UAV Handling Qualities…..You Must be Joking

Warren Williams
Aerospace Sciences Corporation Pty. Ltd.
PO Box 667 Elizabeth, S.A., 5112, Australia
phone: +61 8 8289 9555
fax: +61 8 8289 9555
e-mail: warren@aerosciences.com.au

ABSTRACT

This paper discusses a proposed standard specifying the requirements for UAV handling qualities. Although on the surface remotely piloted UAVs can adopt the same standards as manned aircraft, the differences are significant enough to justify a study of these requirements using a systems engineering approach. This paper presents the differences and discusses the general content of this proposed handling qualities standard.

INTRODUCTION

Unmanned air vehicles (UAVs) have traditionally been designed and developed for specific missions. In order to balance platform characteristics with payload requirements, the resultant UAV systems are mission-specific. Also, as technological advances have been made, the general trend in UAV development has been towards autonomous UAVs rather than remotely-piloted vehicles (RPVs) or remotely piloted UAVs. However, certain specialist missions (such as mining exploration), combined with emerging regulatory environments for UAVs (driven by concerns over autonomous UAVs sharing the airspace with air passenger vehicles), have created further needs for the latter.

Remotely piloted UAVs, by their very inclusion of a human-in-the-loop, have an added dimension that demands a systems engineering approach to ensure its operational effectiveness and operational suitability to the typical end-users (Williams and Harris, 2003). In order to ensure that remotely piloted UAVs can undertake these missions effectively and safely it is necessary to describe a set of minimum requirements for handling qualities.

This paper describes the development of a handling qualities standard, which was in response to a shortfall in existing standards for remotely piloted UAVs. Although on the surface, the air vehicle component of a UAV system is very similar to its manned counterpart, the differences are significant enough to justify a review of these requirements. This paper describes those differences and how they translate into a set of requirements that differ from manned aircraft. However in developing this standard the approach has adopted and adapted the relevant methods and terminology from other applicable design standards to maintain a common baseline.

WHAT ARE HANDLING QUALITIES?

Although the definition of handling qualities of air vehicles is generally well accepted by the aeronautical industry, for UAVs we adopt a wider approach to account for the distributed systems architecture. In this definition we assume that handling qualities is more than just air vehicle stability and control.

A formal definition presented in MIL-STD-1797A (Air Force Flight Dynamics Laboratory, 1997), states that handling qualities is ‘Those qualities or characteristics of an aircraft that govern the ease and precision with which a pilot is able to perform the tasks required in support of an aircraft role’. This definition goes on to state that the context is important:

'Other factors that influence the handling qualities are the cockpit interface (eg. displays and controls), the aircraft environment (eg. turbulence and visibility) and stress, the effects of which cannot be readily segregated'.

However, this definition is not broad enough to capture those attributes of a UAV system, such as the complex system failure states, unique air vehicle dynamics, datalink time delays and flight displays subject to data rate constraints.

Therefore the definition we apply here to remotely piloted UAVs relates to the complex interaction of air vehicle flying qualities (i.e. stability and control characteristics), the cockpit interface, air vehicle environment, system failure states, data link time delays and the flight displays.

PURPOSE OF STANDARD

As stated earlier, the purpose of the handling qualities design standard is to define handling quality requirements for a particular category of UAVs. This category referred to in this document relates to a UAV system type that relies on ground-based pilot operating an air vehicle via direct control inputs, or through a stability augmentation system that can alter a flight path in real time or near real time. Because UAV systems of this control configuration require direct hands-on approach to piloting, the interaction of air vehicle flying qualities, ground station software, hardware and flight displays, data link time delays and latencies, and system failure modes determine the effectiveness of the mission. Furthermore the interaction of these system attributes has direct impact on the operating costs, operational reliability and safety.

Although the derivation of UAV design standards in the past has taken an airframe-centric approach, the handling qualities requirements document as described here takes a system perspective. The unique characteristics of remotely piloted UAV systems necessitate this approach. Shown below is a list of those differences between remotely piloted UAVs and manned aircraft. It is these differences that highlight the shortfall in existing standards that are airframe-centric and derived from manned aircraft.

1. Remotely piloted UAVs conduct specialised and complex missions dependent on the payload type and requirements. This is different from manned civil aircraft missions where the primary design requirements are mainly centred on passenger transportation and cargo carrying missions.

2. The simplest of UAV systems have relatively sophisticated servo-actuated flight control systems. In contrast to manned civil aircraft, all UAVs possess irreversible servo-based control systems with stability augmentation in some cases. Irreversible control systems are typically found in large jet airliners and military fighter aircraft.

