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Introduction to Flight Test Engineering

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by

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14. Abstract

This is the Introductory Volume to the Flight Test Techniques Series. It is a general introduction to the various activities and aspects of Flight Test Engineering that must be considered when planning, conducting, and reporting a flight test program. Its main intent is to provide a broad overview to the novice engineer or to other people who have a need to interface with specialists within the flight test community.

The first two Sections provide some insight into the question of why flight test and give a short history of flight test engineering. Sections 3 through 10 deal with the preparation for flight testing. They provide guidance on the preliminary factors that must be considered; the composition of the test team; the logistic support requirements; the instrumentation and data processing requirements; the flight test plan; the associated preliminary ground tests; and last, but by no means least, discuss safety aspects.

Sections 11 through 27 describe the various types of flight tests that are usually conducted during the development and certification of a new or modified aircraft type. Each Section offers a brief introduction to the topic under consideration, and the nature and the objectives of the tests to be conducted. It lists the test instrumentation (and, where appropriate, other test equipment and facilities) required, describes the test maneuvers to be executed, and indicates the way in which the test data is selected, analyzed, and presented.

The various activities that should take place between test flights are presented next. Items that are covered are: who to debrief; what type of reports to send where; types of data analysis required for next flight; review of test data to make a comparison to predicted data and some courses of action if there is not good agreement; and comments on selecting the next test flight.

The activities that must take place upon completion of the test program are presented. The types of reports and briefings that should take place and a discussion of some of the uses of the flight test data are covered.

A brief forecast is presented of where present trends may be leading.

This AGARDograph was sponsored by the Flight Vehicle Integration Panel of AGARD.

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Preface

Soon after its founding in 1952, the Advisory Group for Aerospace Research and Development (AGARD) recognized the need for a comprehensive publication on Flight Test Techniques and the associated instrumentation. Under the direction of the Flight Test Panel (now the Flight Vehicle Integration Panel) a Flight Test Manual was published in the years 1954 to 1956. This original Manual was prepared as four volumes: 1. Performance, 2. Stability and Control, 3. Instrumentation Catalog, and 4. Instrumentation Systems.

As a result of the advances in the field of flight test instrumentation, the Flight Test Instrumentation Group was formed in 1968 to update Volumes 3 and 4 of the Flight Test Manual by publication of the Flight Test Instrumentation Series, AGARDograph 160. In its published volumes AGARDograph 160 has covered recent developments in flight test instrumentation.

In 1978, it was decided that further specialist monographs should be published covering aspects of Volumes 1 and 2 of the original Flight Test Manual, including the flight testing of aircraft systems. In March 1981, the Flight Test Techniques Group was established to carry out this task. The monographs of this latter series (with the exception of AG 237 which was separately numbered) are being published as individually numbered volumes in AGARDograph 300. In 1993, the Flight Test Techniques Group was transformed into the Flight Test Editorial Committee, thereby better reflecting its actual status within AGARD. Fortunately, the work on volumes could continue without being affected by this change.

An Annex at the end of each volume of both AGARDograph 160 and AGARDograph 300 lists the volumes that have been published in the Flight Test Instrumentation Series (AG 160) and the Flight Test Techniques Series (AG 300) plus the volumes that were in preparation when this volume was published.

In 1987 when several volumes in the Flight Test Techniques Series had already been published, it was decided that it was an omission not to have an introductory volume to the Flight Test Techniques Series. This volume was to provide an overview of the field of flight test engineering for the novice engineer engaged in this field. It took some time before an editor was found who would work closely with over fifty lead authors and contributing authors. Mr. F.N. Stoliker, former Technical Director of the US Air Force Flight Test Center at Edwards Air Force Base in California, was willing to undertake this heavy task and he started his preparations in 1989. The first authors started writing in 1991.

In 1995 the Volume has now been published and AGARD is convinced that it is a significant volume that will be met with great appreciation in the flight test community.

Foreword

The volumes that currently exist in the Flight Test Techniques Series are quite specific in their focus and are generally aimed at the engineer who has some knowledge in the field of flight test engineering. Even though these volumes meet a strong need for this type of information it was felt that there was a need to provide information to the novice engineer or to other people who have a need to interface with the flight test community. This volume is intended to lightly touch all those areas that must be considered when planning, establishing, conducting, closing out, and reporting on a flight test program. This volume is NOT intended to be a complete guide as to how to conduct a flight test program. Rather, it is a primer and contains references to additional material that will provide greater detail. The serious reader is encouraged to do further reading in the various volumes of the AGARD Flight Test Techniques series and the Flight Test Instrumentation series, AGARDographs 300 and 160, respectively, and other documents which are referenced in each Section of this volume.

The first two Sections are the Introduction and Historical Perspective. They provide some insight into the question of why flight test and give a short history of flight test engineering.

Sections 3 through 10 deal with the preparation for flight testing. They provide guidance on the preliminary factors that must be considered, such as the technical, commercial, and political background to the tests, and any relevant existing data or considerations (Section 3); the composition of the test team (Section 4), the logistic support requirements (Section 5); the instrumentation and data processing requirements (Sections 6 and 7); the overall flight test plan and the associated preliminary ground tests (Sections 8 and 9); and last, but by no means least, Section 10 discusses safety aspects.

