Mission Task Element Development Process: An Approach to FAA Handling Qualities Certification

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Development of new air vehicles (e.g., personal air vehicles, urban taxis, etc.) have led to a proliferation of Vertical Takeoff and Landing (VTOL) vehicle concepts including electric vehicles, many of which are well funded and are in various stages of prototype development and test. These vehicles will almost exclusively feature fly-by-wire flight control systems that may feature advanced response-types. The processes and requirements needed to certify these disparate vehicles for operation within the National Airspace System are still emerging. To aid in the requirements and certification process, a mission-oriented approach is being applied to define handling qualities mission task elements that will serve as a means of compliance with Part 23 certification requirements.

I. Introduction

The FAA knows how to certify civilian fly-by-wire aircraft as illustrated for the many models produced by Boeing, Airbus, Dassault, Gulfstream, Embraer, and Bombardier. Since the existing rules (i.e., 14 CFR Part 25) did not account for advanced fly-by wire technology, all of these certifications required a “patch” called special conditions. These special conditions were onerous and very time consuming to process. Furthermore, each special condition was different due to each design being unique.

Consequently, an alternative means to certify fly-by-wire aircraft without requiring special conditions for every single design would be beneficial and serves as the motivation for the work described in this paper. At the same time, the FAA forecasts the proliferation of fly-by-wire technology to smaller aircraft. These smaller aircraft could use tailorable rules for special class aircraft (i.e., 14 CFR part 21.17b) or use rules adopted in 2017 for small airplanes.

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Modern vertical take-off and landing aircraft could also benefit from an alternative means to certify fly-by-wire. Leveraging lessons learned from military helicopter certification, the FAA proposed to adapt military methodologies called Mission Task Elements outlined in the document ADS-33-PRF [1]. Mission Task Elements from ADS-33-PRF need to be modified appropriately for the civilian missions and the civilian certification rules. Military requirements are specified in terms of prescriptive key-performance parameters, whereas the FAA is seeking means of compliance via a standard to high level performance-based rules.

The approach proposed by the FAA Small Airplane Standards Branch is outlined in this paper. The FAA launched a research project in 2018 with Systems Technology, Inc. (STI) to bridge the gap between military and civilian certification. The end goal of this research is to develop appropriate means of compliance to civilian rules and develop a catalogue of appropriate mission task elements. This paper outlines that approach with work done to date. As part of this work, the team will perform dry runs of the mission task elements written for eVTOL vehicles in various simulators including the NASA AMES Vertical Motion Simulator, and the NASA Langley Cockpit Motion Facility. The FAA Small Airplane Standards Branch conceived of and authored the cooperative agreements that are now in place between the FAA and NASA to facilitate these tests. Furthermore, the team plans to refine the mission task elements described herein with actual flight tests. Actual flight tests will be conducted with eVTOLs prior to certification as part of the NASA-FAA National Campaign for Advanced Air Mobility, previously known as the “Grand Challenge.”

In a mission-oriented approach to aircraft handling qualities [2], means of compliance are based in part on realistic mission task elements (MTEs). Specific flight test demonstration maneuvers are then defined for each MTE as a tool to assess if there are any handling quality deficiencies. Ultimately, a truly mission-oriented means of compliance will have quantitative requirements tied directly to appropriate MTEs. Thus, the MTE provides an explicit way of testing suitability for identified mission as well as satisfying some airworthiness requirements or rules. This is perhaps the most significant “mission-oriented” concept, and, as such, led to the research effort reported in [3]. This fixed wing research was based on the approach to handling qualities that was successfully established for military rotorcraft via ADS-33, the latest release of which is ADS-33E-PRF [1].

Aircraft size is not considered in a mission-oriented approach. A number of the requirements in the fixed wing military standard (i.e., MIL-STD-1797B), for example, have different values depending upon aircraft size, defined in terms of four Classes of aircraft. This includes in particular the modal requirements that were defined in MIL-F-8785B/C and have remained through to the current fixed wing standard. This division is arbitrary and is sometimes irrelevant. For example, if a mission requires a high level of aggressiveness and precision, it should not matter if the airplane proposed for that mission is small or large. Only the mission requirements should set handling qualities. It is recognized that, in some cases, this may lead to unreasonable demands on very large airplanes. As an example, consider a vehicle that has been designated for the urban air mobility mission that includes VTOL operations in a dense urban air space. It is therefore reasonable to consider a precision hover MTE as a means of compliance with FAA Part 23 regulations, regardless of aircraft size, weight, or mode of operation (i.e., lift+cruise, multi-copter, tilt rotor, tilt wing, tilt sitter, etc.).