3. Unlike most manned civil aircraft, UAVs possess relatively sophisticated software-based flight and navigational displays and associated systems. These displays and associated systems have complex failure modes determined by the air segment and ground segment architecture.

4. Unlike manned civil aircraft, UAVs have the 'cockpit' on the ground. Therefore the usual 'seat-of-the-pants' flight cues are not available to the pilot. Flight cues in UAVs need to be 'created'.

5. Unlike manned civil aircraft, remotely piloted UAVs are subject to time delays produced by the data link, which can have an adverse effect on system handling qualities.

6. Unlike manned aircraft, UAV systems may include several different air vehicle types that must be

interoperable with a common ground control station.

7. Unlike manned aircraft, UAVs are launched and recovered using a variety of methods. These launch methods may range from conventional wheeled takeoff, catapult launch from rails to rocket augmented rail launches and takeoffs. The recovery methods may range from conventional wheeled landings, net recovery, and parachute recovery to arrestor wires.

Therefore it is apparent that UAVs are significantly different to their manned aircraft equivalent. The formulation of this new design standard, although similar to that used for manned aircraft, reflects these differences.

It is interesting to note that the paper by Walker (1997) highlights a shifting trend towards remotely piloted UAVs, particularly in the early phases of flight testing. This has been evident in the very public failures of fully autonomous UAV systems such as that of 'Darkstar'. Furthermore contemporary work undertaken on the areas of Uninhabited Combat Air Vehicles (UCAVs) has in most cases involved remotely piloted configurations. This is the emphasis of Thurlings' (2002) work where the effect of time delays on UCAVs can have a significant effect on system operational effectiveness. As stated earlier, the emerging regulatory environments for UAVs (driven by concerns over autonomous UAVs sharing the airspace with air passenger vehicles) have created further needs for human-in-the-loop operation. Therefore, it cannot be overstated that in these roles it is important that human-in-the-loop control is maintained and that handling qualities meet a minimum standard.

Therefore the intent of this standard was to produce a simple concise document to provide UAV developers with design guidance material. In doing so it is hoped that the adoption of this design standard will result in a UAV system that is effective and safe to operate. Furthermore it is hoped that this design standard will help establish a 'handling qualities' baseline for air vehicle interoperability. This latter aspect being the main interest to the author, where several different types of air vehicles are proposed for use with a common ground control station.

CLASSIFICATION OF UAVs

In broad terms UAVs can be classified with respect to their maximum takeoff weight and the degree of autonomy. The Australian Civil Aviation Safety Authority (CASA, 2001) places UAVs in one of the following classes as in accordance with takeoff weight as follows.

- Class I Micro UAVs with a take-off weight of 100 grams or less.
- Class II Small UAVs with a take-off weight of less than 150 kg.
- Class III Large UAVs with a take-off weight of more than 150 kg.

Within these classes, the UAVs can be further sub-divided into those systems that involve autonomous, semi-autonomous or remotely piloted operation.

It should be noted that the handling qualities requirements as discussed in this paper applies to that type of fixed-wing UAVs flown primarily using a remotely-located pilot operating from a ground control station (GCS) set-up. Obviously those UAVs that are operated autonomously are not applicable to this paper.

Flight Phase Categories. The flight phases are divided into three categories using the same approach adopted by MIL-F-8785C (United States Air Force, 1996). These are detailed as follows:

Category A – These are the flight phases that require rapid manoeuvring, precision tracking, or precise flight path control. Included in this Category are low-level tracking and terrain following, reconnaissance and surveillance and close formation flying.

Category B – These are the flight phases that are normally accomplished using gradual manoeuvres without precision tracking, although accurate flight path control may be required. Included in this Category are climb, cruise, loiter, descent, emergency descent and flight termination.

Category C – These are terminal flight phases normally accomplished using gradual manoeuvres and usually require accurate flight path control. Included in this Category are takeoff, rail/catapult launch, powered approach, missed approach/go around and landing.

Levels of Handling Qualities. The levels of flying qualities are defined in the same way as that in MIL-F-8785C (United States Air Force, 1996). These levels are:

Level 1 Handling qualities clearly adequate for the mission flight phase.

Level 2 Handling qualities adequate to accomplish the mission flight phases, but some increase in pilot workload or degradation in mission effectiveness, or both exists.

Level 3 Handling qualities such the air vehicle can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. That is Category A flight phases can be terminated, and Category B and C flight phases can be completed.

