Development of a Process to Define Unmanned Aircraft Systems Handling Qualities

Defining Handling Qualities for Unmanned Aircraft Systems Stakeholders Workshop at NASA Langley Research Center
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Presentation Outline

• Phase II SBIR Program Overview
• Motivation
• Proposed Approach
• Example Candidate Metric
• Summary – Reality Check
Phase II SBIR Program Overview
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Key Phase II Technical Objectives

• Expand stakeholder engagement.
  – Engage government, industry and academic stakeholders at regular intervals.
  – Identify means to expand UAS data sources to enhance the requirement definition process.

• Identify and define UAS handling qualities metrics and criteria.
  – Define these in support of each MTE category.
  – Examine and define MTE performance requirements in support of a draft specification.

• Conduct fixed wing flight tests across flight envelope with a representative sUAS, where sUAS < 55 pounds.
  – Perform system identification flights.
  – Evaluate MTE’s.

• Perform similar, but more limited testing with a representative multi-rotor sUAS.
  – Low speed flight regime.

• Evaluate the UAS-HQ process.
  – Leverage the collected flight test data from the fixed and multi-rotor flight tests.
Motivation
In the Beginning...

- Initial work concerning the definition of UAS handling qualities occurred nearly a decade ago.
- Work at the time was dominated by focus on relatively large, military UAS that have much in common with manned aircraft.
- There was a natural push to preserve the use of the manned handling qualities requirements, to the extent this was possible.
... and Then Everything Changed

- Small, low cost drones proliferated and users and potential users demanded access to the air space.
- Commercial use cases are growing at a rapid pace:
  - Agriculture
  - Inspection and patrol
  - Videography
  - Package delivery
  - Many more
- Unlike the large military UAS, these vehicles will operate at low altitude and do not require airports for launch and recovery.
- Traditional HQ requirements not likely to apply in their current form (i.e., data needed to establish new boundaries).
Micro to Macro UAS

-- One Size Does Not Fit All --

AV Wasp III, 0.95 lbs
Aeryon Scout, 3.74 lbs
Martin UAV Bat-3, 7.3 lbs

MQ-8B Fire Scout, 3,150 lbs
MQ-9B Reaper, 10,500 lbs
RQ-4B Global Hawk, 32,250 lbs
Barriers to Requirements

- The UAS arena includes toy makers, traditional airframers, established UAS manufacturers, academic institutions, and many newcomers such as Amazon, Google, and Facebook that see UAS as a means to other commercial ends.
- While progress is now being made, issues continue to slow the development of verification, validation, and certification methods that will enable the safe introduction of UAS to the NAS.
- These issues include the lack of quantitative certification requirements including the definition of handling qualities.
- The “how to” of safely integrating UAS in the NAS raises many questions, and to date, there have been few answers.
- Because of a lack of quantitative data, attempts to address core problems thus far have failed to achieve consensus support.
It’s all about the Data

• A successful set of UAS HQ requirements cannot be established without flight test data.
• Data are needed for all:
  – UAS classes.
  – Mission Task Element (MTE) categories.
• In the absence of data, requirements established for manned vehicles have been considered and applied.
  – Is this an appropriate approach?
  – How do these requirements apply to sUAS?
• Dynamic models for a wide variety of UAS are also needed to assess requirements analytically.
Proposed Approach
Flying versus Handling Qualities

• **Flying Qualities:**
  – Analytical and empirical parameters or criteria that can be measured for a given airplane.
  – Related to the demands the pilot places on the airplane to achieve desired performance.

• **Handling Qualities (Our Focus):**
  – Describes operations while the pilot is actively in the loop.
  – Cooper and Harper stated:
    • “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.”
  – For UAS, consideration must be given to the ability of the autonomous system to perform the task.
Handling Qualities and Autonomy

• Historically, handling qualities are defined for piloted aircraft.
  – UAS operations, on the other hand, may be:
    • Remotely Piloted
    • Remote Pilot Assisted
    • Fully Autonomous
    • or a combination of the three
  – When actively engaged in flying, the pilot provides GNC functions.
  – Autopilots can provide regulation of some of these functions, but they are not autonomous functions, they are regulators.

• Autonomous functions feature a decision making capability that attempts to replicate or even improve upon piloted operations.

