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This paper presents the author's view that the new ADS-33 test methods must be very carefully applied in practice in order to avoid potential damage or loss of the test aircraft. This opinion comes about after review of several accidents, both fixed and rotary wing, and finding a common thread of frequency related control inputs. A discussion ensued within the AHS Test and Evaluation Committee, bringing forth some seven accidents/incidents involving these these methods. This Technical Note is the final result.

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The New ADS-33 Process: Cautions For Implementation

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Abstract

This paper presents the author's view that the new ADS-33 test methods must be very carefully applied in practice in order to avoid potential damage or loss of the test aircraft. This opinion comes about after review of several accidents, both fixed and rotary wing, and finding a common thread of frequency related control inputs. A discussion ensued within the AHS Test and Evaluation Committee, bringing forth some seven accidents/incidents involving these test methods. This Technical Note is the final result.

Introduction

The Army has been working on the new ADS-33 Flying Qualities specification for a while, and now the Navy is starting to show an interest in the new methods and procedures contained in the new specification[1]. While the new methods and tools are extremely useful to the Flying Qualities community, a word of caution must be raised over proper implementation in order to conduct a safe test. Flight testing covers many disciplines. Several of these overlap and must be considered in future test programs (Fig. 1). Since the Structural Demonstrations of our older helicopters were not done with these ADS-33 techniques in mind, there may be a lack of adequate knowledge of the Structural and Dynamic areas of many of our older helicopters as regards control frequency sweeps, which can get the flight test crews into serious trouble. This Technical Note will discuss some of the pitfalls and cite some examples out of both the fixed-wing and rotary wing community identifying some of the "lessons learned" (some the hard way), which need to be applied to "Frequency Sweep" and similar types of testing. Some will say "What's new! That is the nature of Flight Testing." Maybe nothing is new - You decide.

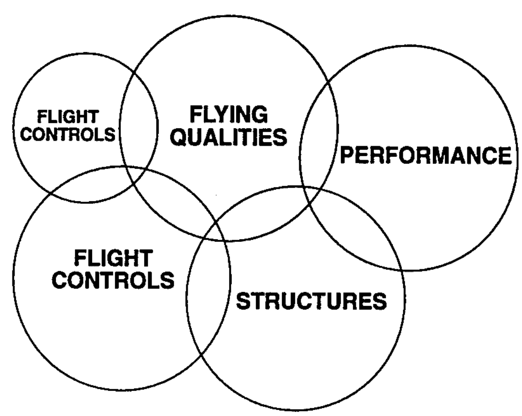

Fig. 1 General Flight Testing

Structural Demonstrations

A paper presented at an AHS Specialist Meeting in 1988 addressed the Navy's approach to having the contractor conduct, with Navy witnessing, the Structural Demonstration as part of the development process for a new helicopter. Ref. 2 contains the details, but for purposes of this discussion, the points to be made are that: the aircraft is instrumented for structural parameters; structural engineers are monitoring Do Not Exceed (DNE) limit loads on the telemetry ground station; they are conducting a systematic buildup, one parameter at a time; and, they are prepared to invoke the "Knock-it-off" call that will eventually come. Questions regarding Flying Qualities and Performance are raised and, of course accounted for, but they are secondary to the structural test. Fig. 2 characterizes this situation.

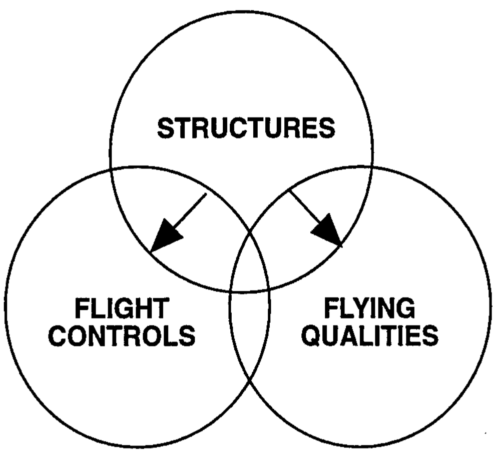

Fig. 2 Structural Demonstration

Flying Qualities Testing

In the past, flying qualities testing has been done with little regard for structural considerations because they, for the most part, were not that important. Not so any more. With the frequency sweep testing methods of ADS-33, not only does one need to learn new analysis techniques in the Frequency Domain (Bode Plots, Phase Gain Margins, and others - long-standing tools of the flight controls engineers), we must be intimately aware of the structural DNE limits of the aircraft and have them instrumented and monitored, if necessary. Fig. 3 characterizes our new situation and poses the question we must ask. We must be aware of the structural results of the dynamics modes of the airframe, engine, and main and tail rotor systems as well. If you don't believe these words, read the example Case Histories in the following section.