AN OVERVIEW OF REQUIREMENTS

General Requirements. The handling qualities requirements discussed in this paper apply to all UAV operational missions associated with the types and classifications as discussed above. This also applies to all air vehicle configurations (flaps, undercarriage, high-power RF modes) encountered in the applicable flight phases of the mission, including those configurations associated with the ground control station and associated sub-systems.

It is quite important that the UAV system normal and failure states are defined by the appropriate state table, as it is these operational modes that will influence the method of demonstrating compliance. This aspect is discussed later.

In a similar way the operational flight envelope should be defined stating the boundaries of speed, altitude and load factor within which the air vehicle must be capable of operating under.

Flying Qualities. The formulation of flying qualities requirements draws upon the relevant requirements as stated in MIL-F-8785C, MIL-HDBK-1797, FAR Part 23, JAR-VLA, JAR 22 and JAR 23. These documents were similar in terms of basic flying qualities requirements. However the Military standards provided detail in some areas, where the civilian standards do not. An example was in application of Stability Augmentation Systems (SAS), spiral stability requirements, pilot induced oscillations and catapult launching requirements.

Nevertheless the approach taken here was to adopt and adapt the relevant requirements from the standards listed above, tailoring as required to account for the differences in airframe characteristics. For example is was necessary to tailor some requirements to account for the lower wing loading and higher power loading found on most UAVs. This tailoring was based on previous research in this area by Williams (2002) where UAV flying qualities were investigated using a simulator-based approach.

In general these requirements covered the following flying qualilties areas:

- Longitudinal static stability- Speed stability, phugoid stability and flight path stability.
- Longitudinal manoeuvre stability – Short-period response, longitudinal

pilot induced oscillations (PIO), and longitudinal control.

- Lateral-directional stability – Dutch roll mode, roll mode, spiral stability, lateral PIO, roll control effectiveness and directional control in crosswinds.

Miscellaneous Flying Qualities. Miscellaneous flying qualities covered such areas as dangerous flight conditions (high rate of descent, low altitude alerts, low fuel states, battery under-voltage or low data link strength conditions) and stall approach, prevention and recovery characteristics.

Characteristics of the Primary FCS. As specified in MIL-F-8785C, the term primary flight control system includes pitch, roll and yaw controls, associated stability augmentation systems, and all servo systems that they operate, both in the air vehicle and the ground control station. This section of the design standard covers GCS controller freeplay, dynamic characteristics, augmentation systems, failures and transfer to alternate control modes.

Characteristics of the Secondary FCS. The secondary flight control system includes those elements such as the trim function, speed control and flight path control devices. This section covers the functional aspects of the secondary FCS during transients and changes of trim.

System Time Delays. This section of the design standard covers the requirements for maximum allowable system time delays. The system time delays are introduced by the data link system. The combined delay of the data link and the response of the air vehicle system correspond to the total allowable system delay. This maximum system time delay is derived from a study conducted by Thurling (2002) which involved a series of UAV flight tests and simulations undertaken with several research pilots. In this study the research pilots were subjected to various levels of additional time delays, and asked to rate the tendency to enter Pilot Induced Oscillations (PIOs). The results of this study have been used as the basis of this standard.

Flight Displays. As stated earlier, the pilot interface is considered as playing an important part in UAV flying qualities. This section of the standard presents the minimum update rates for flight displays used in visual and instrument-based flight applications. Also specified are the requirements for audible and visual warnings for systems failures and cautions, as also requirements for audible engine and aerodynamic noise cues. The study by Hare (2002) highlighted the importance of data update in performance of basic visual flight tasks. The results of the study were incorporated as the basis of requirements in the standard as well as inflight observations from actual flight tests conducted by the author.

Incorporation of audible engine RPM and wind related noise is now a generally accepted requirement for remotely piloted UAVs as discussed by Walker (1997). Furthermore the results of flight testing by Williams (2003) concurs with the findings of Walker (1997) where several flights were conducted without these cues, to the detriment of overall UAV handling qualities.

DEMONSTRATING COMPLIANCE

General. Compliance with the requirements can be demonstrated through analysis, simulation and flight test. Furthermore many of the requirements may be demonstrated by a combination of simulation and flight test where appropriate.

Analyses. Analysis is used to demonstrate compliance with the requirements in the assessing the effects of failure modes and the effects of gusts and turbulence. The design standard provides a method with which to undertake these analyses. This method is based on a similar method presented in MIL-F-8785C.

Simulation. Simulation is used in the areas where hazards, risk of resources or difficulties are encountered in flight testing. Such areas may include the assessment of severe atmospheric turbulence, mission tasks conducted close to the ground, critical failure modes and/or combined events.

