June 19, 2020

Mr. Brandon Roberts
Office of Rulemaking
Acting Designated Federal Official, Aviation Rulemaking Advisory Committee
Federal Aviation Administration
800 Independence Avenue, SW
Washington, DC 20591

RE: Flight Test Harmonization Working Group; Topic 15 Final Recommendation Report

Dear Mr. Roberts,

On June 18, 2020, the Aviation Rulemaking Advisory Committee (ARAC) voted unanimously to accept the Final Recommendation Report submitted by the Flight Test Harmonization Working Group (FTHWG) on Topic 15 – Pilot Induced Oscillations.

On behalf of the ARAC members, please accept the FTHWG Final Recommendation Report and submit to the relevant program offices for consideration and implementation.

Please do not hesitate to contact me with any questions. Thank you very much.

Sincerely yours,

Yvette A. Rose
ARAC Chair
202.293.1032
yrose@cargoair.org

cc: Keith Morgan, TAE Chair
Brian Lee, Boeing, Working Group Co-Chair

FAA Aviation Rulemaking Advisory Committee

FTHWG Topic 15
Pilot-Induced Oscillations

Recommendation Report
May, 2020

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Executive Summary

14CFR25.143(a), (b), and (k) require that transport airplanes be safely controllable and maneuverable in normal operations in each flight phase, between flight phases, and in icing conditions (if applicable). In the 1990's, considerable research was conducted by NASA, the US military, and by industry to identify and understand a phenomenon referred to as "Pilot Induced Oscillations" (PIO). This is a rare, unintended deviation in aircraft attitude or flight path caused by anomalous interactions between the pilot and the airplane.

As airplanes get larger, and structures are refined, low frequency structural dynamic modes can appear which, when the pilot is merely holding the controller, generate unintended, involuntary control motions coupled with the structural motion.

Both of these phenomena can potentially interfere with the pilot's ability to fly the airplane precisely, and therefore may not meet the intent of relevant paragraphs of §25.143. Note also that there are other airplane characteristics which would not meet 14CFR25.143(a), (b), and (k), but the focus of this task is on the two phenomena mentioned here.

In the late 1990's the FAA inserted draft guidance material into AC 25-7A. This material was not well accepted by industry and not harmonized across other authorities. As a result, most Part 25 transport airplanes since, particularly those with fly-by-wire flight control systems, have been certified with regard to PIO characteristics via issue papers identifying an alternate means of compliance.

ARAC has tasked the Flight Test Harmonization Working Group (FTHWG) with harmonizing means of compliance guidance which will be accepted universally.

The FTHWG believes the requirements as already contained in §25.143(a), (b), and (k) are appropriate. Through extensive deliberation, the FTHWG has generated harmonized guidance material recommended in this report. It is recommended that this guidance material be incorporated in AC 25-7. It is further recommended that the other authorities similarly adopt this harmonized guidance.

Background

In the late 1990's FAA published guidance in AC 25-7 (for 25-7A) intended to determine the Pilot Induced Oscillation (PIO) susceptibility of the airplane and whether it was satisfactory for compliance with §25.143(a), (b). This guidance material was not well accepted by airplane manufacturers. Further, it was not harmonized with European Authorities (JAA). At the time, FAA agreed to consider that material as a "placeholder" until further harmonization could be undertaken. In the interim, most new transport airplanes were certificated using a Means of Compliance issue paper, particularly airplanes with fly-by-wire flight control systems.

In the early 2000's, the then JAA undertook to construct a new European Flight Test Guide. FAA appropriately took that opportunity to harmonize as much as possible the content of AC 25-7 with the proposed JAA guide, NPA 25B-335 including provisions for evaluating PIO. Many Flight Working Papers were produced and much discussion took place. In the end, the PIO issue was not harmonized, because of lack of agreement on the evaluation mechanism: FAA advocating for their Handling Qualities Rating Method (HQRM), which JAA would not accept.

The Flight Test Harmonization Working Group has once again undertaken to harmonize the means of compliance for the PIO evaluations in compliance to §25.143(a), (b), and (k) (subparagraph (k) coming from the FTHWG Phase 2 recommendations on side stick controllers). Knowing that harmonizing the methods referred to by FAA as HQRM had been tasked to the FTHWG, the FTHWG was able to reach consensus on a means of compliance which would both simplify and standardize the methods for evaluating an airplane's susceptibility to PIO.

In addition, the FTHWG recognized that larger airplanes with lower-frequency structural modes might be susceptible to a coupling between the pilot and the aircraft structure to an extent which could interfere with the pilot's ability to precisely fly the airplane. The working group adopted the name Bio-Dynamic Coupling (after a NASA description) for this phenomenon, and agreed to include appropriate evaluations as well.

What is the underlying safety issue addressed by the FAA CFR / EASA CS?

Some inherent characteristics of modern transport category airplanes are also identified as potential sources for adverse pilot-in-the-loop characteristics which could interfere with pilots' control of the airplane. These are identified in two frequency regions. At airplane rigid-body dynamic frequencies, the pilot may get out-of-phase with the airplane while attempting to control the attitude or flight path. This is identified as a Pilot Induced Oscillation (PIO). At higher frequencies, usually associated with structural dynamic response of large airplanes, the pilot may generate inadvertent control inputs as a result of simply holding on to the controller. This is what is referred to as Bio-Dynamic Coupling (BDC). If the responses are large enough to interfere with controlling the airplane, neither would be compliant with the provisions of §25.143(a), (b), and (k).