A mission-oriented approach provides for the possibility of different dynamic response characteristics or flight control system response-types. One shortcoming of several of the requirements of MIL-STD-1797B, for example, is that they are not applicable to all response-types. Thus, aircraft with an attitude response-type such as pitch attitude command/attitude hold dynamics cannot be evaluated using the control anticipation parameter (CAP) criteria for short-term response. The number of different response types possible for VTOL airplanes is extensive, so this issue must be a consideration in the certification process.

Finally, one of the most significant features of the mission-oriented approach is the inclusion of MTEs as an integral part of the standard. This was done for rotorcraft in ADS-33 and an initial fixed wing catalog of maneuvers (Ref. 4), but in the fixed wing case these maneuvers have not yet been incorporated into the military standard though they are being considered for inclusion in the forthcoming MIL-STD-1797C. Qualitative flight test evaluations by trained evaluation test pilots that are familiar with the handling qualities rating process as established by Cooper and Harper (Ref. 5) should be made an integral part of the handling qualities means of compliance evaluation process.

II. Flying and Handling Qualities

Historically, there has been a tendency to use the terms “flying qualities” and “handling qualities” interchangeably. For the engineering community, there is typically no recognized difference between these key...
words. To some, however, the terms have begun to take on different meanings, and this difference has been reflected, where possible, in this working paper. The terms are interpreted as follows.

“Flying qualities” is taken to mean those analytical and empirical parameters or criteria that can be measured for a given airplane. All such parameters or criteria can be related to the demands the pilot places on the airplane to achieve desired performance. That is, they are open-loop metrics describing pilot-in-the-loop operations. Here we are talking about metrics such as Aircraft Bandwidth/Phase Delay as defined in [1] and elsewhere. This metric is based on crossover model theory [6] and as such the open-loop metric parameters derived from a flight test frequency response of attitude output to pilot inceptor input give a measure of the pilot-vehicle system bandwidth (i.e., crossover frequency) for a 45 deg phase margin closure. The phase delay parameter provides a measure of the higher frequency phase roll off, the magnitude of which quantifies effective time delay in the region of pilot-vehicle system control. Thus, these parameters that are obtained via an open-loop test input can be used to predict closed-loop pilot-vehicle system performance.

By contrast, “handling qualities” is meant to describe operations while the pilot is actively in the loop. This includes the definition put forth by Cooper and Harper: “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.”

In this context, the “flying qualities” criteria are measures from which we attempt to quantify the “handling qualities” of the airplane. By this definition, the criteria of ADS-33E-PRF and MIL-STD-1797B are flying qualities criteria, and the MTEs are handling qualities maneuvers. The flying qualities criteria are thus measures of predicted handling qualities, while Cooper-Harper Ratings (CHR) are measures of actual handling qualities. MTEs thus become the closed-loop pilot-vehicle system measure. The Cooper-Harper ratings assigned by an experienced test pilot using well-defined MTEs including desired and adequate performance requirements that facilitate use of the CHR scale together with verification of task performance measure actual handling qualities.

Flying qualities and handling qualities requirements are also reflected in Part 23 of the Airworthiness Standards: Normal Category Airplanes. As illustrated in Figure 1, the Part 23 requirements can be divided between flying qualities and handling qualities requirements using the above descriptions. First note that the list of flying qualities related requirements is longer than illustrated in the figure. Second, there will be some overlap in requirements as indicated by the complete lists provided in Table 1. For example, 23.2145 Stability appears on both lists, since airplane stability must be displayed via both open- and closed-loop pilot-vehicle system maneuvering. To meet these requirements, MTEs are applied as a means of compliance. Here Flying Qualities MTEs or FQTEs are the flight test maneuvers that measure flying qualities and related performance parameters. The FAA has long established flight test methodologies that serve as means of compliance with the Part 23 requirements (Ref. 7). Using the MTE template herein to the extent it is appropriate, FQTEs can be written in a format that is complimentary to the process described to aid in the development of a standardized means of compliance flight test methodology. Handling Qualities MTEs or HQTEs are the flight test maneuvers that address closed-loop pilot-vehicle system performance. The remainder of this working paper will address the process to develop HQTEs.

