VTOL AND VSTOL HANDLING QUALITIES SPECIFICATIONS
AN OVERVIEW OF THE CURRENT STATUS

Kevin W. Goldstein
Aerospace Engineer
Naval Air Development Center
Warminster, PA

The highlights of a comparative analysis between the current helicopter and VSTOL handling qualities specifications and four representative state of the art rotary wing aircraft are presented. Longitudinal, lateral, and directional control power and dynamic stability characteristics were analyzed for hovering conditions. Forward flight static and dynamic stability were analyzed for the longitudinal and lateral-directional axes. Results of the analyses in terms of the applicability/utility of the MIL-H-8501A criteria are presented for each of the above areas. The review of the MIL-H-8501A criteria against those in MIL-F-83300 and AGARD 577 indicated many areas in which MIL-H-8501A does not give adequate design guidance.

Notation

M_q	Pitch Rate Damping (second^{-1})
M_{δ_B}	Pitch Control Sensitivity (rad/second^2/inch)
N_r	Yaw Rate Damping (second^{-1})
N_{δ_A}	Yaw Control Sensitivity (rad/second^2/inch)
n	Normal Acceleration (feet/second^2)
α	Angle of Attack (radians)
δ_A	Lateral Control Deflection (inch)
ω_n	Undamped Natural Period (rad/second)
ζ	Damping Ratio
ϕ_1	Roll Angle Attained within One Second (degrees)
CTOL	Conventional Take-off and Landing
VSTOL	Vertical/Short Take-off and Landing

Introduction

With the development of a new generation of rotary wing aircraft for military operations, it has become apparent that the present helicopter handling qualities specification, MIL-H-8501A[1], cannot accurately assess the characteristics of these aircraft. The fact that MIL-H-8501A was last updated 20 years ago only tends to amplify this point. The Navy Light Airborne Multi-Purpose System (LAMPS) SH-60B, the Army Utility Tactical Transport Aircraft System (UTTAS) UH-60A, and the Advanced Attack Helicopter (AAH) all use advanced flight control systems for stability and control augmentation. The need to adequately address the flying qualities of these state of the art vehicle/control systems has necessitated the use of "type specifications" or "prime item development specifications" uniquely devised for each new aircraft/control system. Many papers have been written describing the numerous shortcomings of MIL-H-8501A in realistically regulating handling qualities of present and future helicopters[2-6], indicating a very real need for an updated version of MIL-H-8501A. A summary of the major problem areas described by the above papers is presented as a background and overview of the current status.

To facilitate the development of revised criteria it is necessary first to compile a data base of past and present helicopter stability and control characteristics. This paper presents the beginning of such a compilation. Six degree of freedom math models of the SH-60B and the CH-53D single rotor helicopters were analyzed against the fundamental stability and control aspects addressed by MIL-H-8501A. Vertical control response and autorotation criteria were not included at this time. Flight test data for the XH-59A Advancing Blade Concept (ABC), the XV-15 tilt-rotor, and the CH-46A tandem rotor were also included and discussed.

In the development of the present day VSTOL handling qualities specifications, MIL-F-83300[7] and AGARD 577[8] extensive rotary wing pilot rating data were analyzed to substantiate the finalized hover/low speed criteria. Although AGARD 577 is not intended to be a helicopter specification and MIL-F-83300 has not been used by the Navy or Army for a helicopter development program, these specifications do supply alternative methods of addressing VTOL handling qualities characteristics. The alternative criteria from MIL-F-83300 and AGARD 577 were directly compared with the criteria from MIL-H-8501A to highlight helicopter specification deficiences and vehicle anomalies.

MIL-H-8501A Deficiencies

As described above, the major military helicopter development programs since 1965 have used type specifications designed exclusively for the flying qualities characteristics of a particular vehicle mission and rotor configuration. Although the type specifications were at first basically MIL-H-8501A with slight revisions, recent development of the SH-60B and the AAH was based on type specifications very different from MIL-H-8501A. This is due to the need to address the increased mission requirements of these helicopters. The launch and recovery of the SH-60B from a seaborne platform in up to Sea State 5 conditions is an example of these requirements. Recent work with the HXM type specification highlighted new problem areas, including the need to address characteristics that may be unique to a tilt-rotor configuration. Through the past decade many papers have been written describing specific areas in which MIL-H-8501A is deficient. Three of these areas are discussed in the following paragraphs.