Sections 11 through 27 describe the various types of flight tests that are usually conducted during the development and certification of a new or modified aircraft type. Each Section offers a brief introduction to the topic under consideration, and the nature and the objectives of the tests to be made. It lists the test instrumentation (and, where appropriate, other test equipment and facilities) required, describes the test maneuvers to be executed, and indicates the way in which the test data is selected, analyzed, and presented.

Section 28 "Post-flight Operations" discusses the various activities that should take place between test flights. Items that are covered include who to debrief, what type of reports to send where, types of data analysis required for the next flight, review of test data to make a comparison to predicted data, some courses of action if there is not good agreement, and comments on selecting the next test flight.

Section 29 "Post Test Operations" covers the activities that must take place upon completion of the test program. Briefly discussed are the types of reports and briefings that should take place and a discussion of some of the uses of the flight test data.

Section 30 "Future Trends" gives a brief forecast of where present trends may be leading.

The material presented in the Volume reflects the experience of the prime author and any contributing author(s) for each Section. The Sections will normally be typical of the procedures and practices of the author's home station; however, they are representative of those used by many organizations. As such, an individual Section may or may not include comments about civil and/or rotary wing aircraft. Wherever possible the authors and reviewers have provided bibliographic entries that would be useful to those who desire to test other than fixed wing military aircraft. The users of this Volume are reminded that they should interpret the advice given in the context of the rules, processes, and procedures of their parent/home organization.

Also, the reader must be aware that terms such as "project" are used in the context of the Section author's home base and experience. The same term could have an entirely different meaning at another base or another country. For example, in the US, "project" normally means a given set of tests whereas in the UK "project" usually means "aircraft type" such that "AV-8B Project" would encompass all aspects of that aircraft type's development.

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F.N. Stoliker
Camarillo, CA, US
March 1995

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The Flight Test Editorial Committee, formerly the Flight Test Techniques Working Group 11, was fortunate to have one of its past members and former chairman take on the difficult task of Editor for this AGARDograph. The committee is most grateful for the hard work and persistence of the Editor, Mr. Fred Stoliker, in bringing this volume into existence.

Besides the Editor, the following current and past members of the Flight Test Editorial Committee have taken an active part in the preparation of this Volume:

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14.0 INTRODUCTION

Flutter is an aeroelastic phenomenon in which aerodynamic, elastic and inertia forces couple unfavorably at a sufficiently high speed to produce an unstable oscillation which may grow without limit and so result in a structural failure. Flutter is, unfortunately, not a problem that will just "go away": modern aircraft, in particular, are progressively more flexible, fly faster, and are highly control configured, more maneuverable and more system dependent. The development of active control systems for flutter suppression will actually complicate the problem by introducing a fourth "servo" dimension into the aeroelastic scene and will at best only defer flutter to higher speeds.

Clearly, an important problem during the design of new aircraft is to make sure that the proposed and actual structure is free from flutter within the proposed flight envelope. This requirement is essential since flutter involves a structural instability and as such will cause damage to the structure when it occurs. Flutter can only be prevented by a proper design of the structure and, as a consequence, the study of flutter must start at an early stage of the development of a new aircraft. It will continue along with this development up to and into the early flight test stage. For modified aircraft, structural modifications or flight control modifications require that the flutter stability has to be re-established. It must be remembered that even a minor structural modification could have major implications for flutter stability. For military aircraft which are to be equipped with a large variety of external stores, the study of the flutter problem will often extend well beyond the first stage of flight testing. This is caused by the fact that variations in the external loading of an aircraft, due to new requirements, may change its flutter characteristics appreciably and by the fact that "intermediate" configurations (after release of stores and with fuel tank partial loadings or fuel transfer failures) must also be considered.

Flutter was recognized as a problem even in the early days of flying and although considerable effort has been made towards the understanding of the problem, flutter still remains a major consideration when designing new aircraft. This is due in part to the fact that newer construction materials and more sophisticated construction techniques have led to an ever decreasing relative thickness of the aircraft's lifting surfaces. The stiffness of these structures has, however, hardly increased and, therefore the sensitivity to flutter has increased accordingly. On the other hand flying speeds have also increased considerably from subsonic to transonic and supersonic speeds and, as a consequence, the aerodynamic loads related to flutter have not only grown but have also changed their character due to encountering shock waves.

Because of the direct impact flutter may have on the design of a new aircraft, the eventuality of flutter is considered from the beginning of a new design. During the development phase this investigation will pass various stages as indicated in figure 14-1 obtained from reference 14-1.

Flight flutter tests are conducted to demonstrate freedom from flutter for critical aircraft conditions. The stability results derived from those tests are used to validate the flutter analysis. Both test results and calculated

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results are used to demonstrate compliance with the airworthiness requirements. Active control systems (ride control, gust load alleviation, flutter suppression, etc.) add to the scope and complexity of these tests in that control system instability due to aeroelastic interactions must also be considered. Wind tunnel tests usually form part of the validation process and flutter in this environment can result in costly damage or loss to the wind tunnel.

Reliable flight and wind tunnel test procedures are therefore required to minimize the hazard of these tests. This requires that effective methods be used for exciting the aircraft or model and that reliable, on-line and off-line methods be used for estimating the stability from the measured structural and control system responses (parameter estimation). In addition, effective procedures for preventing damage must be available in the event that an instability is experienced. In some instances this has led to the use of active flutter suppression systems on wind tunnel models.

The principal impediments to achieving reliable estimates for stability parameters are the short test time on condition and the high noise levels in the data collected. A number of methods have been developed or are being proposed to address these problems and will be discussed below.

