Presented at the AGARD Structures and Materials Panel - Athens/Greece. September 1986.

[5.9] In. LEE and Jung-Jin LEE. Vibration analysis of composite wing with tip mass using finite elements. Computers & structures, Vol 47, N0 3, pp 495-504, 1993.

[5.10] L.MEIROVITCH and T.J.SEITZ. Structural modeling of low aspect ratio composite wings. AIAA-93-1371-CP, 1993.

[5.11] G.KARPOUZIAN and L.LIBRESCU. Comprehensive model of anisotropic composite aircraft wings suitable for aeroelastic analyses. Journal of Aircraft, V01 31, No 3, May-June 1994.

[5.12] Ang HAISONG, Chiao SHING, Jiang LIPING and Yu YIN. Aeroelastic analysis of composite wing with control surface. ICAS-92-5.9.4

[5.13] Lianzhu HE, I-Chih WANG and Daze TANG. Dynamic responses of aircraft wing made of composite materials. pp 1342-1346.

[5.14] Arthur.A.REGIER. The use of scaled dynamic models in several aerospace vehicle studies. ASME colloquium, November 1963, Philadelphia, pp 34-50.

[5.15] Stanley.G.KALEMARIS. Feasibility of forward swept wing technology for V/STOL aircraft. 801176.

[5.16] J.SCHWEIGER, G.SCHEIDER, O.SENSBURG and G.LOBERT. Design of a forward swept wing fighter aircraft. Paper presented at the International conference on “Forward swept wing aircraft”, 24-26 March 1982, Bristol, England.

[5.17] Liviu LIBRESCU and Sorot THANGJITHAM. Analytical studies on static aeroelastic behavior of forward swept composite wing structures. Journal of Aircraft, February 1991, Vol 28, No 2, pp 151-157.

[5.18] Anita.L.TRACY and Inderjit CHOPRA. Aeroelastic analysis of a composite bearingless rotor in forward flight using an improved warping model. Journal of the American Helicopter Society, July 1995, Vol 40, No 3.

[5.19] O.SENSBURG, G.SCHMIDINGER & K. FULLHAS. Integrated Design of Structures, Journal of Aircraft, March 1989, Vol 26, No 3.

6. REFERENCES - SMART STRUCTURES.

[6.1] Elamr.J.BREITBACH, Rolf.LAMMERING, Jorg.MELCHER and Fred.NITZCHE. Smart structures research in aerospace engineering. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 11- 18.

[6.2] Peter.D.DEAN. Intelligent aircraft structures - A technique to verify sensor integrity. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 59- 62

[6.3] P.JANKER and W.MARTIN. Research need for piezoactuators in adaptive structures. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 80- 85

[6.4] S.S.S.ROBERTS, R.J.BUTLER and R.DAVIDSON. Progress towards a robust, user friendly, system for active structural damping. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 117- 120.

[6.5] Daryoush ALLAEI. Smart aircraft by continuos condition monitoring of aircraft structures and components. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 152- 155

[6.6] Yoichi MUKAI, Eizaburo TACHIBANA and Yutaka INOUE. Active response control using rotor fin for wing-induced structural vibrations. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 190- 193

[6.7] Daryoush ALLAEI. Vibration and noise control in civil structures by “smart” design. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 198- 201

[6.8] W.BEN WU. Dynamic analysis on smart materials. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 269- 272

[6.9] Victor.GIURGIUTIU, Zaffir.CHAUDHRY and Craig.A.ROGERS. Efficient use of induced strain actuators in aeroelastic active control. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 273- 276

[6.10] M.N.ABDUL-WAHED and T.A.WEISSHAAR. Finite element modeling of three-dimensional integral sensors for the control of aeroelastic structures. Second European conference on Smart Structures and Materials, Glasgow 1994. pp 346- 349.

7. ADDITIONAL AEROELASTICITY PAPERS

[7.1] S.S.RAO. Optimization of airplane wing structures under gust loads. Computers & Structures, March 1984, Vol 21, No 4, pp 741-749.

[7.2] Robert L SWAIM. Aircraft elastic mode control. Journal of Aircraft, February 1971, Vol 8, No 2, pp 65-71.

[7.3] Lester D EDINGER. Design of elastic mode suppression systems for ride quality improvement. Journal of Aircraft, March-April 1968, Vol 5, No 2, pp 161-168.

[7.4] Terrence A WEISSHAAR and Thomas A ZEILER. Dynamic stability of flexible forward swept wing aircraft. Journal of Aircraft, December 1983, Vol 20, No 12, pp 1014-1020.

[7.5] Proceedings of the International Forum on Aeroelasticity & Structural Dynamics 1991. Conference held 3-5 June 1991 at Aachen, Germany.

[7.6] Proceedings of the International Forum on Aeroelasticity & Structural Dynamics 1993. Conference held in 1993 at .

[7.7] Proceedings of the International Forum on Aeroelasticity & Structural Dynamics 1995. Conference held in August 1995 at Manchester University, Manchester, UK.