MIL-H-8501A presently addresses helicopter flying qualities in terms of the longitudinal, lateral, directional, and vertical axes. There is no systematic delineation between hover/low speed characteristics and forward flight characteristics. In hover a helicopter pilot tends to use longitudinal, lateral and directional controls independently. For example, in a station keeping task, translation along the longitudinal and lateral axes is implemented by the respective cyclic input, while heading angle is controlled by pedal inputs. Forward flight characteristics of a helicopter tend to resemble those of an airplane, thus the pilot needs to use lateral and directional controls in a coupled manner. Also many single rotor helicopters show a coupled pitch-roll dynamic oscillation in hover, whereas in forward flight a dutch-roll type response is often found. A breakdown of the helicopter specification into hover/low speed criteria and forward flight criteria (similar to MIL-F-83300) would be a means to address the different axis couplings between hover and forward flight.

A suggestion by Key[4] is that a restructuring of MIL-H-8501A in line with MIL-F-83300 and MIL-F-8785C would allow for a more thorough treatment of degraded flying qualities. MIL-H-8501A presently has qualitative criteria for failures of power boosted controls, automatic stabilization systems and engine failures. Table 1 presents one section of the criterion addressing failure of an automatic stabilization system. There is little quantitative guidance available defining sufficient levels of control or stability. With the complex augmentation systems being employed on the SH-60B and the CH-53E there is a need to set minimum quantitative levels of degraded flying qualities for partial AFCS failures and single or dual engine failures. The three levels of flying qualities (see Table 2) used in the VSTOL and CTOL specifications could be incorporated in MIL-H-8501A to specify quantitative levels of degraded flying qualities for control response, static stability, and dynamic stability in any flight mode.

Table 1. Example of MIL-H-8501A criteria for stabilization system failures

3.5.9(d)	Helicopters employing automatic stabilization and control or stability augmentation equipment or both shall possess a sufficient degree of stability and control with all the equipment disengaged to allow continuation of normal level flight and the maneuvering necessary to permit a safe landing under visual flight conditions.

Table 2. Flying qualities levels

Pilot Rating	FQ Level	FQ Description
1.0-3.5	1	Flying qualities clearly adequate for the mission Flight Phase
3.5-6.5	2	Flying Qualities adequate to accomplish the mission Flight Phase but some increase in pilot workload or degradation in mission effectiveness or both, exists.
6.5-9.0	3	Flying qualities such that the airplane can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both.

A third area that could benefit from a restructuring of MIL-H-8501A is in defining criteria that are mission oriented. The helicopter specification currently uses a weight parameter for hover control power considerations that is the result of scaling laws and not meant to represent the variations in control response which may be required for vehicle mission differences. Both the VSTOL and CTOL specifications define four classes of vehicles according to overall mission requirements, although in MIL-F-83300 the class distinctions are only used for control force limits and roll control effectiveness in forward flight. Table 3 shows a general breakdown of mission as used in MIL-F-83300. Shipboard recovery and nap-of-the-earth (NOE) flight mission categories could be incorporated into these type of class divisions.

Table 3. MIL-F-83300 classification of aircraft

CLASS	DESCRIPTION
I	Small, light aircraft such as - light utility - light observation
II	Medium weight, low-to-medium maneuverability aircraft such as - utility - search and rescue - anti-submarine - assault transport
III	Large, heavy, low-to-medium maneuverability aircraft such as - heavy transport - heavy bomber
IV	High maneuverability aircraft such as - fighter - attack

The Navy has begun a program assessing the basic flying qualities criteria in MIL-H-8501A against the VSTOL specifications (MIL-F-83300 and AGARD 577) and representative present and future rotary wing aircraft. The significant results from the assessment of hover control power criteria and dynamic response criteria are presented in the following sections.