![Figure 1: Mission task elements as a means of compliance.](https://example.com/image.png)
### Table 1: Breakdown of Part 23 Airworthiness Requirements

<table>
<thead>
<tr>
<th>Flying Qualities</th>
<th>Handling Qualities</th>
</tr>
</thead>
<tbody>
<tr>
<td>§23.2110   Stall speed.</td>
<td>§23.2130   Landing.</td>
</tr>
<tr>
<td>§23.2115   Takeoff performance.</td>
<td>§23.2135   Controllability.</td>
</tr>
<tr>
<td>§23.2120   Climb requirements.</td>
<td>§23.2140   Stability.</td>
</tr>
<tr>
<td>§23.2125   Climb information.</td>
<td>§23.2150   Ground and water handling characteristics.</td>
</tr>
<tr>
<td>§23.2130   Landing.</td>
<td>§23.2155   Performance and flight characteristics requirements for flight in icing conditions.</td>
</tr>
<tr>
<td>§23.2135   Controllability.</td>
<td>§23.2165   Performance and flight characteristics requirements for flight in icing conditions.</td>
</tr>
<tr>
<td>§23.2140   Trim.</td>
<td></td>
</tr>
<tr>
<td>§23.2145   Stability.</td>
<td></td>
</tr>
<tr>
<td>§23.2150   Stall characteristics, stall warning, and spins.</td>
<td></td>
</tr>
<tr>
<td>§23.2160   Vibration, buffeting, and high-speed characteristics.</td>
<td></td>
</tr>
<tr>
<td>§23.2165   Performance and flight characteristics requirements for flight in icing conditions.</td>
<td></td>
</tr>
</tbody>
</table>

### III. Handling Qualities Task Elements

In flight test, it is desirable to categorize segments of aircraft missions into test maneuvers that address relevant Part 23 handling qualities requirements. The ability of the aircraft to accomplish these tasks is predicted according to the appropriate criteria. Parameters for these requirements are generated first analytically, then via simulation, and finally via flight test. It is not practical, or necessary, to derive a separate set of criteria for every defined task. Instead, the tasks are grouped in terms of the criteria boundaries that apply to them, in this case the appropriate Part 23 requirement. As introduced previously, the handling qualities tasks in a mission-oriented specification are formally defined as Handling Qualities Task Elements or HQTEs. This approach has been well established for military rotorcraft in ADS-33 (e.g., [1]). It is intended that the civilian HQTEs be specified in detail, including desired and adequate handling qualities performance requirements that facilitate use of the Cooper-Harper rating scale.

#### A. Definition

Building upon past work, the FAA Small Airplane Standards Branch has developed the following HQTE definition as it applies to Means of Compliance for the Part 23 Requirements listed above. Handling Qualities Task Elements are repeatable tests based on vehicle CONOPS and tailored to evaluate aircraft characteristics to assure:

- Safe operations within the flight envelope, and;
- The ability to perform the intended mission(s) with acceptable pilot workload/compensation and awareness.

The MTE should link to operationally relevant task (see notes) while accounting for a) environmental conditions and flight manual limits; and b) expected failure conditions detailed in FMA (Failure Mode Analysis).

Notes:

1. Aircraft characteristics evaluated during development need to consider integration of flight control laws, displays, inceptors, and sensors.
2. Operational suitability determination may require additional testing. Linkage to ACS (Airman Certification Standards) or PTS (Practical Test Standards) may be relevant.
3. Level of precision and aggressiveness for a task may be contrived to uncover pilot-induced oscillations (PIO) and other handling qualities deficiencies.
4. HQTE MUST link to aircraft certification regulation(s) and can be used in partial fulfillment with respect to showing compliance to the regulation(s).
5. HQTEs may utilize Cooper Harper Ratings (CHR) as a tool for correlating task performance and pilot compensation. Here, compensation is a factor in pilot workload. Compliance determination to regulations will need to consider more than just a CHR as a pass/fail criterion.
6) Uncovering the source of Handling Qualities deficiencies may require breaking out tasks in one axis at a time.