[7.8] Proceedings of the International Forum on Aeroelasticity & Structural Dynamics 1997. Conference held 17-20 June 1997 at 'La Sapienza' University in Rome, Italy.

8. DIVERGENCE.

[8.1] L.LIBRESCU, L.MEIROVITCH and O.SONG. A refined structural model of composite aircraft wings for the enhancement of vibrational and aeroelastic response characteristics. AIAA-93-1536-CP, 1993.

[8.2] Rodney.H.RICKETTS and Robert.V.DOGGETT. Wind-tunnel experiments on divergence of forward swept wings. NASA Technical Paper 1685, 1980

[8.3] Maxwell.BLAIR and Terrence.A.WEISSHAAR. Swept composite wing aeroelastic divergence experiments. Journal of Aircraft, AIAA 81-1670R, November 1982, Vol 19, No 11, pp 1019-1024.

[8.4] Kenneth.E.GRIFFIN and Franklin.E.EASTEP. Active control of forward swept wings with divergence and flutter aeroelastic instabilities. Journal of Aircraft, AIAA 81-0637R, October 1982, Vol 19, No 10, pp 885-891. 81-0637.

[8.5] Maxwell.BLAIR and Terrence.A.WEISSHAAR. Divergence of swept wings with composite structures. AIAA Aircraft Systems and Technology Conference, AIAA 81-1670, August 11-13, 1981, Dayton, Ohio.

[8.6] Kenneth E GRIFFIN and Franklin E EASTEP. Active control of forward-swept wings with divergence and flutter aeroelastic instabilities. Journal of Aircraft, October 1982, Vol , No 10, pp 885-891.

[8.7] Maxwell BLAIR and Terrence A WEISSHAAR. Swept composite wing aeroelastic divergence experiments. Journal of Aircraft, September 1982, Vol 19, No 11, pp 1019-1024.

[8.8] Richard R CHIPMAN, Alex M ZISLIN and Catherine WATERS. Control of aeroelastic divergence. Journal of Aircraft, December 1983, Vol 20, No 12, pp 1007-1013.

9. FLUTTER.

[9.1] O.SENSBURG, A.LOTZE and G.HAIDL. Wings with stores flutter on variable sweep wing aircraft. Presented at the 39th Structures and Materials Panel of AGARD in Munich, Germany. 6-12 October 1974.

[9.2] A.SIMPSON. The solution of large flutter problems on small computers. The Aeronautical Journal, April 1984.

[9.3] A.LOTZE. Asymmetric store flutter. Presented at the 46th Structures and Materials Panel of AGARD in Aalborg, Denmark. 10-14 April 1978.

[9.4] A.LOTZE , O.SENSBURG, and M.KUHN. Flutter investigations on a combat aircraft with a command and stability augmentation system. Presented at the AIAA Aircraft Systems and Technology meeting at Los Angeles, California. 4-6 August 1975.

[9.5] J.R.BANERJEE. Flutter characteristics of high aspect ratio tailless aircraft. Journal of aircraft, Volume 21, No. 9, September 1984, Page 733.

[9.6] G.HAIDL. Active flutter suppression on wings with external stores. Presented at the 37th AGARD Structures and Materials Panel - Den Haag , Netherlands. 7-12 October 1973.

[9.7] V. MUKHOPADHYAY. Interactive flutter analysis and parametric study for conceptual wing design. AIAA 95-3943, 1st AIA Aircraft Engineering, Technology and Operations Congress, September 19-21 1995, Los Angeles, California.

[9.8] R.B.RAMSAY. Flutter certification and qualification of combat aircraft. British Aerospace Defense Ltd (military Aircraft Division), Warton Aerodrome, Preston. Lancashire, England.

[9.9] H.P.LEE. Divergence and flutter of a cantilever rod with an intermediate spring support. International Journal of Solids & Structures, Vol 32, No 10, pp 137-1382, 1995.

[9.10] Hiroshi TORII and Yuji MATSUZAKI. Subcritical flutter characteristics of a swept back wing in a supersonic flow. The Japan Society for Aeronautical and Space Sciences, Vol 38, No 120, August 1995.

[9.11] Vivek.MUKHOPADHAY. Interactive flutter analysis and parametric study for conceptual wing design. AIAA-95-3943, 1st AIAA Aircraft Engineering, Technology and Operations Congress, September 19-21, 1995, Los Angeles, California.

[9.12] Anon. A flutter design parameter to supplement the Regier number. AIAA Journal of Aircraft, July 1964, Vol 2, No 7, pp 1343-1345.

[9.13] Dario.H.BALDELLI and Hirobumi.OHTA. Flutter margin augmentation synthesis using normalized coprime factors approach. Journal of Guidance, Control, and Dynamics, July-August 1995, Vol 18, No 4.

[9.14] Mordechay KARPEL. Design for active flutter suppression and gust alleviation using state-space aeroelastic modeling. Journal of Aircraft, March 1982, Vol 19, No 3, pp 221-227.