Hover Control Power

Helicopter control power requirements are usually determined by the hover mission control requirements. As described above, MIL-H-8501A uses a weight parameter to specify attitude response within one second or less. In an extensive review of MIL-H-8501A, Walton and Ashkenas [2] suggest that the MIL-H-8501A weight dependency is too simplified to give adequate guidance for various vehicle missions. In comparison to MIL-H-8501A the two VSTOL specifications define a constant limit of attitude response. The boundaries for roll attitude per inch of lateral control displacement as a function of the vehicle gross weight for all three specifications are shown in Fig. 1. The lower boundaries of all three specifications are substantiated by the level 2 rating given to the XV-15 with augmentation off. There are two other major points to be raised from Fig. 1. First the CH-53D AFCS on response has been described as quite adequate for the assault mission, yet the vehicle does not satisfy the VSTOL boundary. This then substantiates the need for some type of weight dependency as used by MIL-H-8501A. It is questionable though whether or not pilots will accept a lower response for extremely large vehicles. For example, a vehicle in the heavy lift helicopter (HLH) gross weight category (gw=130000 lb) would only need to attain a bank angle of 2.1 degrees within one second for a one inch lateral stick displacement to satisfy the MIL-H-8501A requirement.

The second point from Fig. 1 is the large difference in roll response between the similar weight SH-60B and CH-46A (ten degrees per inch versus four degrees per inch). The CH-46A has been described as having very satisfactory response characteristics for its assault and vertical replenishment missions. The SH-60B has been qualitatively described as having just adequate response characteristics for a turbulent, high sea state condition, indicative of the LAMPS mission. Yet the SH-60B shows a response well above the visual flight rules (VFR) or instrument flight rules (IFR) MIL-H-8501A boundaries. The difference between these two vehicles then raises the point of having attitude response criteria dependent on the vehicle mission and weight. In particular the small landing platforms and dynamic atmospheric conditions Navy helicopters will be expected to launch and recover from are an example of a mission that may not be adequately designed for by the still wind, out-of-ground effect control power criteria presently in MIL-H-8501A.

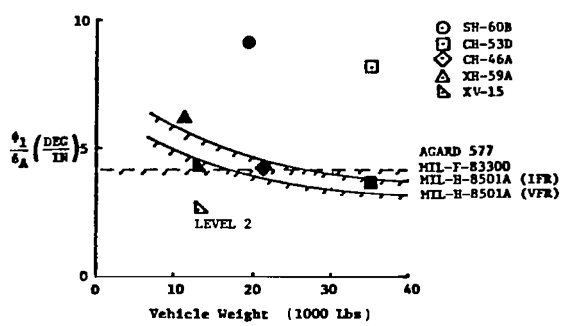

Fig. 1. Hover roll response comparisons

To insure that the helicopter response is not initially too sensitive MIL-H-8501A also has minimum angular rate damping criteria for the longitudinal, lateral, and directional axes. Using these damping boundaries with the above attitude response criteria, rate damping versus sensitivity boundaries can be developed. Fig. 2 shows the ABC and tilt-rotor compared to the MIL-H-8501A requirements for the yaw axis. The interesting point here is that neither aircraft satisfied the requirement yet the ABC has been described in a recent Navy flight test program [9] as having "crisp, predictable" yaw control and that the "high yaw rates (in excess of 45 degrees per second) that resulted from one inch pedal step inputs were well-damped and easily arrested, allowing large, rapid heading changes." The XV-15 in comparison was described as sluggish and not adequate. The point here is not that the ABC is good and the XV-15 bad, but the differences in the two rotor configurations. The ABC develops yaw control through differential collective of the two rotor systems while the tilt-rotor develops yaw control via differential cyclic inputs. The results presented in Fig. 2 show an apparent anomaly between MIL-H-8501A and the different rotor configurations of the ABC and tilt-rotor. Fig. 3 shows the pitch response characteristics of the SH-60B, CH-53D and the XV-15. Similar to the directional axis MIL-H-8501A adequately predicts the single rotor vehicle ratings (the SH-60B and the CH-53D) but again the tilt-rotor shows a discrepancy.