B. Required Precision and Aggressiveness

In a mission-oriented specification, the Flight Phase Categories are defined in terms of the level of precision and aggressiveness required of the pilot. Four HQTE categories under consideration are defined as follows:

- Non-Precision, Non-Aggressive
- Non-Precision, Aggressive
- Precision, Non-Aggressive
- Precision, Aggressive

The intent of the HQTE categories is that the requirements in a given category are sufficiently similar so that a single criterion boundary will apply. For example, the Aircraft Bandwidth/Phase Delay criteria [1, 6, 8] should have a form similar to that shown in Figure 2. Data will be required to properly define these boundaries for Part 23 aircraft applications.

![Figure 2: Relationship between HQTE categories and specification boundaries for Aircraft Bandwidth/Phase Delay Criteria [2].](image-url)

**Non-Precision, Non-Aggressive:** Non-precision tasks that require only a moderate amount of closed-loop control fall in this category. Examples include:

- Low speed tasks such as hover turn and landing.
- Cruise flight tasks such as heading changes, altitude (climb/descent) changes, and altitude rate (climb rate/descent rate) changes.

**Non-Precision, Aggressive:** This category is intended to include the large amplitude maneuvering HQTEs that emphasize control power over precise dynamic response. It is true, however, that a reasonably good dynamic response is inherently necessary to effectively utilize a large amount of control authority, i.e., to stop and start the large amplitude maneuvers with some precision. The moderate- and large-amplitude maneuvering requirements will be of primary interest for these HQTEs. Examples include:

- Low speed and transition tasks such as depart abort and obstacle avoidance.
- Cruise flight tasks such as collision avoidance with other aircraft.

**Precision, Non-Aggressive:** This category includes tasks where considerable precision is required, but without aggressive control activity. The dynamic response requirements for these tasks are expected to be less stringent than for **Precision, Aggressive**, but significantly greater than for **Non-Precision, Non-Aggressive**. Examples include:

- Low speed tasks such as precision hover, lateral reposition and hold, and pirouette.
- Cruise flight tasks such as pitch attitude captures, bank angle captures, and flight path regulation.
**Precision, Aggressive**: This category includes precision tasks, where an extremely crisp and predictable response to control inputs is required. Ride qualities are typically not a factor. The results of not achieving the required precision are usually significant in terms of accomplishing the mission or safety of flight. Examples include:
- Low speed tasks such as obstacle avoidance in a dense, urban environment.
- Cruise flight tasks such as flight path regulation in the presence of moderate to high turbulence.

### IV. HQTE Development Process

#### A. Process Description

The process to develop HQTEs is illustrated in Figure 3. In short, the first step in the HQTE development process is mission segment deconstruction of the Part 23 airplane. Since aircraft use cases may be unique for different Part 23 airplanes, there will not only be unique HQTEs based on these use cases, but also common HQTEs. For example, all fixed wing airplane will takeoff, land, climb, descend, loiter, etc. There will, however, be HQTEs that are specific to the unique use case. This may result in a common HQTE with separate performance requirements or a new HQTE. This section will describe the elements of the HQTE development process including a detailed HQTE template and evaluation questionnaire that can be used in the HQTE assessment process.

![Figure 3: HQTE development process.](image)

1. **Mission Break Down**
   
   As described above, the mission of the Part 23 Small Airplane will be dissected into elements that individually address the key components of the overall mission. For Part 23, this will include fixed wing airplanes and the great variety of emerging vertical takeoff and landing aircraft that are being developed for new urban air mobility and personal air vehicle use cases.

2. **HQTE Naming Convention**
   
   Currently, the MTE naming convention is still being defined. The objective is to provide for a title that will allow users to extract information about configuration, test environment, etc., and provide a link to an operationally relevant maneuver. As stated elsewhere in this working paper, the HQTE is defined to consistently expose handling qualities deficiencies in a repeatable manner, not to provide operational relevance, per se.

#### B. HQTE Template

This section defines the elements of a Handling Qualities Task Element that has been defined as means of compliance for FAR Part 23 requirements.

1. **HQTE NAME**
   
   - Specify name that clearly indicates intention of HQTE.

2. **FAR Part 23 Requirement**
   
   - Identify Part 23 requirement to which the HQTE serves as a means of compliance.
• Handling qualities requirements apply to:
  o §23.2130 Landing;
  o §23.2135 Controllability;
  o §23.2145 Stability;
  o §23.2155 Ground and water handling characteristics; and
  o §23.2165 Performance and flight characteristics requirements for flight in icing conditions.