Nonlinear aerodynamics, structural dynamic, or control system characteristics provide further impediments to reliable stability parameter estimates because a larger data base is required to identify and characterize the nonlinear behavior and because estimation methods generally used assume linear processes. It is therefore important to determine what parameter estimation methods have been used and how successful those methods have been particularly in the presence of nonlinear conditions.

This section will spell out the airworthiness requirements, the subcritical clearance philosophy, typical test objectives and procedures, denote excitation devices used and excitation signal types, instrumentation/recording required, and touch upon data analysis techniques and typical products of the test conduct. Finally, some practical problems and future needs will be considered. More details can be found in references 14-1, 14-2 and 14-3.

14.1 REQUIREMENTS

Analyses, wind tunnel and laboratory tests, and aircraft ground and flight tests shall demonstrate that flutter, divergence, and other related aeroelastic or aeroservoelastic instability boundaries occur outside the 1.15 times design limit speed envelope. The aircraft shall meet the following stability design requirements for both normal and emergency conditions:

- Flutter margin: Fifteen percent equivalent airspeed margin on the applicable design limit speed envelope, both at constant altitude and constant Mach number as indicated in Figure 14-2a obtained from reference 14-4.
- Damping: The damping coefficient, g, for any critical flutter mode or for any significant dynamic response mode shall be at least three percent (0.03) for all altitudes on flight speeds up to the design limit speed as indicated in Figure 14-2b , also obtained from reference 14-4.

14.2 TEST OBJECTIVES

The prime objective must always be to provide flutter free operation in the intended envelope of the test aircraft in a safe and economical fashion. This objective must be reflected in all subsequent flutter test activities.

The preliminary flight test plan should always be prepared by experienced flutter engineers based upon their analysis of flutter calculations and wind tunnel tests. They will determine where, in the planned flight envelope, it is safe to fly without flutter testing and where flutter testing is required. Where it is required they will specify the vibration sensors (accelerometers, preferably, and/or strain gage bridges, mostly available for other purposes), and their location in the aircraft. Using the same analysis and information they will specify the type of vibration exciters and where they are to be located. At this point the flight test and instrumentation engineers will participate in the detailed design of the instrumentation system and the excitation system.

Next, the flutter and flight test engineers must prepare a detailed flight test plan showing the combinations of speed and altitude that must be flown to demonstrate the freedom from flutter. Then a detailed sequence of testing must be prepared wherein tests are first flown at the conditions where analysis indicates that there are no predicted flutter problems. As each test point is flown, the test results are reviewed to ensure flight safety and compared to the predicted results. If the test results and the predictions disagree to a significant degree in the view of either the flutter or flight test engineer, the tests are halted until the cause of the variance is explained.

The test plan must clearly specify the duties and responsibilities of all the test participants to include who has the specific responsibility for calling a halt to or proceeding on with a test series. In all cases, the test pilot has the authority to stop any test series if he detects any items that indicate any type of a departure from anticipated results.

14.3 TYPICAL MEASUREMENTS

Flight flutter testing comprises three steps: structural excitation, structural response measurements, and stability analysis. Accordingly, the data to be collected during the flight flutter tests can be divided into two groups: those for measuring the excitation force and those for measuring the response of the aircraft.

In the first group, for measuring excitation forces, the sensor used will depend entirely upon the type of exciter used. For example, an electromagnetic exciter will require the measurement of a current while a strain gage bridge will be required for measuring the vane excitation force.

In the second group, the most commonly used transducers are accelerometers and strain gage bridges. If amplitude accuracy is not critical, there is no clear preference between the two types. Strain gages are normally used only on new aircraft as they need to be installed during assembly of the aircraft since they are generally located in areas which are inaccessible once the aircraft has been assembled. On the other hand, accelerometers can be installed in many cases after the aircraft has been assembled. If the flutter tests are to be conducted on an existing vehicle, which is being equipped with new external stores, for example, the use of accelerometers may be dictated by the relative ease of installation. The two different types of sensor require quite different placement. In a wing, for example, the strain gage bridge will generally be applied near the wing root where the structural loads are large, whereas the accelerometer would be placed near the wing tip where the displacements are large. In the case of "classical" flutter, amplitude accuracy is not very critical since the engineer will be concerned with damping ratios rather than absolute amplitude. Good linearity is required for this case and it is essential that the phase relationship between the various sensors is of good quality. However, if nonlinear phenomena, such as transonic aerodynamics and nonlinear control system characteristics are present, absolute displacement amplitude sizes become important as well. Consequently, a preference for accelerometers is becoming more common.

The selection of sampling rates for digitized data is critical. The consequence of sampling a fluctuating signal at too low a rate can be that high frequency signal components are interpreted as low signal components. To avoid this problem which is called data aliasing, the sampling rate for digitized signals should be at least twice the maximum frequency present in the original signal. It should be noted that the frequencies encountered in flight tests normally range up to about 50 Hz for transport type aircraft and 50 to 100 Hz for fighter type aircraft.

Despite the considerable improvements in test/analysis techniques that have been made in recent years, flutter testing is still a hazardous exercise. It is therefore important that the test aircraft not significantly overshoot the test points as it progressively clears the envelope. Therefore, airspeed and altitude must be controlled very accurately. As the testing approaches the boundaries of the envelope the airspeed tolerances usually become even more restricted with no positive tolerance allowed. In order to achieve these tight tolerances special airspeed and pressure instrumentation is generally required such as a trailing cone or special instrumentation mounted in a flight test nose boom.