Flight Test. The required flight tests are defined by operational, technical and resource limitations. The standard does not intend to be prescriptive of the type or extent of flight testing required. Rather this is left to the UAV developer to determine within the constraints listed.

SUMMARY

This paper has discussed in general the formulation of handling qualities requirements of remotely piloted UAVs. It has highlighted that differences between UAVs and manned aircraft in this area are significant enough to justify the preparation of a 'new' design standard. This 'new' design standard is based on existing standards for manned aircraft. However the differences relate to primary and secondary flight control systems, data link time delays, system failure states and flight display requirements.

ACKNOWLEDGEMENT

The author wishes to acknowledge the generous support of the University of South Australia in funding of this research study and Mr Michael Harris of the Systems Engineering Evaluation Centre for his assistance.

REFERENCES

Civil Aviation Safety Authority 2001, *Unmanned Aircraft and Rockets*, Civil Aviation Regulations, Part 101, CASA, Canberra, Australia.

Air Force Flight Dynamics Laboratory, 19 Dec 1997, *MIL-HDBK-1797 - Flying Qualities of Piloted Aircraft*, WPAFB, Dayton, Ohio USA.

Federal Aviation Administration, n.d., *FAR Part 23 – Airworthiness Standards: Normal, Utility, Aerobatic and Commuter Category Airplanes*.

Hare A., 10 August 2002, *Developmental Test and Evaluation of an Unmanned Air Vehicle Ground Control Flight Display*, Systems Engineering And Evaluation Centre, University of South Australia.

Joint Airworthiness Regulation, n.d., *JAR-VLA - Airworthiness Standards: Very Light Aircraft – Less Than 750 kg Gross Weight, 26.4.90*.

Joint Airworthiness Regulation, n.d., *JAR-22 - Airworthiness Standards: Sailplanes and Gliders,* Amendment 6.

Joint Airworthiness Regulation, n.d., *JAR-23 - Airworthiness Standards: Normal, Utility, Aerobatic and Commuter Category Airplanes,* Amendment 1.

Lax, M. and Sutherland, B. 1996, *An Extended Role for Unmanned Aerial Vehicles in the Royal Australian Air Force*, Report 46, Air Power Studies Centre, Fairbairn, Australia.

Thurling A.J., March 2000, *Improving UAV Flying Qualities Using Time Delay Compensation*, Masters of Science Thesis, United States Air Force Institute of Technology, USA.

United States Air Force, 28 August 1996*, MIL-F-8785C Notice 2 – Military Specification Flying Qualities of Piloted Airplanes.*

Walker L.A., October 1997, NASA Contractor Report 198058, *Flight Testing the X-36 – The Test Pilot's Perspective*, NASA.

Williams W.R., 1 February 2003, *Unmanned Air Vehicle – Flight Test Report – Beaver UAV/GCS Flights Conducted 31 January 2003*, Newmont Australia.

Williams, W. 2002, *'A Simulator Based Approach to DT&E of Small UAVs'*, Masters of Engineering minor thesis, Systems Engineering and Evaluation Centre, University of South Australia, Adelaide, Australia.

Williams, W. and Harris, M. B. 2003, *'Determination of the Operational Effectiveness of UAVs for Mining*

Exploration', in Proceedings of UAV Asia-Pacific Conference, Melbourne Australia.

Williams, W. and Harris, M. B. 2002, *'The Challenges of Flight-Testing Unmanned Air Vehicles'*, in Proceeding of SETE 2002: The Systems Engineering and Test and Evaluation Conference, Systems Engineering Society of Australia, and the Southern Cross Chapter of the International Test and Evaluation Association, Sydney, Australia.

ABOUT THE AUTHOR

Warren Williams is a consulting engineer with fourteen year's experience in the aeronautical engineering field. Mr Williams' career has been in the areas of aerodynamic testing, missile flight dynamic modelling and simulation, aircraft structural design and analysis, and aircraft flight-testing. His flight test experience has included weapons separation testing, towed target flight dynamics evaluations, helicopter towed array testing, aircraft drag performance tests, stall speed tests, vibration testing and flight loads measurement. Mr Williams is a recent graduate of the National Test Pilot School (USA), completing courses in fixed-wing flying qualities and performance flight-testing, and avionics flight-testing. His employment history includes experience with the Defence Science and Technology Organisation, the RAAF Aircraft Research and Development Unit, and various Defence contractor firms.

Mr Williams is currently a consultant to the mining exploration industry in the area of airborne systems. He holds a current fixed-wing pilots licence, and has over seventeen years flying experience.