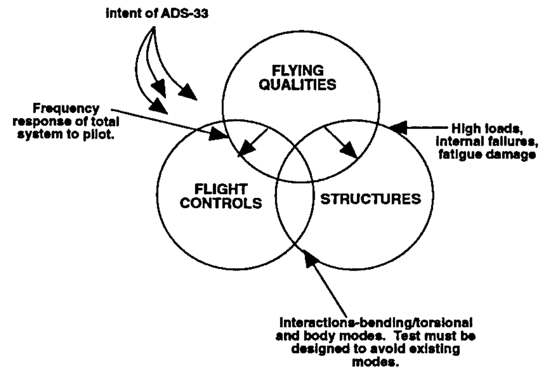

Fig. 3 ADS-33 Flying Qualities Test

Case Histories

1. A fixed-wing strike fighter was evaluating the structural adequacy of a new store mounted on a wing station. They were exciting the "short period" mode and were on-frequency by pumping the stick longitudinally at ± 1 inch displacement when some form of failure occurred associated with the longitudinal control system. The aircraft pitched nose down and crashed. The most likely failure scenario involves bending/breakage or a disconnect of the longitudinal control rod.

2. A fixed-wing Anti-Submarine Warfare (ASW) airplane was being used to collect data for a simulator using rudder frequency sweep methods. Prior to test, a search for sideslip limits was conducted among the flight clearances which supposedly defined limitations for flight and design limits, but no limitations on sideslip were found. It was also believed that harmful lateral loads on the fin could not be generated, since the airplane incorporated a means to hydraulically limit rudder deflection as a function of airspeed. During a rudder frequency sweep at high airspeed, the vertical tail failed, resulting in loss of control and breakup of the airplane. The crew ejected and the airplane crashed. Post-mishap review revealed that references to sideslip limits, which were part of early developmental testing, had been dropped from recent flight clearances. Further, high-speed "dynamic" yaws conducted during structural demonstration tests, did not generate the worst case dynamic loads because they were done using only step inputs.

3. One contractor's helicopter was being tested at another contractor's plant. Permission was requested to seek information from the airframe manufacturer, in order to conduct safe testing. Permission was denied by the project sponsor. In the process of

doing frequency sweeps in roll in a hover, an aluminum shear pin in the lateral cyclic was sheared, reverting aircraft control to the "fly home" minimum control fly-by-wire backup system with a control input in. The aircraft rolled over and crashed: the crew survived. Subsequent discussions between the manufacturer and the testers revealed that they also had an occurrence of shear pin failure in their testing in forward flight flying safely home. In their testing since the incident, they routinely substituted steel shear pins to prevent inadvertent pin shearing during the test.

4. A Navy test plan was written and approved as part of a new engine installation on an old airframe. As part of the test, it was planned and APPROVED to do collective frequency sweeps. The contractor denied permission for the test team to do the planned test citing lack of knowledge of what the dynamics and structural effects of the rotor system and airframe would be as no such tests had been done on the airframe during its 30 year testing history.

5. A low/omni directional airspeed system was mounted above the rotor on a standpipe on an ASW helicopter by the Navy. Inspection after a flight revealed that several mounting bolts on the sensor head had broken. One comment heard was "Install bigger bolts". An input from an avionics engineer about the configuration (weight of the sensor head cantilevered above the upper bearing at 1/2 of the distance between the upper and lower bearings of the standpipe, along with "Good Lord, I can't build an oscillator with that little damping" about the "thump test" time history), led to analysis of the mechanical magnification ratio which turned out to be about 5.5 (Fig. 4). Nothing except "normal" flying had been done on the aircraft to that point. Subsequent lowering of the sensor head and adding mass below it reduced the magnification ratio to around 2 for safe completion of the test without increasing the bolt size.