14.4 TYPICAL MANEUVERS

It will be necessary to excite an aircraft in order to obtain the resonance frequencies and the corresponding damping coefficients of all required structural vibration modes to establish the flutter characteristics of the aircraft (see figure 14-3 obtained from reference 14-2). The means of excitation of the aircraft may be "natural" or "deliberate". Natural in this context means that the aircraft response to the naturally occurring atmospheric turbulence is used so that no excitation equipment is required. Whilst this option may appear attractive it is not ideal as will become clear later on. Several means of "deliberate" excitation have been developed and applied that appear to be quite different from each other. However, a detailed examination reveals that they are based on a limited number of basic principles, such as aerodynamic, moving mass, and pyrotechnic exciters. A brief description of each and their relative advantages and disadvantages are listed below. More detailed descriptions, factors involved in the choice of excitation device, and discussion are contained in references 14-1 and 14-2.

14.4.1 Aerodynamic Excitation

There are basically three types of aerodynamic excitation sources used in flutter testing. These are the aircraft control surfaces, special oscillating vanes attached to the tips of the lifting surfaces or to external stores, and atmospheric turbulence. The advantages of these excitation sources are that they add very little mass to the structure and that they can be used to provide a wide range of input frequencies.

In case of the control surface and oscillating vane excitation sources, the oscillating input force to the aircraft structure comes from changes in the aerodynamic lift on the oscillating surface. Such changes in aerodynamic lift can also be obtained by a rotating slotted cylinder along the trailing edge of a fixed vane, as described in reference 14-5. These sources can be used to provide either frequency sweep inputs (i.e., sweeping from low to high frequencies or vise-versa), constant frequency burst inputs, or random frequency inputs. In addition, control surfaces are also used for pulse or rap inputs which simulate impulse inputs to the structure. A further advantage is that it is usually possible to arrange aerodynamic excitation to be symmetric or asymmetric about the centerline of the aircraft, so aiding the process of separating out the structural vibration modes.

Atmospheric turbulence provides a random input to the structure which generally encompasses a spectrum of frequencies up to about 10 Hz. Even though the input is not generally felt by the pilot, there is always some energy content transferred to the structure from the air mass. However, the amount of input from this source is generally very small, which results in slow, unreliable, poor quality test data, compared to the other types of "deliberate" aerodynamic excitation sources and therefore is less satisfactory as pointed out in references 14-2 and 14-6.

14.4.2 Moving Mass Excitation

There are basically two types of moving mass excitation sources: inertia exciters and electrodynamic exciters. These exciters impart a force into the structure via reacting the inertia of a moving mass attached to the aircraft structure. They are generally mounted inside the aircraft and therefore do not present any aerodynamic interference. These can provide frequency sweep, frequency burst and, in some cases, random inputs similar to the aerodynamic exciters.

Inertia exciters generally consist of a rotating out-of-balance mass mounted on a shaft which can be driven through the frequency range of interest. In some cases a "wand" is used which consists of a mass placed at the end of a pivoted arm attached to a shaft located at the tip of a wing or tail surface. One disadvantage of this system is that larger masses are needed to excite the lower frequencies and the overall system weight may become prohibitive.

Electrodynamic exciters are akin to the electrodynamic shakers used in ground vibration tests (GVTs) as presented in paragraph 9.5. In this case the force is generated by a mass excited by a electromagnetic field. The mass is suspended by springs and consists of a permanent magnet with coil windings attached. When an alternating current is sent through another set of coils in close proximity, the mass can be made to move within the electric field. The frequency of movement is proportional to the electric signal. This system has the same advantages and disadvantages as the inertia exciter.

14.4.3 Pyrotechnic Excitation

The pyrotechnic excitation source which is sometimes called a "bonker" consists of a very small explosive charge that is typically placed externally on the aircraft structure and detonated electrically. The tiny explosion produces an excitation of short duration. The actual time history of this force and, thus the frequency content, can be controlled by the design of the exciter. Some of the advantages of this type of exciter are that the short duration of the excitation makes it useful for short flight maneuvers such as dives, and since the exciter is small, a number of them can be mounted almost anywhere on the aircraft without disturbing its vibrational characteristics. The disadvantage of this excitation source is the limited number of excitations (one per exciter) that can be produced during a given flight.

14.5 FLIGHT TEST PROCEDURES

In the conduct of flutter tests, a subcritical envelope expansion procedure is used whereby less critical points are flown prior to the more critical ones. The aircraft structural response data and flight parameters are also monitored in real time. This procedure provides the test engineer an opportunity to determine damping and frequency trends as dynamic pressure and airspeed increased during the test.

Generally, the buildup will consist of points of incrementally increasing airspeeds or Mach number which are flown at either a constant altitude or along a constant dynamic pressure line. If the buildup is flown at a constant altitude then it usually begins at a high altitude where the dynamic pressure will be the lowest. The airspeed increments between points will depend upon the proximity to the predicted flutter boundary and the confidence in the flutter analysis. Smaller steps are required when close to a flutter condition or when a rapid decrease in damping is observed. Some practical initial airspeed must be selected to begin the buildup sequence since the aircraft must take off and climb to the first test altitude. The choice of the initial test airspeed and altitude is based on a conservative review of the predicted flutter modes and flutter margin.