A. What is the task?

The FTHWG was tasked to recommend changes to guidance provided in AC 25-7D to both simplify and standardize the methods for evaluating an airplane's susceptibility to PIO/BDC.

B. Why is this task needed?

Guidance provided in AC 25-7D for evaluation of PIO is not well accepted by airplane manufacturers, is not harmonized with EASA, and has been superseded to some extent in recent certification programs via Issue Paper.

C. Who has worked the task?

The FTHWG, during Phase 3 activities, has worked the task. Six face–to-face meetings and fifteen telecons along with numerous e-mail and phone conversations were dedicated to this topic.

Participants in this FTHWG task included:

Airframe Manufacturers:
Airbus, Boeing, Bombardier, Dassault, Embraer, Gulfstream and Textron

Airworthiness Authorities:
FAA, EASA, TCCA, ANAC (CAAI and JCAB as observers)

Operators:
Norwegian Airlines (as an observer)

Labor Union:
ALPA

D. Any relation with other topics?

Topic 7 (Side Stick Controls) and Topic 18 (Go-Around Handling Qualities & Performance) each modified §25.143, to which the PIO susceptibility guidance material applies. While Topic 1 (Envelope Protection) and Topic 7 (Side Stick Controls) resulted in some minor editorial changes to the relevant advisory material, those changes are not particularly germane to the topics of PIO or BDC. Beyond those, this proposed guidance is stand-alone.

Historical Information

A. What are the current regulatory and guidance material in CS-25 and FAR 25?

Regulatory Material

The relevant material in 14CFR25 resides in paragraph §25.143 (a), (b), and (k) (Subparagraph (k) was added by Topic 7, Side Stick Controls, from Phase 2.) This regulatory material does not specifically call out the phenomenon of Pilot Induced Oscillations. While the proposal from Topic 7, Side Stick Controls, from Phase 2 makes reference to “unsuitable pilot-in-the-loop control characteristics, there is general agreement, both from previous guidance material and among the members of the working group that the presence of significant PIO tendencies would not meet the intent of requirements of §25.143(a), (b), and (k).

The pertinent paragraphs of 14CFR25.143(a), (b), and (k) are:

Sec. 25.143 General.[1]
(a) The airplane must be safely controllable and manoeuvrable during:
(1) ~~T~~take-off;
(2) ~~C~~climb;
(3) ~~L~~level flight;

[1] Orange text here indicates mark-up proposed in Topic 18 Go-Around HQ & Performance, in order to harmonize with the EASA CS at Amendment 21.

(4) ~~D~~descent; ~~and~~
(5) ~~Landing~~ approach and go-around; and~~.~~
(6) approach and landing.

(b) It must be possible to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the airplane limit-load factor under any probable operating conditions, including: –

(1) The sudden failure of the critical engine~~.~~;
(2) For airplanes with three or more engines, the sudden failure of the second critical engine when the airplane is in the en route, approach, or landing configuration and is trimmed with the critical engine inoperative; ~~and~~
(3) Configuration changes, including deployment or retraction of deceleration devices~~.~~; and
(4) Go-around maneuvers with all engines operating. The assessment must include, in addition to controllability and maneuverability aspects, the flight crew workload and the risk of somatogravic illusion

(…)

(k) It must be shown that unsuitable pilot-in-the-loop control characteristics are not encountered when considering precision path control tasks and turbulence. In addition, pitch and roll control force sensitivity and displacement sensitivity must be compatible, so that normal inputs on one control axis will not cause significant unintentional inputs on the other.[2]

Applicable EASA regulations, given in CS-25 at Amendment 24 are:

CS 25.143 General
(See AMC 25.143)
(a) (See AMC 25.143(a) and (b)) The aeroplane must be safely controllable and manoeuvrable during:

(1) take-off;
(2) climb;
(3) level flight;
(4) descent;
(5) approach and go-around; and
(6) approach and landing.

(b) (See AMC 25.143(b) and (b)) It must be possible to make a smooth transition from one flight condition to any other flight condition without exceptional piloting skill, alertness, or strength, and without danger of exceeding the aeroplane limit-load factor under any probable operating conditions, including:

(1) The sudden failure of the critical engine; (See AMC 25.143(b)(1))
(2) For aeroplanes with three or more engines, the sudden failure of the second critical engine when the aeroplane is in the en-route, approach, go-around, or landing configuration and is trimmed with the critical engine inoperative;
(3) Configuration changes, including deployment or retraction of deceleration devices; and
(4) Go-around manoeuvres with all engines operating. The assessment must include, in addition to controllability and manoeuvrability aspects, the flight crew workload and the risk of a somatogravic illusion. (See AMC 25.143(b)(4))

(…)
(k) It must be shown that unsuitable pilot-in-the-loop control characteristics are not encountered when considering precision path control tasks and turbulence. In addition, pitch and roll control force

[2] Red text here indicates proposed wording from Phase 2 recommendation report.

sensitivity and displacement sensitivity must be compatible, so that normal inputs on one control axis will not cause significant unintentional inputs on the other.