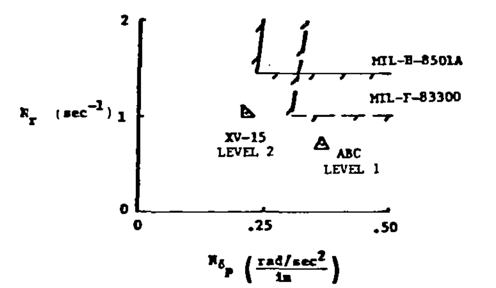

Fig. 2. Yaw rate vs. sensitivity comparisons

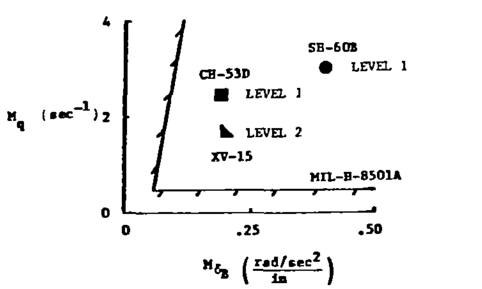

Fig. 3. Pitch rate vs. sensitivity comparisons

Overall it was found that the MIL-H-8501A attitude response and angular rate damping criteria gave minimal design guidance in comparison to the vehicles analyzed. Further analysis and data are needed to determine the effect of vehicle mission and varied rotor configurations.

Dynamic Stability

Following a disturbance (control or atmospheric) to a helicopter in hover the rate damping criteria discussed above should ensure an initial satisfactory response. After this initial response the aircraft may still have an unacceptable dynamic response. In a precision hover task it is mandatory that the pilot be able to correct easily for unwanted oscillatory responses. Uncommanded pitch or roll responses can cause tracking or station keeping errors, plus any short period dynamic responses must be well-damped so as not to impede precise control of the helicopter.

Satisfactory boundaries for dynamic stability characteristics are defined by each of the specifications reviewed through the use of second-order response parameters. The general trend is similar for all the specifications such that short period oscillations require a damped response while for longer periods, neutral stability to slight instability is acceptable. Fig. 4 shows a plot of nondimensional damping ratio versus damped natural period with a comparison of the three specifications for pitch or roll hover dynamic responses. Note that only MIL-H-8501A has a separate boundary for VFR conditions.

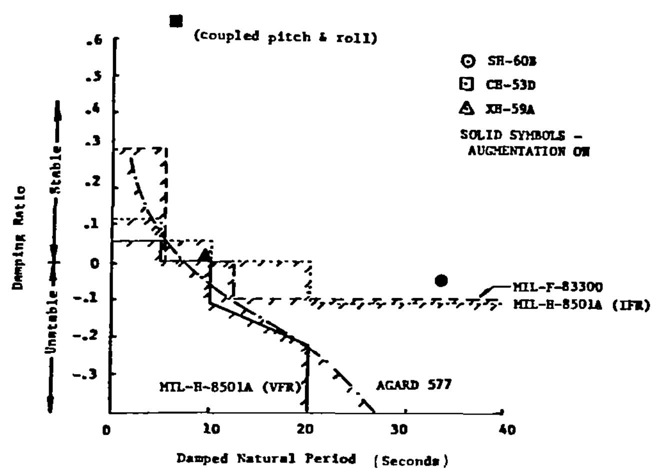

Fig. 4. Hover longitudinal dynamic stability requirements

It should be noted that it is assumed within MIL-F-83300 that "IFR capability is inherent in all military aircraft operational missions." For the limited data available very few conclusions can be drawn about the adequacy of the specifications boundaries. Of the three aircraft shown only the SH-60B shows a "conventional" phugoid mode. Within reference 3 the point is presented that for modern helicopters the MIL-F-83300 boundary shown in Fig. 4 is generally undemanding. This is questionable considering the SH-60B response that Navy pilots described as adequate for the LAMPS mission. Both the CH-53D and the XH-59A have also been qualitatively described as having level 1 characteristics. In particular the CH-53D has essentially dead-beat dynamic responses in hover. From the data analyzed it appears that MIL-H-8501A gives adequate guidance for hover dynamic responses.