Clearly, the test program will differ according to whether the aircraft is to be cleared for low subsonic, high subsonic or transonic/supersonic speed regimes. In all cases a part of the flight envelope is cleared by calculations for initial flying, obviously allowing a good margin of safety. Typical procedures for testing of these speed regimes are shown in figure 14-4, obtained from reference 14-1.

The maneuvers used in flutter testing depend upon the type of aircraft structural excitation available and the data to be collected. If sweep, burst, or random data is to be required, the aircraft will stabilize on condition (i.e., fly at a constant airspeed and altitude) for the time required to do the excitation. Generally, when dive test points have to be flown, the aircraft will reach a target airspeed, and the excitation data will be taken between a band of altitudes to prevent significant changes in the dynamic pressure during the maneuver. Sometimes, windup turns are carried out to determine the effect of g-forces on the aircraft flutter characteristics.

14.6 DATA ACQUISITION AND ANALYSIS

Until relatively recently, the measured signals were handled manually all the way to analysis in an analog format. This meant that only simple procedures could be applied unless time lapse did not play a significant role. In fact, trace recordings of time histories, particularly those of decaying oscillations, were processed manually and further evaluations in the frequency range domain were seldom performed. This process is still used, along with more sophisticated methods, for aircraft that are expected to exhibit one predominate critical modal response such as with aircraft with external stores or large transport type aircraft.

With the advent of computers, plus improved data acquisition systems and the development of Fast Fourier Transform techniques, more complex analysis procedures involving two signals simultaneously in both the time and frequency domain have been developed. It is now possible to produce real-time quantities such as auto spectra of input or output and transfer functions in the frequency domain and auto correlations of input or output, cross correlations, and impulse responses in the time domain as discussed in chapter 11 of reference 14-3. In addition, new near real-time curve fitting techniques in both the frequency and time domains help expedite damping and frequency calculations.

Signals from the sensors often contain components of no interest to the flutter investigation and the data is subject to filtering before recording and/or analysis. Data from the sensors are normally always recorded on board the aircraft utilizing magnetic tape recorders and selected parameters are usually sent to the ground for "quick look" and intermaneuver analysis by suitable specialists (Large transport/cargo aircraft will often have equipment on board for analysis in flight). This not only reduces risk but permits more test points per flight. In figure 14-5 a block diagram of a typical data acquisition and analysis system is shown. The analysis system is normally part of telemetry ground station. Data analysis can be done in real time using the data coming in via a telemetry link, or postflight, using data recorded on board the aircraft or on the ground station itself.

There is no need to process much of the data past the "quick look" stage. Data that is required to be processed further must be judiciously selected by the flutter engineer to avoid saturation of the data processing facilities. Typical results during flight tests are shown in figure 14-6 and the final result of flutter stability in figure 14-7.

14.7 TYPICAL PRODUCTS

The most important product resulting from the flutter test is the report providing clearances/limitations/special operating procedures as derived from test and data analysis.

Other products of importance to the flutter community are the quantities such as (in the frequency domain) autospectra of input or output, cross transfer and transfer functions and (in the time domain) autocorrelations of input or output, cross-correlations, and impulse responses.

Another very important product is the validation or updating, as appropriate, of the flutter model developed as a result of the wind tunnel testing and data analysis.

14.8 SPECIAL CONSIDERATIONS

Safety of flight must be the prime consideration when conducting flutter tests. Tests should not be continued, if in the opinion of the test pilot or the flutter engineer, unexpected results are encountered. Procedures must be clearly spelled out as to who has the authority to interrupt any given set of data points of the specified flight test program in order to conduct an inserted detailed data analysis.

All flutter tests should begin in that part of the flight envelope where wind tunnel data and data analysis unambiguously indicate freedom of flutter. Further tests should progress toward the anticipated edges of the envelope in carefully calculated increments that get smaller as less safe conditions are expected. Flight test data that show differences from predicted flutter and/or damping characteristics should result in a stand-down until the differences are explained and/or rectified.

The flight test engineer and the flutter engineer should carefully debrief the test pilot after each flight. Special attention should be given to pilot comments about any vibrations or oscillations experienced during each test point. These comments could provide valuable clues of which data to further process or of items to look for when processing data.

During real-time testing the flight test engineer should be continually on the look-out for trends in the damping and frequency that indicate that flutter could be imminent. This is performed primarily by monitoring the time signals or the processed data frequency and damping of the critical modes as a function of airspeed and/or dynamic pressure. If the damping starts to decrease at a faster rate than anticipated, then testing should be done at smaller increments or terminated. If the structural time history response starts to become more sinusoidal, with less relative noise, as the test progresses from point to point then the tests should proceed with extreme caution since flutter may occur. In any event, the damping coefficient should not be allowed to go below three percent as specified in figure 14-2b.

14.9 CONCLUDING REMARKS

Flutter can destroy or seriously damage an aircraft. Therefore, flutter considerations must be addressed early in the design process and the concern for flutter problems must be addressed at every stage of the aircraft's development and as early as reasonable in the flight test program. However, a vehicle representative of the production version must still be tested to provide representative data, especially if the aircraft is designed to carry a variety of stores.

Rapid strides are being made in flutter analysis and suppression techniques. The entire subject of flutter is being addressed by a planned AGARD Structure and Materials Panel Specialist's Meeting to review the state-of-the-art and consider future directions (to be held in the spring, 1995).