Guidance Material

Current guidance for evaluation of PIO characteristics originated from a Special Certification Review and was inserted in draft AC 25-7A, released for public comment in early 1996, and published in March, 1998. The material is contained in paragraph 5.1.4 of AC 25-7D and is as follows:

5.1.4 Pilot Induced Oscillations (PIO).
5.1.4.1 Explanation.

5.1.4.1.1 Section 25.143(a) and (b) require that the airplane be safely controllable and maneuverable without exceptional piloting skill and without danger of exceeding the airplane limiting load factor under any probable operating conditions. Service history events have indicated that modern transport category airplanes can be susceptible to airplane-pilot coupling under certain operating conditions and would not meet the intent of this requirement.

5.1.4.1.2 The classic PIO is considered to occur when an airplane's response is approximately 180° out of phase with the pilot's control input. However, PIO events with 180° phase relationships are not the only conditions in which the airplane may exhibit closed-loop (pilot-in-the-loop) characteristics that are unacceptable for operation within the normal, operational, or limit flight envelopes. Others include unpredictability of the airplane's response to the pilot's control input. This may be due to nonlinearities in the control system, actuator rate or position limiting not sensed by the pilot through the flight controls, or changing pitch response at high altitude as the airplane maneuvers into and out of Mach buffet. Artificial trim and feel systems which produce controllers with too small a displacement and light force gradients may also lead to severe over control. This is especially true in a dynamic environment of high altitude turbulence or upsets in which the autopilot disconnects. This places the airplane in the hands of the unsuspecting pilot in conditions of only a small g or airspeed margin to buffet onset and with very low aerodynamic damping. These characteristics, while not a classic 180° out of phase PIO per se, may be hazardous and should be considered under the more general description of airplane-pilot coupling tendencies.

5.1.4.1.3 Some of the PIO tendency characteristics described in paragraph 5.1.4.1.2 above are attributes of transport airplanes (e.g., low frequency short period, large response lags) that are recognized by part 25. Limits are placed on some of these individual attributes by part 25 (e.g., stick force per g, heavily damped short period) to assure satisfactory open-loop characteristics. However, service reports from recent years have indicated that certain operating envelope conditions, combined with triggering events, can result in airplane-pilot coupling incidents. Some of the conditions that have led to these PIOs include fuel management systems that permit extended operations with a CG at or near the aft limit, operating at weight/speed/altitude conditions that result in reduced margins to buffet onset combined with tracking tasks such as not exceeding speed limitations and severe buffet due to load factor following an upset, and control surface rate or position limiting.

5.1.4.1.4 This service experience has shown that compliance with only the quantitative, open-loop (pilot-out-of-the loop) requirements does not guarantee that the required levels of flying qualities are achieved. Therefore, in order to ensure that the airplane has achieved the flying qualities required by § 25.143(a) and (b), the airplane should be evaluated by test pilots conducting high-gain (wide-bandwidth), closed-loop tasks to determine that the potential of encountering adverse PIO tendencies is minimal.

5.1.4.1.5 For the most part, these tasks should be performed in actual flight. However, for conditions that are considered too dangerous to attempt in actual flight (i.e., certain flight conditions outside of the operational flight envelope, flight in severe atmospheric disturbances, flight with certain failure states, etc.), the closed loop evaluation tasks may be performed using a motion base high fidelity simulator if it can be validated for the flight conditions of interest.

5.1.4.2 Special Considerations.
5.1.4.2.1 The certification team should understand the flight control system and airplane design.

5.1.4.2.2 The applicant should explain why the design is not conducive to a PIO problem and how this is to be shown in both developmental and certification flight tests.

5.1.4.2.3 The applicant should explain what has been done during the development flight test experience and any design changes that were required for PIO problems.

5.1.4.2.4 The certification flight test program should be tailored to the specific airplane design and to evaluate the airplane in conditions that were found to be critical during its development program and PIO analytical assessment.

5.1.4.2.5 The FAA flight test pilots should also continuously evaluate the airplane for PIO tendencies during the certification program in both the airplane and simulator. This evaluation should include both normal and malfunction states; all certification flight test points; transitions between and recoveries from these flight test points; and normal, crosswind, and offset landing task evaluations.

5.1.4.2.6 Since the evaluation of flying qualities under § 25.143(a) and (b) is basically qualitative, especially evaluations of PIO susceptibility, the high-gain tasks discussed herein should be accomplished by at least three test pilots. Use of other pilots can provide additional insights into the airplane handling qualities, but for the purpose of demonstrating compliance with this requirement the evaluation pilots should be trained test pilots.

5.1.4.3 **Procedures: Flight Test.**

5.1.4.3.1 Evaluation of the actual task performance achieved, e.g., flight technical error, is not recommended as a measure of proof of compliance. Only the pilot's rating of the PIO characteristics is needed as described in paragraph 5.1.4.6. The tasks are used only to increase the pilot's gain, which is a prerequisite for exposing PIO tendencies. Although task performance is not used as proof of compliance, task performance should be recorded and analyzed to insure that all pilots seem to be attempting to achieve the same level of performance.

5.1.4.3.2 Tasks for a specific certification project should be based on operational situations, flight testing maneuvers, or service difficulties that have produced PIO events. Task requirements for a specific project will be dictated by the particular airplane and its specific areas of interest as determined by the tailored flight test program mentioned above. Some of these include high altitude upset maneuvers, encounters with turbulence at high altitude in which the autopilot disconnects, crosswind/crossed control landings with and without one engine inoperative, and offset landings to simulate the operational case in which the airplane breaks out of instrument meteorological conditions (IMC) offset from the glideslope and/or localizer beam and the pilot makes a rapid alignment correction. Tests should be conducted at or near the critical altitude/weight/CG combinations.