Just as in hovering conditions, it is necessary that a helicopter have satisfactory dynamic response characteristics in forward flight. For example, in contour flying or mine sweeping missions, a slowly divergent phugoid response with a gradual altitude loss would be objectionable. MIL-H-8501A specifies VFR and IFR dynamic response criteria for the longitudinal axis (the same as the above hover requirements), while only stipulating IFR criteria for the lateral-directional axes.

Looking first at the longitudinal criteria, Fig. 5 shows a comparison between the VSTOL and helicopter specification boundaries. The helicopter specification is by far the most lenient in specifying stability requirements, in particular for long period responses (>20 seconds) under VFR conditions. In contrast, the VSTOL specifications do not allow divergent long period dynamic responses. With augmentation on, the three vehicles shown on Fig. 5 easily satisfied all the specifications.

Each aircraft has also been given level 1 ratings, in particular the SH-60B is described as having excellent phugoid damping. It should be noted that both VSTOL specifications have additional requirements for short period oscillations such that the damping ratio must be at least 0.3. AGARD 577 defines a short period response such that the damped period is less than 3 to 6 seconds. MIL-F-83300 specifies short period requirements according to Fig. 6. Note that the frequency boundary is a function of the vehicle n/α ratio. The CH-53D was the only vehicle analyzed that showed a short period type response, and it compared favorably with the Fig. 6 boundaries (e.g. $\zeta > 0.3$). For the vehicles compared against MIL-H-8501A, the specification gives lenient but adequate guidance for normal flight conditions.

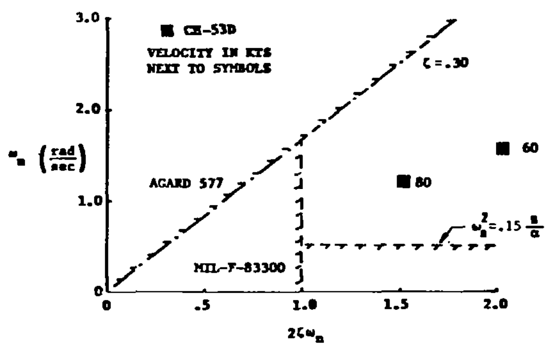

Fig. 6. VSTOL specification short period requirements

The lateral-directional dynamic stability requirements as specified by the VSTOL and helicopter specifications are shown on Fig. 7. The same general trend is followed by each criterion. Note that MIL-H-8501A has no requirement for VFR lateral-directional dynamic stability.

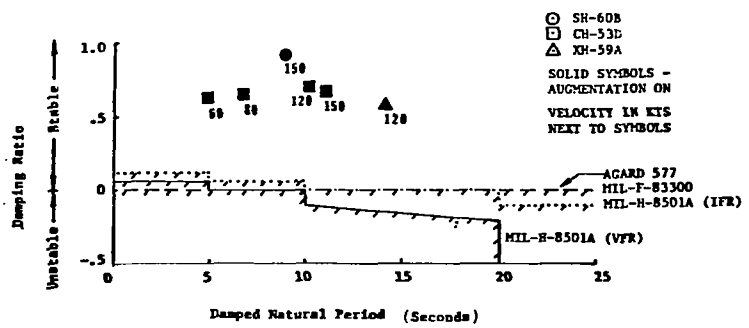

Fig. 5. Forward flight longitudinal dynamic stability requirements

The cluster of open symbols shows a common damped dutch roll response for the single rotor helicopters (SH-60B, CH-53D, SH-3A) analyzed. This type of yaw-roll coupled dynamic response has been given unsatisfactory ratings for single rotor helicopters. Thus there should at least be a baseline criteria limiting allowable divergent responses for VFR conditions. For augmentation on the responses are all well-damped over a wide range of frequencies. An interesting comparison between varied rotor configurations is shown on Fig. 7 as the ABC has a dutch roll response that falls right on the MIL-F-83300 level 1 boundary. Pilots described the ABC as having very satisfactory lateral-directional forward flight characteristics that were very similar to a fixed wing aircraft. A Sikorsky report (reference 10) on the ABC compared this response to MIL-F-8785, the fixed wing flying qualities specification. The ABC again appears as an anomaly in comparison to the helicopter specification boundary. For the vehicles analyzed MIL-H-8501A gives adequate guidance for IFR lateral-directional dynamic responses but has no guidance for VFR conditions.

guidance to address the differences in handling qualities characteristics between hovering and forward flight conditions.