• If a UAS mission is to, for example, station keep over a given location it matters not in terms of handling qualities whether it is remotely piloted or autonomous, the mission requirements will be the same.
The Need for UAS Classification

• To define UAS handling qualities, there must first be an effective classification scheme:
  – The Navy approach as defined in AIAA-2008-6555 (Holmberg, et al.) has been to base classification as defined in the fixed wing flying qualities specifications that classifies based on aircraft size and weight.
  – Cotting, as part of his doctoral dissertation, proposed an approach that classifies by Reynolds number, Mach number, and weight.
  – A more recent NASA-funded study led by Embry-Riddle Aeronautical University used maximum kinetic energy, weight, and wingspan.

• The common denominator in all of these approaches is size, weight, andairspeed.

• Application of the Mission Oriented Approach allows for a simplified classification scheme that is discussed next.
UAS Classification

- The Mission-Oriented Approach is itself a classifier.
- This allows for a simple classification based on weight classes, e.g.:
  - Very Large UAS (VLUAS) Weight > 1320 pounds
  - Large UAS (LUAS), 330 < Weight < 1320 pounds
  - UAS, 55 < Weight < 330 pounds
  - Small UAS (sUAS), 20 < Weight < 55 pounds
  - Mini UAS (mUAS), 4.4 < Weight < 20 pounds
  - Micro UAS (μUAS), Weight < 4.4 pounds
- Other classifiers such as speed, type (e.g., fixed wing, rotary wing, ducted fan, etc.) will be naturally captured by the defined mission – as represented by MTEs.
- For example, consider a precision hover MTE:
  - The MTE naturally defines a vehicle type that can hover!
  - MTE and weight classification selection then leads to appropriate requirements.
Proposed UAS HQ Assessment Process
Example Candidate Metrics
Aircraft Bandwidth

- Developed to address 6DOF control modes (AFWAL-TR-81-3027 by Hoh, et al.).
- Expanded to cover “modern” airplanes: the Neal-Smith data.
- Considerable development since initial release:
  - Added flightpath Bandwidth requirement.
  - Added frequency-domain pitch rate overshoot requirement.
  - Greatly relaxed handling qualities Levels.
  - Added Pitch Rate Overshoot parameter to account for excessively high short-period dynamics.
  - Developed PIO limits.
- Primary response requirement in US Army rotorcraft handling qualities specification, ADS-33E-PRF.
- Metric is independent of vehicle response type, which is an important UAS consideration.
Aircraft Bandwidth and Pitch Rate Overshoot Parameters

\[ \omega_{BW_\theta} = \text{MIN}(\omega_{BW_{gain}}, \omega_{BW_{phase}}) \]

\[ \tau_{p_\theta} = \frac{\Delta \phi}{57.3} \left( \frac{2\omega_{180}}{2\omega_{180}} \right) \]

\[ \Delta G(q) \]

Aircraft Bandwidth

Pitch Rate Overshoot
Airplane Pitch/Roll Attitude Bandwidth Requirements for Transport Aircraft

*Note: Landing, Feel System Excluded*

Pitch Attitude Bandwidth

Roll Attitude Bandwidth
Airplane Bandwidth Parameters for NASA AirSTAR with Mode 1 FCL

*Note: Approach Flight Condition (Offset Landing MTE)*

- **Pitch Attitude**
  Airplane BW = 7.19 rad/s
  Phase BW = 7.19 rad/s
  Gain BW = 8.13 rad/s
  $\omega_{180} = 10.9$ rad/s
  $\phi_2 = -223$ deg
  $\tau_p = 0.0346$ sec
  $\Delta G(q) = 9.91$ dB

- **Roll Attitude**
  Airplane BW = 6.2 rad/s
  Phase BW = 6.2 rad/s
  Gain BW = 7.7 rad/s
  $\omega_{180} = 10.6$ rad/s
  $\phi_2 = -217$ deg
  $\tau_p = 0.0308$ sec
Airplane Pitch/Roll Attitude Bandwidth with AirSTAR Model Data

Note: Landing, Feel System Excluded

Pitch Attitude Bandwidth

Roll Attitude Bandwidth
Summary – Reality Check

• Existing HQ Standards evolved over decades
• Government $$$ for research, piloted simulation, and flight test
• Fixed Wing, MIL-STD-1797B
  – Evolved from MIL-F-8785C
  – Criteria based on Aircraft Categories and Flight Phases
  – Collection of modal to high order systems requirements
• Rotorcraft V/STOL, ADS-33E-PRF
  – Mission-Oriented Spec
  – Introduced MTEs
• Our Reality – One Phase II SBIR program will not have the breadth to fully address the need, that is, to fully define UAS handling qualities, but we’ll try!