ACKNOWLEDGEMENT

Mr. L. Tracy Redd of the US Air Force Flight Test Center made substantial contributions to the preparation of this Section.

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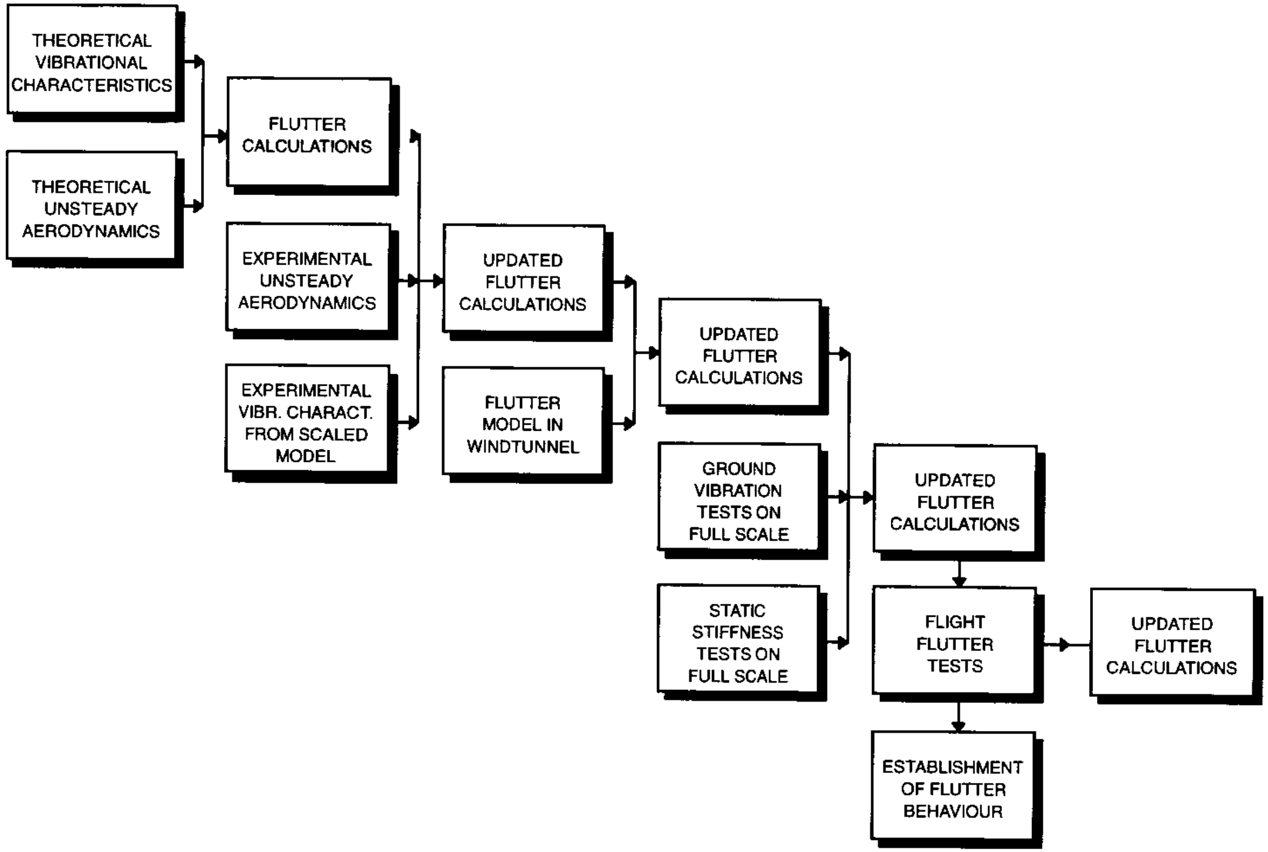
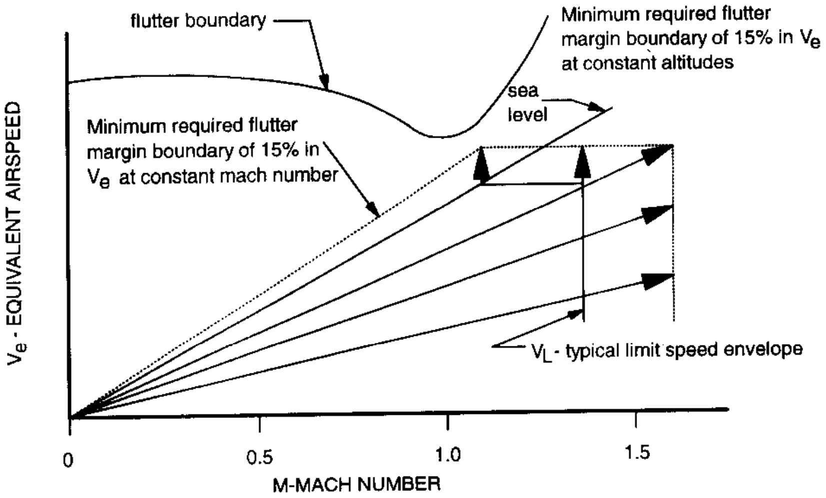
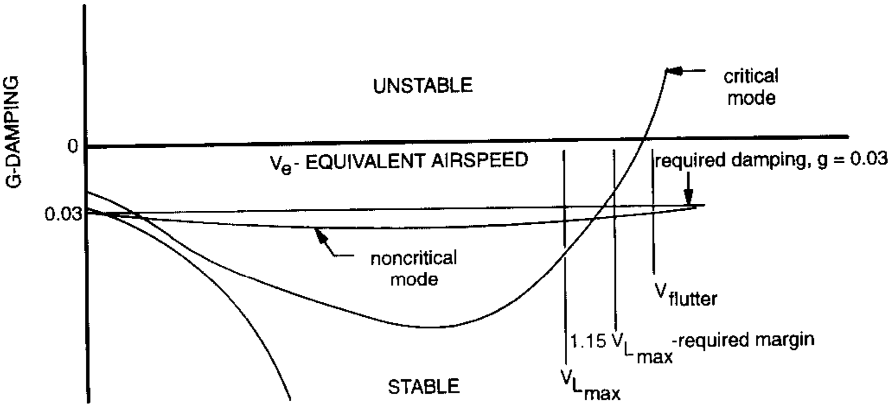