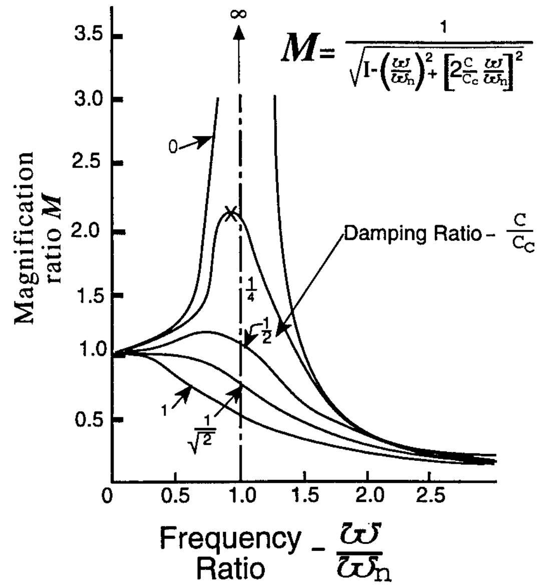

Fig. 4 Magnification Ratio as a Function of the Impressed Frequency Ratio for Various Amounts of Damping

6. Finally, in ADS-33 testing reported by the Army in Ref. 3, an incident involving an OH-58 is worthy of review. This test was done correctly in that a systematic buildup was done. It was instrumented for structural loads and monitored via Telemetry. The aircraft was cycled with frequency sweeps on the ground before flying. The flight had a chase. When the frequency sweep test was conducted, the helicopter encountered a resonance of the mast-mounted sight. What is interesting about this case is that the pilots didn't feel the resonance and the telemetry parameters did not build up rapidly enough to elicit a "knock-it-off" call from the Telemetry Room. The chase pilots SAW THE DEFLECTION and provided the "knock-it-off" call.

What's the Point

We are entering a new interdisciplinary era of testing with ADS-33, in which the Flying Qualities engineers and pilots need to be much smarter about testing than they were in the past. All of the examples above, except #5, involve a flying quality test where control inputs or frequency sweeps were done, in which STRUCTURAL failures occurred, or could have. Frequency-sweep testing has the potential to generate higher loads than those maneuvers of the structural demonstration in our older airframes. The ADS-33 Users Guide (Ref. 8) addresses the Operational Flight Envelope (OFE) for mission maneuvers and the Service Flight Envelope (SFE) based on the helicopter's limits. In our present qualification system, the Structural Demonstration provided the safe clearance for all maneuvers to be done in the OFE (Fig. 5A). In our older airframes it appears that no one ever foresaw using frequency-response methods to test airplane flying qualities and that maneuvers currently being done can exceed the structural limits which have been demonstrated (Fig. 5B). In our newer airframes perhaps we should include a new spectrum of maneuvers in the Structural Demonstration designed to cover the maneuvers involved in the new frequency sweep test methods as well as for new innovative maneuvers being generated by Fleet operators to enhance maneuverability for such things as Evasive Maneuvering in order to again safely quantify the SFE. In our testing at the Naval Air Warfare Center Aircraft Division (NAWCAD), we use a Flight Test Envelope (FTE) which is defined as the OFE (NATOPS) plus or minus whatever the Flight Clearance authorizes. The concept of a FTE, as defined by a specific Flight Clearance for the test, needs to be included in the Users Guide (Ref. 8).