5.1.4.3.3 Tasks described here may be useful in any given evaluation and have proven to be operationally significant in the past. It is not intended that these are the only tasks that may be used or may be required depending on the scope and focus of the individual evaluation being conducted. Other tasks may be developed and used as appropriate. For example, some manufacturers have used formation tracking tasks successfully in the investigation of these tendencies. For all selected tasks, a build-up approach should be used and all end points should be approached with caution. Capture tasks and fine tracking tasks share many common characteristics but serve to highlight different aspects of any PIO problem areas that may exist. In some cases, depending on individual airplane characteristics, it may be prudent to look at capture tasks first and then proceed to fine tracking tasks or combined gross acquisition (capture) and fine tracking tasks as appropriate.

5.1.4.4 Capture Tasks.

5.1.4.4.1 Capture tasks are intended to evaluate handling qualities for gross acquisition as opposed to continuous tracking. A wide variety of captures can be done provided the necessary cues are available to the pilot. Pitch attitude, bank angle, heading, flight path angle, angle-of-attack, and g captures can be done to evaluate different aspects of the airplane response. These capture tasks can give the pilot a general impression of the handling qualities of the airplane, but because they do not involve closed-loop fine tracking, they do not expose all of the problems that may arise in fine tracking tasks. Capture tasks should not be used as the only evaluation tasks.

5.1.4.4.2 For pitch captures, the airplane is trimmed for a specified flight condition. The pilot aggressively captures 5° pitch attitude (or 10° if the airplane is already trimmed above 5°). The pilot then makes a series of aggressive pitch captures of 5° increments in both directions, and then continues this procedure with 10° increments in both directions. An airplane with more capability can continue the procedure with larger pitch excursions. If possible, the initial conditions for each maneuver should be such that the airplane will remain within ±1,000 feet and ±10 knots of the specified flight condition during the maneuver; however, large angle captures at high-speed conditions will inevitably produce larger speed and altitude changes. If the airplane should get too far from the specified condition during a task, it should be re-trimmed for the specified condition before starting the next maneuver.

5.1.4.4.3 The other kinds of captures are usually done in a similar manner, with some minor differences. G captures can be done from a constant-g turn or pull ups and pushovers using ±0.2 g and ±0.5 g. Heading captures can be used to evaluate the yaw controller alone (usually small heading changes of 5° or less).

5.1.4.4.4 Bank angle captures are also commonly done using bank-to-bank rolls. Starting from a 15° bank angle, the pilot aggressively rolls and captures the opposite 15° bank angle (total bank angle change of 30°). The pilot then rolls back and captures 15° bank in the original direction. This procedure should continue for a few cycles. The procedure is then repeated using 30° bank angles, and then repeated again using 45° bank angles. A variation of this is to capture wings-level from the initial bank condition.

5.1.4.4.5 Where suitable, combined conditions could be used as described in the task shown in paragraph 5.1.4.4.6 below, in which a target g and bank angle are tightly tracked until the target pitch attitude and heading are captured.

5.1.4.4.6 The following upset and/or collision avoidance maneuvers have been found to be effective in evaluating PIO susceptibility when the airplane is flying at high altitude under conditions of low g to buffet onset, typically 0.3 g. This emphasis on cruise susceptibility stems from operational experiences, but should not be interpreted as placing less emphasis on other flight phases.

1. Trim for level flight at long range cruise Mach number. Initiate a slight climb and slow the aircraft while leaving power/thrust set. Push the nose over and set up a descending turn with 30° to 40° of bank and approximately 10° nose below the horizon, or as appropriate, to accelerate to the initial trim speed. At the initial trim airspeed initiate a 1.5 g to 1.67 g (not to exceed deterrent buffet) pull up and establish a turn in the opposite direction to a heading which will intercept the initial course on which the airplane was

trimmed. Establish a pitch attitude which will provide a stabilized climb back to the initial trim altitude. The pilot may use the throttles as desired during this maneuver and should pick a target g, bank angle, heading, and pitch attitude to be used prior to starting the maneuver. The target g and bank angle should be set and tightly tracked until the target pitch attitude and heading are obtained respectively. The stabilized steady heading climb should be tightly tracked for an adequate amount of time to allow the pilot to assess handling qualities, even through the initial trim altitude and course if required. The pilot should qualitatively evaluate the airplane during both the gross acquisition and fine tracking portions of this task while looking for any tendency towards PIO in accordance with the criteria in paragraph 5.1.4.6.

2. This maneuver should be repeated in the nose-down direction by accelerating to M_{MO} from the trim condition 10° nose down and then recover as above.

3. Trim for level flight as above. Initiate a 1.5 g to 1.67 g (not to exceed deterrent buffet) pull-up and approximately a 30° bank turn. Once the target g is set, transition the aircraft to approximately a 0.5 g pushover and reverse the turn to establish an intercept heading to the initial course. Using power or thrust as required, set up a stabilized steady heading descent to intercept the initial course and altitude used for the trimmed condition. The pilot may continue the heading and descent through the initial conditions to allow more tracking time if needed. Attempt to precisely set and track bank angle, g, heading, and pitch attitude as appropriate. The pilot should qualitatively evaluate the airplane during both the gross acquisition and fine tracking portions of this task while looking for a PIO tendency in accordance with paragraph 5.1.4.6.