Figure 14-1 Flutter Investigation During Development Stage of a New Aircraft.



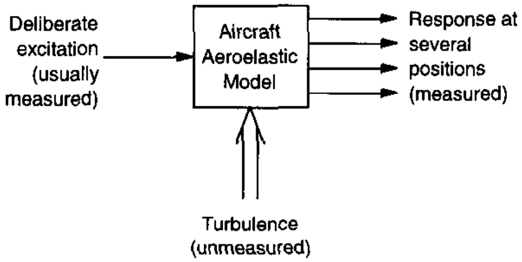
(a) Minimum Required Flutter Margin.



(b) Required Damping.

Figure 14-2 Flutter Requirements.

(a) Deliberate excitation



(b) Natural excitation

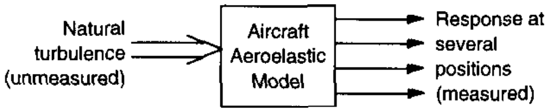
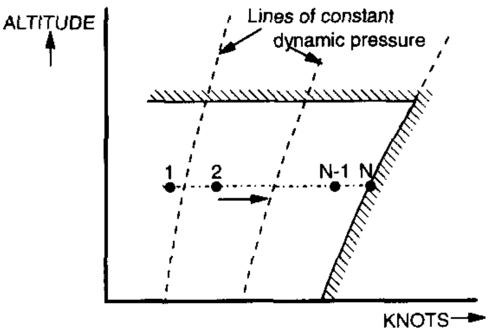
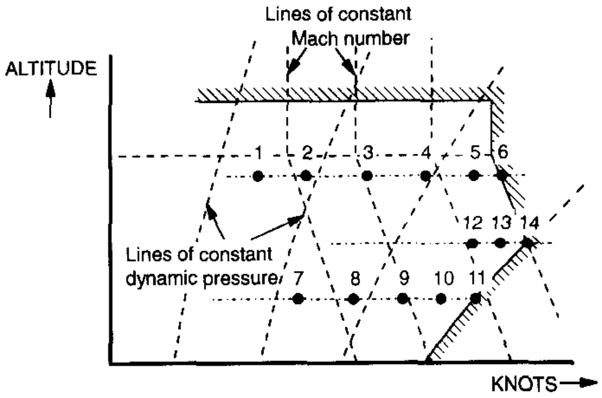


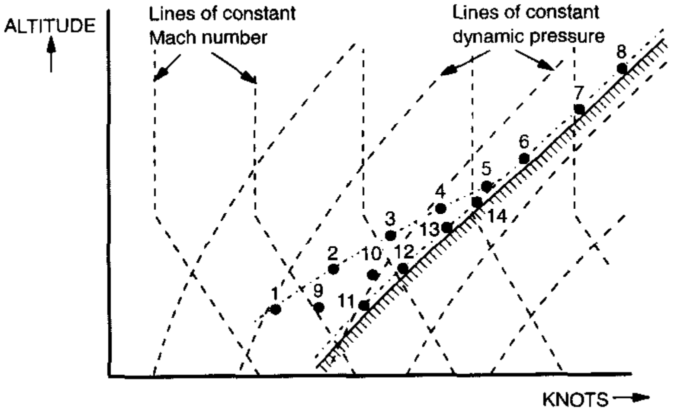
Figure 14-3 Identification of Dynamic Characteristics.



(a) Low Subsonic Speed Regime.



(b) High Subsonic and Transonic Speed Regime



(c) Transonic and Supersonic Speed Regime.

Figure 14-4 Flutter Test Procedures.