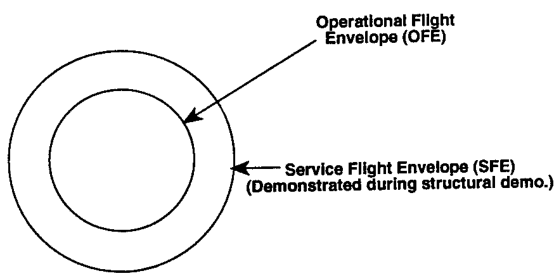

Fig. 5A Old Qualification System

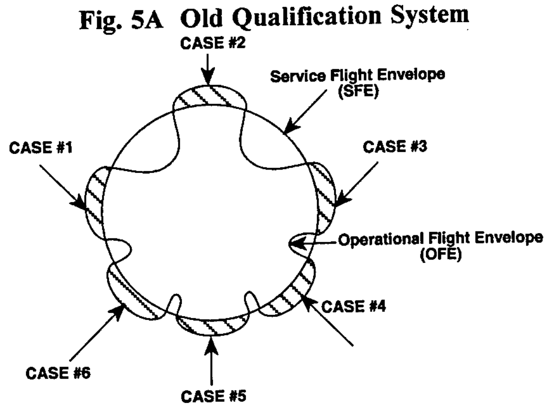

Fig. 5B ADS-33+ Experience

It is clear that we must borrow from the rigors of a Structural Demonstration to do Flying Qualities testing safely. This includes instrumenting pertinent parameters with monitoring on telemetry, knowledge of the airframe structural limits and "threat frequencies" (Fig. 6, Ref.4), a chase aircraft, and careful buildup of control inputs in both magnitude and frequency. A buildup must be done starting with static then dynamic ground tests. Only after these are done should flight tests be contemplated. Small amplitude frequency sweeps to a limited frequency should be done first, and only AFTER THE DATA IS REDUCED AND ANAYLIZED should higher frequencies and/or larger amplitude inputs be considered. It takes very little input AT RESONANCE to break something as in case #5 above. In fact, no unusual control inputs were made in that case. Also, non-linear harmonic responses can yield large increases in response for moderate control inputs. The references are the best available information on the subject from the people who have been doing the tests to date. Secure these as reference material for the future. A summary of testing conclusions out of the references is contained in Encl. 1.

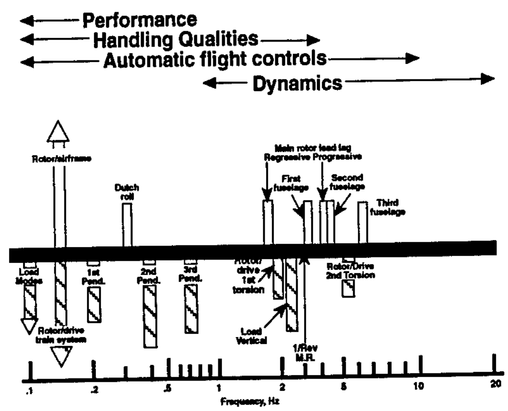

Fig. 6 Helicopter Modes of Interest

Conclusion

The flight test community can no longer afford to separate the flight test disciplines of flying qualities, performance, dynamics, and structures. With the techniques required to test handling qualities using the ADS-33 methods, we need an interdisciplinary approach. We must take heed of the lessons learned so far in the ADS-33 and frequency sweep testing and keep a copy of this Technical Note handy to show to management when they want to cut corners or deny access to information needed to safely perform your flying qualities testing. Ask them which of the above cases they want to be. A NAWCAD Rotary Wing point paper made the following four conclusions:

1. Frequency Sweep test techniques are useful and necessary for the next generation specification requirement.

2. Frequency Sweep techniques need not present any greater flight risk when employed with proper preparation, buildup, and analysis.

Summary of Testing Conclusions

1. "1)* Frequency domain flight testing requires careful planning and real time monitoring of potential excited modes to avoid structural damage."[6]

2. "2) Model activity can be extracted from the frequency response results."[6]

3. "5) Emerging aircrew and management concerns surrounding risk levels associated with frequency domain and mission maneuver testing warrant continued emphasis as experience is gained."[6]

4. "3) Frequency domain flight testing requires careful planning and real time monitoring to prevent possible structural damage."[3]

5. "5) A combination of establishing a pre-determined cutoff frequency, realtime loads and input monitoring, limiting the magnitudes of inputs, and pilot-engineer ground training may significantly reduce the potential for damage during piloted frequency sweeps."[3]

6. "6) Pilot and engineer training is essential prior to conducting frequency sweep tests."[3]

7. "7) Piloted frequency sweeps yield much better quality data than computer generated sweeps since the pilot can maintain the trim condition with uncorrelated off-axis inputs."[3]

8. "15) Training in recovery from unusual attitudes is very important for many maneuvers. Training should be conducted in an aerobatic airplane and helicopter if possible."[3]

9. "17) .... a flight test manual needs to be written to cover flight test techniques for ADS-33 compliance testing. This should be an out-growth of the recommended government/industry/university working group on ADS-33 flight test concerns."[3]

10. " .... Modeling of rotor dynamics remains the most critical area of investigation."[4]

11. "The flexible fuselage can be adequately represented by a set of linear second-order differential equations; however, the appropriate mode shape data are highly subject to the forcing condition."[4]

12. "2. The frequency-sweep technique has been successfully demonstrated on the Bell 214ST helicopter using the following procedure: ...."[7]

***Refer to the item numbers contained in each reference.**