5.1.4.5 Fine Tracking Tasks.

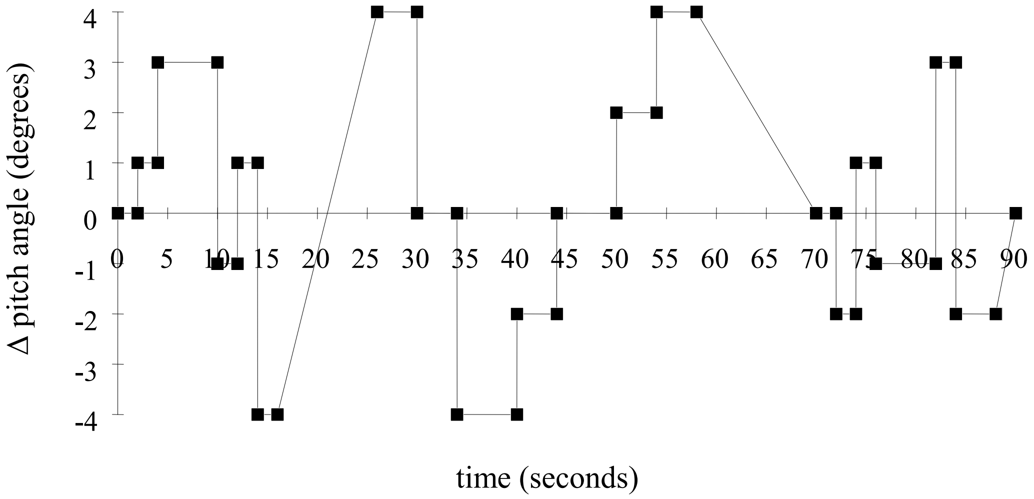
5.1.4.5.1 These tasks may be used to assess the airplane's PIO susceptibility when flying in turbulent atmospheric conditions. In this task, a tracking target is displayed which commands pitch and roll changes for the evaluation pilot to follow. Whatever visual cue is used (e.g., head up display (HUD), flight director, etc.), it should present the tracking task without filtering, smoothing, or bias. The pitch and roll commands should be combinations of steps and ramps. The sequence of pitch and roll commands should be designed so as to keep the airplane within ±1,000 feet of the test altitude and within ±10 knots of the test airspeed. The sequence should be long enough and complex enough that the pilot cannot learn to anticipate the commands. The unfamiliarity is intended to help keep the test pilot's gain high and to preclude inadvertent pilot compensation while accomplishing the task. Such compensation, along with reduced gains, could mask any PIO tendencies.

5.1.4.5.2 Even though these fine tracking tasks will provide insight into PIO susceptibility of a conventional airplane when flying in turbulence, other considerations apply to augmented airplane types. For example, structural load alleviation systems that use the same flight control surface as the pilot will limit the pilot's control authority in turbulent atmospheric conditions. Under these circumstances of rate or position limiting, PIO tendencies will be more critical as previously discussed. Therefore, specific evaluations for turbulent atmospheric conditions with these systems operating are necessary for these airplane types.

5.1.4.5.3 For single axis tasks, it has been found that aural commands given in a timed sequence provide an adequate cue in the event it is not possible to modify the flight director to display the pitch commands.

5.1.4.5.4 Based on PIO events seen in service, high altitude tracking tasks (with up to approximately ±4° pitch excursions from trim occurring at varying intervals of approximately 2 to 5 seconds) have been effective in evaluating PIO susceptibility. These tasks have been used where the airplane is flying under conditions of low g margin to buffet onset. The time history in figure 5-1 below is a pictorial representation of a sample task in MIL-STD-1797A that has the desired attributes for high altitude PIO evaluations.

Figure 5-1. Sample Pitch Tracking Task



5.1.4.6 PIO Assessment Criteria.

5.1.4.6.1 The evaluation of an airplane for PIO susceptibility will be conducted using the FAA handling qualities rating method (HQRM). (See appendix E of this AC for more information on the HQRM). Tasks should be designed to focus on any PIO tendencies that may exist. Table 5-1 below contains the descriptive material associated with PIO characteristics and its relationship to the PIO Rating Scale called out in the U.S. Military Standard.

Table 5.1 PIO Rating Criteria and Comparison to MIL Standard

FAA HQ Rating	PIO Characteristics Description	MIL-STD-1797A PIO Rating Scale
SAT	No tendency for pilot to induce undesired motion.	1
	Undesirable motions (overshoots) *tend to occur* when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique. (*No more than minimal pilot compensation is required*.)	2
ADQ	Undesirable motions (unpredictability or over control) easily *induced* when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort. (*No more than extensive pilot compensation is required*.)	3
CON	*Oscillations tend to develop* when pilot initiates abrupt maneuvers or attempts tight control. Adequate performance is not attainable and pilot has to reduce gain to recover. (Pilot can recover by merely reducing gain.)	4
UNSAT	*Divergent oscillations* tend to develop when pilot initiates *abrupt maneuvers* or attempts tight control. Pilot has to open control loop by releasing or freezing the controller.)	5

	Disturbance or *normal pilot control* may cause divergent oscillation. Pilot has to open control loop by releasing or freezing the controller.	6

SAT= Satisfactory CON = Controllable
ADQ = Adequate UNSAT = Unsatisfactory or Failed

5.1.4.6.2 Table 5-1 above provides the FAA handling qualities (HQ) rating descriptions of airplane motions that may be seen during the conduct of specific PIO tasks or during tests throughout the entire certification flight test program. The italicized phrases highlight major differences between rating categories in the table.