3. Link to Practical Test Standards
   To the extent possible, the HQTEs should attempt to be linked to practical test standards (Ref. 9). It is recognized, however, that the primary role of the HQTE is to expose handling qualities. Thus, any linkage to airman proficiency standards may aid in a secondary role of pilot acceptance.

4. Precision and Aggressiveness Level
   • Identify specified level as linked to desired/adequate performance requirements.
   • Levels to be specified are: 1) Non-Precision/Non-Aggressive; 2) Precision/Non-Aggressive; 3) Non-Precision-Aggressive; and 4) Precision/Aggressive.

5. Task Objectives
   • Approximately two to four high-level bulleted items that will help the user determine why this HQTE should be used, and the expected outcomes.

6. Task Description
   • Brief but explicit description of the task, including test course layout and specialized equipment/displays, if needed.
   • Keep the HQTE simple in operation. If it becomes too elaborate, consider breaking it into two (or more) HQTEs.
   • Be careful setting time as a task parameter. Consider whether time is a part of the task description (meaning it must be met) or a performance limit (meaning it is a measure of goodness).
   • Task description should read as a flight test card with precise instructions for the evaluation pilot.

7. Desired Performance
   • Bullet list of the desired levels of task performance that can be achieved with appropriate level of pilot compensation (e.g., HQR ≤ 4).
   • List primary task parameters and secondary measures that impact performance.

8. Adequate Performance
   • Bullet list of the adequate levels of task performance that can be achieved with appropriate level of pilot compensation (e.g., 5 ≤ HQR ≤ 6).
   • List primary task parameters and secondary measures that impact performance.

9. Task Variations
   1. Enumerate any variations, if any, in HQTE execution (e.g., flight condition variations, unique entry/exit conditions, etc.).
   2. Specify any variations in required environmental conditions (e.g., visual conditions, steady winds, turbulence, etc.).
   3. Identify failure cases, if any, that will be considered.

C. HQTE Considerations
1. Operational Relevance
   HQTEs should attempt to link to operationally relevant maneuvers, however, it is more important that they consistently expose the handling qualities associated with the Part 23 requirement. Other considerations that outweigh operational relevance include ease of use, repeatability, and ability to effectively expose handling qualities deficiencies, if they exist.
2. **HQTE Build-up**

As certification seekers address HQTEs, a build-up approach will be applied that first introduces single-axis HQTEs. Precision and aggressiveness levels will then be increased. After successful completion of the single-axis MTE set, multi-axis MTEs will be introduced that again build up the precision and aggressiveness levels.

### D. Performance Requirements

The desired and adequate performance requirements of the HQTEs are developed specifically for use with the Cooper-Harper Handling Qualities Rating Scale shown in Figure 4 [5]. The use of Cooper-Harper Handling Qualities Ratings or CHRs requires the definition of numerical values for desired and adequate performance. The performance limits are set primarily to drive the level of aggressiveness and precision to which the maneuver is to be performed. Compliance with the performance standards may be measured subjectively from the cockpit or by the use of chase aircraft or ground observers, if possible. It is not necessary to use complex instrumentation for these measurements. The evaluation pilot should be advised any time the desired or adequate performance limits are not met, immediately following the completion of the HQTE, as the pilot learns the task. Once proficiency in task performance is gained, however, the pilot should assign ratings based on perceived performance. Otherwise, the pilot may inappropriately rate a configuration higher or lower regarding handling qualities solely based on a performance parameter rather than other arguably more important factors such as aircraft characteristics or required compensation. In cases where the performance does not meet the specified limits, it is acceptable for the evaluation pilot to make as many repeat runs as necessary to insure that this is a consistent result. Repeat runs to improve performance may also expose handling qualities deficiencies. Such deficiencies should be an important factor in the assigned pilot rating. For those HQTEs that are by design very short in time (such as attitude captures and landings), at least two or three repeat runs should be encouraged. Desired and adequate CHRs do not in and of themselves equate to compliance and achieving adequate performance does not mean adequate for certification.