MIL-H-8501A has very limited guidance for degraded flying qualities, especially towards defining minimum characteristics for AFCS failures.

The hover control power criteria (attitude response and rate damping criteria) inadequately address varied mission characteristics or rotor configuration differences.

Dynamic response criteria are in general adequate but very lenient, in particular for VFR mission requirements where no guidance is given for lateral-directional responses.

Analyses in the areas of height control response, aerodynamic and gyroscopic cross-coupling characteristics, and autorotation criteria are underway.

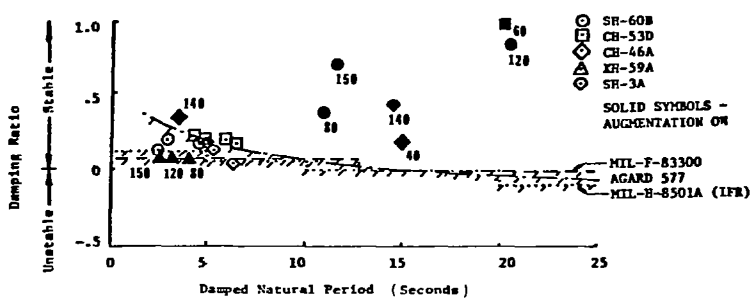

Fig. 7. Forward flight lateral-directional dynamic stability requirements

Conclusions

Although the need to update MIL-H-8501A has been known for many years, very little systematic work has been directed towards developing modern criteria. A step towards this goal is the future Army-Navy program designed to develop an updated rotary-wing handling qualities specification. This paper has presented the major deficiences in MIL-H-8501A as cited by many previous papers as well as the significant results of a preliminary Navy assessment of MIL-H-8501A. In particular:

MIL-H-8501A does not give adequate

References

1. Anonymous, "Helicopter Flying and Ground Handling Qualities; General Requirements for," MIL-H-8501A, 7 Sep 1961.

2. Walton, R. P. and Ashkenas, I. L., "Analytical Review of Military Helicopter Flying Qualities," Systems Technology, Inc., Technical Report No 143-1, Aug 1967.

3. Green, D. L. and Richards, R. B. Jr., "Review of MIL-F-83300 'Flying Qualities of Piloted VSTOL Aircraft' to Assess the Applicability to Helicopters," Pacer Systems, Inc., Technical Report No PWR-054-72, Mar 1972.

4. Key, D. L., "A Critique of Handling Qualities Specifications for US Military Helicopters," AIAA Paper 80-1592, Aug 1980.

5. Dooley, L. W., "Handling Qualities Considerations for NOE Flight," American Helicopter Society Journal, 22, (4), Oct 1977.

6. Pitt, D. M. and Heacock, F. E., "Advanced Scout Helicopter Flying Qualities Requirements, How Realistic Are They?" AHS Report 79-28, May 1979.

7. Anonymous, "Flying Qualities of Piloted VSTOL Aircraft," MIL-F-83300, Dec 1970.

8. Anonymous, "VSTOL Handling Qualities Criteria, Part I - Criteria and Discussion Dec 1970; Part II - Documentation," NATO AGARD Report 577, Jun 1973.

9. MacDonald, LCDR T. L., USN, and Kolwey, S., "Advanced Helicopter Rotor Systems Second NAVY Evaluation of the XH-59A Advancing Blade Concept (ABC) Demonstrator Aircraft," NATC Report RW-39R-80, 24 Dec 1980.

10. Ruddell, A. J., et al, "Advancing Blade Concept (ABC) Technology Demonstrator," USAAVRADCOM-TR-81-D-5, Apr 1981.