5.1.4.6.3 The acceptable HQ ratings for PIO tendencies is shown in Table E-2 of appendix E. As described in that appendix, the minimum HQ rating, and consequently the pass/fail criteria, varies with flight envelope, atmospheric disturbance considered, and failure state. For example, Table 5-2 below shows a handling qualities matrix for a tracking task with the airplane at aft CG trimmed in flight conditions giving 1.3 g to buffet onset.

Table 5.2 Example of acceptable HQ Rating for PIO tendencies

Airspeed	M_{LRC}	M_{LRC}	M_{LRC}	M_{LRC}
Load Factor Range	0.8 to 1.3	-1.0 to 2.5	0.8 to 1.3	-1.0 to 2.5
Buffet Level	Onset	Deterrent	Onset	Deterrent
Turbulence	Light	Light	Light	Light
Failure	None	None	Improbable failure of SAS	Improbable failure of SAS
Flight Envelope	NFE	LFE	NFE	LFE
Minimum Permitted HQ Rating	SAT	ADQ	ADQ	CON

SAT = Satisfactory ADQ = Adequate CON = Controllable

NFE = Normal Flight Envelope LFE = Limit Flight Envelope

SAS = Stability augmentation System LRC = Long range cruise Mach number

The guidance material, expressed in EASA CS 25 Book 2 includes

AMC 25.143(a) and (b)
Controllability and Manoeuvrability
In showing compliance with the requirements of CS 25.143(a) and (b) account should be taken of aeroelastic effects and structural dynamics (including aeroplane response to rough runways and water waves) which may influence the aeroplane handling qualities in flight and on the surface. The oscillation characteristics of the flightdeck, in likely atmospheric conditions, should be such that there is no reduction in ability to control and manoeuvre the aeroplane safely.

B. What, if any, are the differences in the existing regulatory & guidance material CS 25/FAR 25?

Regulatory Material

The existing regulatory wording, as modified by proposals in Topic 7, Side Stick Controls, and Topic 18, Go-Around Handling Qualities & Performance, is identical regarding PIO. The operative words are "safely controllable and maneuverable", "smooth transitions", and "unsuitable pilot-in-the-loop control characteristics".

Guidance Material

While the AC 25-7D guidance contains extensive (but not used) guidance for evaluating PIO, EASA has no comparable guidance material.

On the other hand, the EASA guidance contains wording specific to structural dynamic response and its influence on piloting, while the AC 25-7 does not include this content.

C. What are the existing CRIs/IPs (SC and MoC)?

Most OEM's have been issued Means-of-Compliance IP's and CRI's for evaluation of PIO. These documents are in general not available to the public. Nevertheless, during deliberations, the working group members shared at least one IP, with each other OEM's reading along in their own. The conclusion was that while each differed in small details, they were more similar on content than different.

D. What, if any, are the differences in the Special Conditions (CRIs/IPs) (SC and MoC) and what do these differences result in?

During deliberations, the working group reached the conclusion that while there were differences between their individual CRIs/IPs, the differences probably resulted from specific tailoring to a given airframe/project or from new knowledge gained from past programs. These differences provided significant technical discussion material in the process of generating more generic guidance for acceptable MOC.

Consensus

Discussion

In its deliberations, the FTHWG considered a great many elements and aspects of these phenomena. Through the course of these detailed technical discussions, as consensus was reached, it was felt important to communicate some of the thought processes leading to the recommendations provided.

- PIO vs BDC

Unlike PIO, which is a relatively rare phenomenon, Bio-Dynamic Coupling is relatively easy to incite, if it is going to be present. In fact, the current AMC material provides guidance on just which specific conditions to consider (e.g. rough runways, rough water). As a result, the working group believes a much larger emphasis should be placed on demonstrating lack of PIO tendencies.

- Mechanical Systems Characteristics

The structure of the controllability requirement in both 14CFR25 and the CS25 is that the whole, integrated airplane should be free of undesirable characteristics which interfere with safe control and maneuverability. The working group recognized that such a result represents an integration of many parts, systems, and dynamic characteristics. With the exception of §25.671 which refers to smoothness and positiveness of control, there are no other requirements on the mechanical characteristics of the control system. The working group thought it useful to include a short description in the guidance which includes industry experience that some of these characteristics could contribute to adverse handling qualities not meeting the requirements, even if not characterized as a PIO as per this proposed guidance. In addition, some of these characteristics could contribute to PIO tendencies. This description is not intended to constitute means of compliance, rather only to illuminate the issues and provide both applicants and authorities some additional background information.

- Inclusion of a discussion of industry best practices in the guidance material

Because the topic of PIO is quite specialized, and the phenomenon is somewhat elusive in nature, the working group thought it helpful to include a section outlining many industry best practices. Some members of the working group expressed concern for possible misinterpretation of these items by some regulators, perhaps to the point of requiring each of these as a condition for compliance finding. That is not the intent of including them here. The use of analytical techniques, specialized rating scales, many specially-designed maneuvers, etc. are not considered suitable for finding compliance directly or by themselves, but it is useful to collect the best practices of the industry in one place as a reference.