![Figure 4: Cooper-Harper handling qualities rating scale [5].](image-url)
For some maneuvers the pilot may find it difficult to perceive actual performance. For example, in an offset landing task a limited field-of-view will restrict the pilot’s ability to see the touchdown zone. Aircraft size, too, can play a part, since the pilot sits far ahead of the main landing gear in a large transport, yet the requirements for touchdown performance are referenced to the gear. In such instances the pilot will frequently comment that better performance is simply not possible, since the target is not visible. The best remedy to this problem requires engineering judgment. If feasible, it is always preferable to find a better way of presenting the performance limits to the pilot. In the case of the landing, additional markers may be placed on or near the runway – located so that they are visible to the pilot – to indicate the correct reference for achieving desired performance. Alternatively, and especially if it is not feasible to increase the pilot’s visual references, the best solution may be to accept minor excursions outside of desired performance. In this case the pilot should be asked to specifically comment on the effects of the visual field – in addition to the handling of the airplane – on achievable performance.

The ultimate goal of the performance limits is to set the expected levels of aggressiveness and precision, and the intent of keeping the pilot informed about actual performance is to assure that occasional exceedances are due to lack of perception of the requirements, not lack of intensity on the part of the evaluation pilot. When assigning a rating, the pilot should begin at the bottom of the decision tree. From here, the pilot moves up through the question boxes until a “no” response or the last box is reached. Next, the pilot moves to the right and a rating is then assigned based on perceived performance and workload. It is important to remember that desired performance can still result in a Level 2 rating, if moderate compensation was required. Conversely, a configuration should not be down rated by an occasional exceedance of a performance requirement. In these cases, pilot comments should always accompany the numerical rating to provide the additional insight that may otherwise be missed.

V. Evaluating HQTEs

A. Piloted Simulation

1. Aircraft Model

It is critical to have a test aircraft model for HQTE development that can easily reflect a wide range of handling qualities from Level 1 in terms of the Cooper-Harper scale to Level 3. Furthermore, an aircraft model that is known to have good handling qualities, based on predictions from validated criteria, e.g. [1], and/or prior flight experience, is also required for the evaluation process. As one moves from piloted simulation to flight test evaluations, variable stability in flight simulators (e.g., Calspan Learjets, USAF VISTA, NRC Canada Bell 205 and 412 testbeds, and the VSS Navions) provide an effective means to develop and evaluate HQTEs.

2. Revisions

As the HQTE develops and is evaluated in the simulator using feedback from experienced test pilots, revisions to the task description including visual display requirements, task performance requirements, and task variations are expected. Pilot comments, ratings, and formal pilot questionnaire results should be used as part of the HQTE evaluation process. To the extent possible, feedback from multiple evaluation pilots should be considered as part of the HQTE revision process.

3. Predicted Handling Qualities

Given an accepted HQTE description, evaluations conducted in a piloted simulation can be used to predict handling qualities.

4. Flight Conditions and Aircraft States Including Failure Conditions

There is typically no mention in the HQTE definition of applicable flight conditions, aircraft loadings (configurations), or aircraft States. These maneuvers are intended to be applicable throughout the Operational Flight Envelope of the airplane under consideration, while operating in its normal configurations. The maneuvers should be performed at those Normal States within the Operational Flight Envelope that are most critical from the standpoint of handling qualities. Aircraft performance is not meant to be an issue, and the flight conditions should be selected accordingly. It will, however, be necessary to demonstrate compliance with the Part 23 regulations under failure conditions. To ensure safety, these assessments may be made via piloted simulation.

B. Flight Test

1. Revisions

Once an MTE has evolved via piloted simulation, revisions to the task description including visual aids, task performance requirements, and task variations are expected as the MTE is attempted in flight. Pilot comments, ratings, and formal pilot questionnaire results should be used as part of the MTE flight test evaluation process. To the extent possible, feedback from multiple evaluation pilots should be considered as part of the MTE revision process.
2. Verified Handling Qualities

Given an accepted HQTE description, evaluations conducted in a flight are used to verify handling qualities thereby serving as a demonstrated means of compliance for Part 23 requirements. This will represent a partial fulfillment of requirements as other compliance measures will also be considered.