[9.15] Steven J HOLLOWELL and John DUGUNDJI. Aeroelastic flutter and divergence of stiffness coupled graphite/epoxy, cantilevered plates. Porceedings 23rd AIAA/ASME/ASCE/AHS Structures and structural dynamics and Materials conference, New Orleans, 1982, pp 416-426.

[9.16] Steven J HOLLOWELL and John DUGUNDJI. Aeroelastic flutter and divergence of stiffness coupled graphite/epoxy, cantilevered plates. Journal of Aircraft, January 1984, Vol 21, No 1, pp 69-76.

[9.17] Hidetsugu HORIKAWA and Earl H DOWELL. An elementary explanation of the flutter mechanism with active feedback controls. Journal of Aircraft, April 1979, Vol 16, No 4, pp 225-232.

[9.18] I.LOTTATI. Flutter and divergence aeroelastic characteristics for composite forward swept cantilevered wing. Journal of Aircraft, November 1985, Vol 22, No 11, pp 1001-1007.

10. AEROSERVOELASTICITY.

[10.1] T.E.NOLL. Aeroservoelasticity. Flight-Vehicle Materials, Structures and Dynamics-Assessment and Future Direction, Vol 5 Structural Dynamics and Aeroelasticity, New York, ASME, 1993, Ch 3, pp 179-212.

[10.2] Thomas NOLL, Maxwell BLAIR and John CERRA. ADAM, An aeroservoelastic analysis method for analog or digital systems. Journal of Aircraft, September 1986, Vol 23, No 11, pp 852-858.

[10.3] Malcolm A CUTCHINS, James W PURVIS and Robert W BUNTON. Aeroservoelasticity in the time domain. Journal of Aircraft, September 1983, Vol 20, No 9, pp 753-761.

[10.4] E.LIVNE and W.LI. Aerosevoelastic aspects of wing/control surface planform shape optimization. AIAA journal, Vol 33, No 2, February 1995.

11. ROTARY WING AEROELASTICITY.

[11.1] H.HUBER and V.MIKULLA. Transonic effects on helicopter rotor blades. International symposium on aeroelasticity at Nurnberg, Germany. 5-7 October 1981.

[11.2] R.A.ORMISTON and D.H.HODGES. Linear Flap-Lag Dynamics of Hingeless Helicopter Rotor Blades in Hover. Journal of the American Helicopter Society, Vol 17, No 2, 1972, pp 2-14.

[11.3] E.J.NAGY. Improved methods in Ground Vibration Testing. Journal of the American Helicopter Society, Vol 28, No 2, 1983, pp 24-29.

[11.4] R.H.MILLER and C.W.ELLIS. Blade vibration and flutter. Journal of the American Helicopter Society, Vol 1, No 3, 1956, pp 19-38.

[11.5] R.T.LYTWYN, W.L.MIAO and W.WOITSCH. Airborne and Ground Resonance of Helicopters. Journal of the American Helicopter Society, Vol 16, No 2, 1971, pp 2-9.

[11.6] R.G.LOWEY. A two dimensional approximation to the unsteady aerodynamics of rotary wings. Journal of the American Helicopter Society, Vol 29, No 4, 1984, pp 4-30.

[11.7] R.G.LOWEY. Helicopter vibrations: A Technological Perspective. Journal of Aeronautical Sciences, Vol 24, No 2, 1957, pp 81-92.

[11.8] W.H.REED. Propeller-Rotor whirl flutter: A State-of the Art Review. Journal of Sound and Vibration, Vol 4, No 3, 1966, pp 526-544.

12. AEROELASTIC TAILORING.

[12.1] Michael H SHIRK and Terrence J HERTZ. Aeroelastic tailoring - Theory, practice, and promise. Journal of Aircraft, January 1986, Vol 23, No 1, pp 6-17.

[12.2] Huang CHUANQI and Qiao XIN. Aeroelastic tailoring of aeronautical composite wing structures. Chinese Journal of Aeronautics, Vol 4, No 2, May 1991.

[12.3] Liviu LIBRESCU and Ohseop SONG. Static aeroelastic tailoring of composite aircraft swept wings modeled as thin walled beam structures. Achievement in Composites in Japan and the United States, 1990.

[12.4] V.C.SHERRER, T.J.HERTZ and M.H.SHIRK. Wind tunnel demonstration of aeroelastic tailoring applied to forward swept wings. Journal of Aircraft, AIAA, November 1981, Vol 18, No 11, pp 976-983.

[12.5] V.C.SHERRER, T.J.HERTZ and M.H.SHIRK. A wind tunnel demonstration of the principle of aeroelastic tailoring applied to forward swept wings. 80-0796.

[12.6] K.B.LAZARUS, E.F.CRAWLEY and C.Y.LIN. Fundamental mechanisms of aeroelastic control with control surface and strain actuation. Journal of guidance, control and dynamics. Vol 18, No , Jan-Feb 1995.

[12.7] Jeoung.Yoel.YU, Woo.Young.KANG and Seung.Jo.KIM. Elastic tailoring of laminated composite plate by anisotropic piezoelectric polymers - Theory, Computation, and Experiment. Journal of Composites Materials, Vol 29, No 9, 1995.