- Structure of the compliance and a reasonable means of compliance

The working group believes that in an absolute sense, proving lack of PIO tendencies is perhaps not possible. What is possible, however, is to define a rigorous measure, and demonstrate that an airplane meets that standard. Much time and discussion was spent on just how to do that in a complete way without overwhelming the certification test campaign. In the end, the recommendation is a two-pronged approach:

  - Fly the normal pilot-in-the-loop maneuvers required for certification with "heightened awareness" of PIO. This takes the airplane to all corners of the envelope and subjects the airplane/pilot combination to the rigors of specific maneuvers across the envelope.
  - Fly dedicated, specifically-designed maneuvers in operationally relevant conditions to ensure that no latent tendencies have been missed. These maneuvers have been defined as attitude captures and offset landings, as defined in the Attachment 15B below.

The working group feels that this combination of whole-envelope evaluation and operationally relevant very specific evaluation will adequately demonstrate compliance to §25.143(a), (b), and (k) with respect to PIO.

- Flight Test vs analysis or simulation

The working group believes that finding compliance to relevant sections of §25.143 with regard to PIO should be done in actual flight. While the current AC 25-7D material suggests the use of simulation in some conditions, the working group noted that the use of simulation for safety of flight reasons is addressed elsewhere in the AC and need not be repeated here.

While analysis nor piloted simulation alone, or even taken together is not seen as robust enough to be taken as proof of compliance for PIO, the working group does believe that these techniques and tools can be quite valuable as tools e.g. to help guide the development of efficient test campaigns.

- Consideration of icing conditions

§25.143(a), (b)(3), (c), and (k) require safe control and maneuverability in icing conditions in accordance with §25.21(g) for those configurations for which icing certification is desired. Given the two-pronged approach for the non-iced condition, the working group considers that evaluation of PIO tendencies in maneuvers normally conducted for icing conditions will give the evaluating pilots an appropriate sense for the difference between the iced condition and the non-iced condition. The same consideration of "heightened awareness" as for non-icing conditions should be applied for the maneuvers conducted for icing approval. With no apparent difference in PIO tendencies from the non-iced condition, evaluation of the specially-designed PIO evaluation maneuvers would not normally be necessary in the iced condition.

If deemed necessary, the PIO evaluation maneuvers with ice should not be any different than those used for the non-iced condition, so separate guidance in AC 25.25A is not defined.

- Consideration of failures or failed states

This was discussed in some detail during the working group's deliberations. The group had difficulty requiring explicit evaluations for PIO with failure conditions because the fundamental construct of §25.143 is normal operations, and Subpart B is non-failed states (engine failure is considered in some requirements). Since the working group is tasked with the topic of handling qualities evaluations of failures and failed states under Topic 16 in Phase 4, it was decided to address the discussion of PIO evaluations in failed states under that topic.

- Exclusion of existing AC 25-7D material

There is quite a lot of material from 25-7D which the working group is recommending be deleted, including reference to the HQRM metrics, in favor of the proposal in Attachment 15B below. Some working group members expressed concern that some important constructs might be lost. The working group discussed this and came to the realization that what was drafted in the late 1990's was written mostly in response to a single accident, had never gotten broad acceptance across the industry, nor with other authorities. By the same token, the proposed material, which was deliberated by the whole group is similarly sizable. In the end, the group decided that the proposal in Attachment 15B below was more appropriate.

- An explicit definition of PIO

PIO's are rare events. Exposing PIO tendencies can be challenging. Proving freedom from PIO tendencies may not be possible in an absolute sense. For those reasons, the working group adopted the strategy described above: to approach certification testing with heightened awareness of PIO and augment that with very high demand, high precision PIO-specific maneuvers. For the maneuvers specifically designed to expose PIO tendencies (attitude captures and offset landings), compliance is found if the maneuver can be flown precisely without encountering a PIO. In order to do that, an explicit definition of a PIO which would not be compliant with the requirements of §25.143(a), (b), and (k) was needed. After considerable deliberation and debate, that definition is given in the guidance material proposed in Attachment 15B.

- Pedal-only heading capture-and-track maneuvers

As a result of the accident of American 587, the FAA convened the Flight Controls Harmonization Working Group to propose standards related to large amplitude oscillatory rudder inputs. The FTHWG participated directly in that activity from 2011 through 2013. The FCHWG final report was submitted in November, 2013. That recommendation report resulted in additional maneuvers being required for structural strength of vertical tails and rudders. Because of a concern regarding the potential for pilot induced oscillations that could lead to large alternating rudder pedal inputs, the FTHWG topic leader and the FAA sponsor met with the FCHWG FAA sponsor to discuss the results of the 2013 activity, It was noted that the FCHWG did not achieve consensus. Of the 11 organizational participants, 5 voted for the proposal, 5 voted for an alternate proposal, and one abstained from voting. The report did include a conclusion that the FCHWG could not find an effective Subpart B solution. The number one recommendation was for enhanced flight crew training.

The FCHWG recommendation report referred not to PIO, but rather to "unintended" rudder use. In the conversation between FAA sponsors and the topic leader, given the FCHWG's failure to identify an effective Subpart B solution and the focus of §25.143 on the characteristics of an airplane with no failures being operated per normal procedures, there was no effective place to put an evaluation of airplane response to an unintended control input.