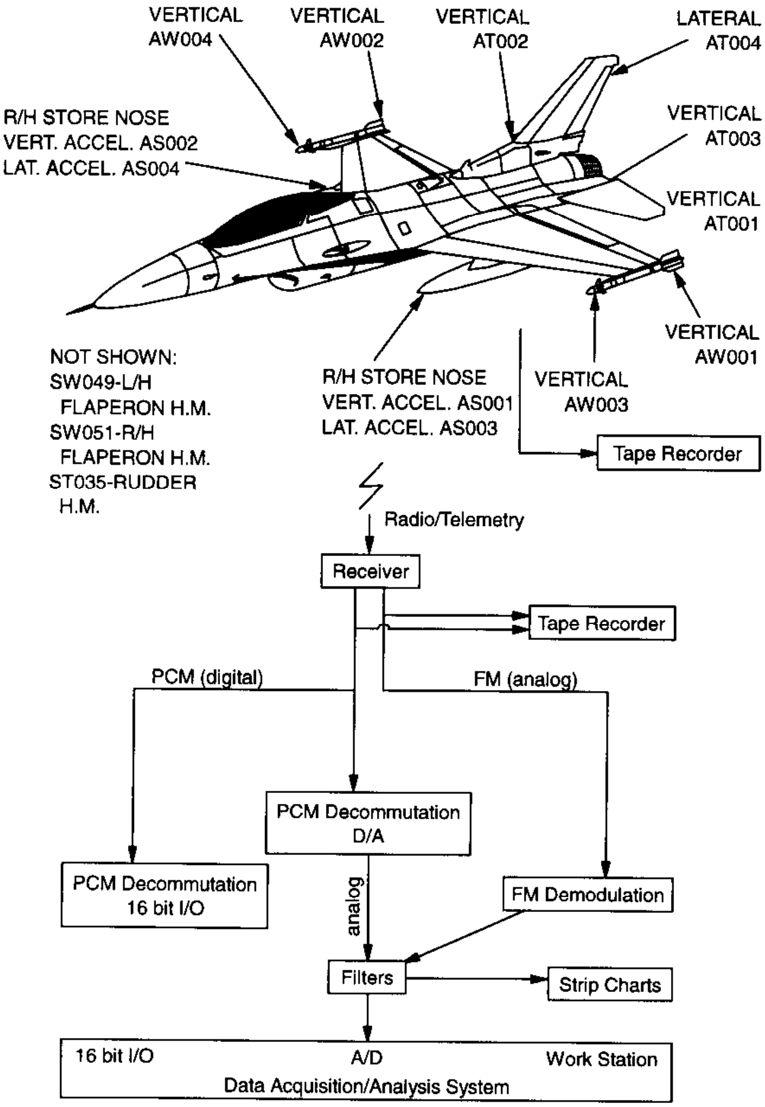


Figure 14-5 Typical Flutter Data Acquisition and Analysis System.

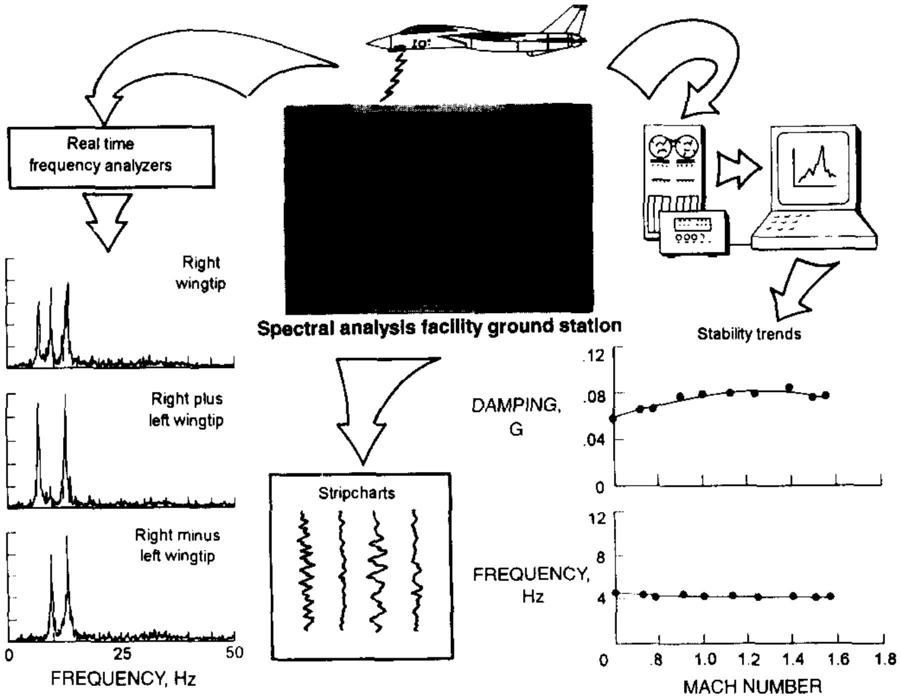


Figure 14-6 Typical Results Obtained from Flight Tests.

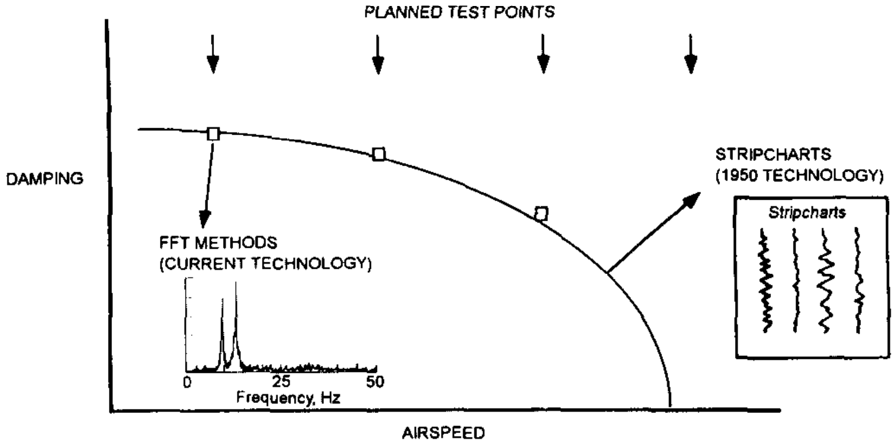


Figure 14-7 Current Stability Determination for Most Airframe Companies/Government Agencies.

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