C. Pilot Questionnaire for HQTE Evaluations

Pilot questionnaires have been effectively used as part of the HQTE evaluation process. This includes the fixed wing handling qualities demonstration maneuvers work conducted in the mid 1990’s [3]. More recently, pilot questionnaires were used to effectively evaluate HQTEs that were developed for high speed rotorcraft evaluations [10, 11, 12, and 13]. The questionnaire shown in Figure 5 has been revised slightly for the Part 23 means of compliance application.

<table>
<thead>
<tr>
<th></th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree Nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>The HQTE is linked to an operational relevant task.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The HQTE is well defined.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The HQTE is repeatable and easy to fly.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Entry/exit conditions for the HQTE were easy to establish.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The display used for the HQTE provided all the information required for performing it.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The HQTE provides a valid medium for handling qualities evaluations.</td>
<td>○</td>
<td>○</td>
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</tr>
<tr>
<td>The HQTE provides a valid medium for PIO evaluations.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>The HQTE is able to effectively expose the aircraft characteristics associated with the linked Part 23 requirements.</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

What changes would you recommend to the HQTE description and the desired and adequate performance requirements (e.g., cockpit displays, course layout, out-of-the-window cues, etc.)?

Comment on the factors other than the task that affected your ratings (e.g., aircraft characteristics, control force/displacements, cockpit displays, etc.).

Figure 5: Example HQTE assessment pilot questionnaire.

D. Apply HQTEs Early in the Design Process

In an ideal world, time and money would not influence the development of new aircraft. Unfortunately, in the real world, scheduling and costs drive the development process. As a result, some items including handling qualities often receive lower priority and may not be addressed until a problem arises. On the other hand, aircraft model development including ground-based simulation begins early in the design process. Thus, one way to rectify the lack of attention paid to handling qualities is to employ HQTEs early in the development process. Common head-down or head-up displays are sufficient to exercise many of the maneuvers, so elaborate displays are usualy not necessary. The process can begin with engineering workstations that use simple joystick type controls.

There are many benefits to this approach:
- Potential handling qualities problems may be identified early in the design process;
• HQTEs will provide repeatable evaluation techniques that can be applied to multiple configurations;
• Program test pilots will become more comfortable with the maneuvers heading into actual flight tests;
• HQTEs tend to expose flight control system discontinuities as well as poor response type transitions or even inadequate mode annunciations that could lead to mode confusion; and
• Valuable flight time will not have to be spent developing a pilot’s learning curve.

The above benefits may also turn out to also be a significant cost saver.

E. Use Other Appropriate Rating Scales

In addition to Cooper-Harper ratings, additional ratings using other relevant scales may be collected to provide further insights into a given HQTE evaluation. The most significant of these is the Pilot-Induced Oscillation Rating (PIOR) Scale shown in Figure 6. Although not specifically designed to expose PIO tendencies, many of the precision HQTEs (e.g., attitude captures and fine tracking maneuvers) often reveal the handling qualities “cliffs” that can lead to PIO. Two scales are combined in Figure 2, one is a decision tree scale [14] and the other is the original “word” scale [15]. The decision tree should be applied by the pilot in a manner similar to that discussed for the Cooper-Harper scale. The additional dialog in the word scale, however, must be considered prior to assigning a rating. This will help the pilot distinguish between undesirable motions such as “pitch bobble” and oscillations (i.e., ~180° out-of-phase vehicle response to pilot control inputs as defined in [16]). Configurations are often rated too harshly when the decision tree scale alone is used to assign ratings.

Figure 6: Pilot-Induced Oscillation tendency rating scale [14 and 15].

VI. Example HQTE

A. Overview

In this section, a description of an example HQTE, Lateral Reposition and Hold, is provided. This HQTE is designed to be representative of the emerging Urban Air Mobility marketplace mission that is tailored to evaluate vehicle characteristics such that the following are ensured:

• Safe operations within the flight envelope; and
• The ability to perform the intended mission(s) with acceptable pilot workload/compensation.
The HQTEs under development, including this example, are heavily influenced by the Mission Task Elements (MTEs) that are defined in the military rotorcraft design standard, ADS-33E-PRF [1], which are a tested and proven way to assess rotorcraft handling qualities. Thus, the emerging HQTEs, including the Lateral Reposition and Hold, are closely related to the ADS-33E-PRF MTEs, however, they have been reimagined and tailored to the UAM mission.

B. Lateral Reposition and Hold

The Lateral Reposition and Hold is used to illustrate a complete HQTE description. This MTE was defined to evaluate the lateral axis, mostly in isolation, while still being representative of low speed maneuvering that will be part of vertiport operations. Note that the course layout and performance requirements are still being developed and tested, so it is likely that elements of this description will evolve as a result. In the end, this evolution will result in an improved HQTE for means of compliance testing.

FAR Part 23 Requirement

- Handling qualities requirements apply to:
  - §23.2135 Controllability; and
  - §23.2145 Stability.

Link to Practical Test Standards

The Lateral Reposition and Hold HQTE requirements and performance standards can be linked to several practical test standards (PTSs) [17]. These PTSs include:

- Hovering maneuvers PTSs of FAA-S-8081-16B [18]
  - Hover Task and Air Taxi tasks
  - Hover Task and Air Taxi tasks

Precision and Aggressiveness Level

- Precision/Non-Aggressive

Task Objectives

- Check roll axis and heave axis handling qualities during mild low speed lateral maneuvering.
- Check for any undesirable coupling between the roll controller and other axes.
- Check ability to recover from mild lateral translation rate with reasonable precision.
- Identify pilot-induced oscillation tendencies, if present.

Task Description

Start in a stabilized hover at 20 ft altitude with the longitudinal axis of the aircraft oriented 90 degrees to a ground track reference line marked on the ground. Initiate a lateral acceleration up to a specified groundspeed followed by a deceleration to laterally reposition the aircraft in a stabilized hover 400 ft down the course. The acceleration and deceleration phases shall be accomplished as single smooth maneuvers. The aircraft must be brought to within ±6 ft of the endpoint during the deceleration, terminating in a stable hover within this band. A stabilized hover shall be maintained for 5 seconds and then the maneuver is repeated back in the other direction towards to original starting point, which is again held for 5 seconds. The maneuver is complete when a stabilized hover is achieved back at the maneuver start point.

The test course shall consist of a reference line and markers on the ground indicating the desired track and tolerances. It is recommended that the test course also include Hover Boards at each stabilization point. These Hover Boards provide lateral position and vertical performance cues to the pilot when attempting to stabilize at the endpoints of the course. A suggested course for the Lateral Reposition and Hold HQTE is shown in Figure 7.
Desired Performance

- Maintain the longitudinal position track within ±6 ft from reference line.
- Maintain altitude within ±5 ft.
- Maintain heading within ±10 deg.
- There shall be no undesirable motions in the lateral axis during the capture or hold.

Figure 7: Suggested course for Lateral Reposition and Hold HQTE.
Adequate Performance

- Maintain the longitudinal position track within ±12 ft from reference line.
- Maintain altitude within ±10 ft.
- Maintain heading within ±15 deg.
- There shall be no objectionable oscillations in the lateral axis during the capture or hold.

Task Variations

- In addition to calm winds, the Lateral Reposition and Hold HQTE may be performed in moderate wind conditions in the most critical direction for the test aircraft. If a critical direction has not been defined, the hover will be accomplished with the wind blowing directly from the rear of the rotorcraft.
- The maneuver may be performed at multiple translational rate rates, starting at 5 knots and up to 20 knots.
- The maneuver may be flown at higher stabilized altitudes to assess out-of-ground effect performance.

VII. Conclusions

This paper introduced a new handling qualities certification process used in part for means of compliance that is designed to address the emerging markets for personal air vehicles and urban air taxis. The testing process for civilian vehicles has evolved from the successful mission-oriented approach that has been a staple of military rotorcraft handling qualities testing for decades. A key element of this approach is the introduction of mission task elements, redefined here as handling qualities test elements (HQTEs), that ultimately become part of the means of compliance with Federal Aviation Administration Part 23 regulations. HQTEs are defined based on levels of precision and aggressiveness required that naturally allow for a build-up test approach from non-precision, non-aggressive to precision, aggressive HQTEs. Furthermore, the HQTEs are defined with desired and adequate performance requirements that facilitate direct use of the Cooper-Harper handling qualities rating scale, noting that achieving adequate performance does not equate with adequate for certification. This will allow for greater discernment of handling qualities than can be achieved via a simple pass/fail assessment. Finally, this paper defines a representative HQTE, Lateral Reposition and Hold. It is anticipated that the description of this HQTE and others under development will evolve as they are exercised via piloted simulation and ultimately flight test.

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