During deliberations for this Topic 15, the FTHWG discussed at great lengths whether demonstration of pedal-only yaw captures should be required in order to show compliance with the requirements of §25.143(a), (b), and (k) with regard to PIO. For the same reasons that the FCHWG could not identify an effective Subpart B solution as well as the fact that the FTHWG could not identify an operationally representative in-air maneuver involving heading captures with pedal only, this maneuver was removed from consideration in the PIO-specific maneuvers of paragraph 5.1.4.4.5.2. The only exceptions might be crosswind landing decrab and on-ground operation. It was noted that the former typically represents more of an open-loop pedal input during the decrab than a conscious modulated loop closure around heading angle. It was also noted that both the decrab and the on-ground tracking are accomplished in very challenging conditions during normal crosswind testing. So the airplane will be exposed to that condition as a matter of course during a certification test campaign, and falls within the boundaries of 5.1.4.4.5.1, which makes specific mention of crosswind test conditions.

- <u>Consensus</u>

The FTHWG reached unanimous agreement on all aspects of this recommendation.

Recommendation

The FAA should adopt the harmonized guidance given in Attachment 15B below. Further, the FAA should liaise with EASA, TCCA, and ANAC to ensure consistent implementation in their jurisdictions.

A. Rulemaking

1. What is the proposed action?

The FTHWG considers that the current wording (as proposed in Phase 2 Recommendations Report and Topic 18 Go-Around Handling Qualities and Performance Recommendations Report) of 14CFR- and CS-25.143(a), (b), and (k) are both adequate and appropriate with regard to Pilot Induced Oscillations and Bio-Dynamic Coupling. So no rulemaking action is recommended.

Further, the FTHWG recommends that similar paragraphs of TCCA AWM 525, ANAC RBAC 25 be adopted.

2. What should the harmonized standard be?

The FTHWG believes that a single standard of airworthiness is achieved in the current regulation as modified by the Phase 2 Recommendations Report and Topic 18, Go-Around Handling Qualities and Performance Recommendation Report.

3. How does this proposed standard address the underlying safety issue?

No change.

4. Relative to the current FAR, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

Since we are not proposing a change to the regulation, the standard of safety remains the same.

5. Relative to current industry practice, does the proposed standard increase, decrease, or maintain the same level of safety? Explain.

Because the current industry practice includes independent MOC IPs/CRIs, and the proposed guidance material is an amalgamation of those, the level of safety remains the same.

6. Who would be affected by the proposed change?

Manufacturers developing new or derivative transport category airplanes and other organizations (e.g. companies developing after-market improvements/upgrades) and the Authorities who will certify them.

7. Does the proposed standard affect other HWG's and what is the result of any consultation with other HWGs?

The FTHWG considered whether any other HWG's would be affected and the need for consultation. The conclusion was that no other HWG's would be affected, and additional consultation would not be required.

B. Advisory Material

1. Is existing FAA advisory material adequate? If not, what advisory material should be adopted?

The FTHWG believes the existing FAA advisory material is not adequate. The FAA agreed in the comment-response document for the A revision of AC 25-7. Recommended revised material is in Attachment 15B below.

2. To ensure harmonization, what current advisory material (e.g., ACJ, AMJ, AC, policy letters) needs to be included in the rule text or preamble?

The FTHWG does not believe any current advisory material needs to be included in the rule text or the preamble.

Economics

A. What is the cost impact of complying with the proposed standard (it may be necessary to get FAA Economist support to answer this one)?

The FTHWG believes that this new guidance material may be less costly than current practice because the need for issue paper/CRI will have been avoided.

B. Does the HWG want to review the draft NPRM prior to publication in the Federal Register?

Yes.

ICAO Standards

How does the proposed standard compare to the current ICAO standard?

The wording of the regulation §25.143(a), (b), and (k) is not proposed to be changed beyond proposals already made and noted above. ICAO Annex 8, Part IIIB, includes:

B.3.2.1 The aeroplane shall be controllable and manoeuvrable under all anticipated operating conditions, and it shall be possible to make smooth transitions from one flight condition to another (e.g. turns, sideslips, changes of engine power or thrust, changes of aeroplane configurations) without requiring exceptional skill, alertness or strength on the part of the pilot even in the event of failure of any power-unit. A technique for safely controlling the aeroplane shall be established all stages of flight and aeroplane configurations for which performance is scheduled.

The working group believes the existing regulations (the working group is not proposing a change to the regulations) are equivalent the ICAO standard. The only change being proposed here is a harmonized means of compliance.

Work Plan - Pilot-Induced Oscillations

1. What is the task?
To recommend a harmonized means of assessing susceptibility to pilot-induced (PIO).
2. Who will work the task?
The Flight Test Harmonization Working Group (FTHWG) will have primary responsibility for this task.
3. Why is this task needed? (Background information)
As a result of in-service occurrences of PIO, a policy was incorporated into FAA's Flight Test Guide, AC 25-7A, dated Mar/31/98. This policy was developed in the 1995 timeframe as a result of an accumulation of the knowledge on PIO among industry, authorities and research organizations. The policy was reviewed by foreign authorities and industry, and was not accepted as a method of compliance by the JAA. As a result of non-acceptance of the PIOs policy by the JAA and industry, there has been an effort to revise and harmonize the PIOs policy in the past several years. A Subgroup of the JAA Flight Study Group was formed for this purpose, although the work was not completed. Therefore, the policy provided in the current FAA guidance AC 25–7C for evaluating PIO is still not well accepted by airplane manufacturers, is not harmonized with EASA, and has been superseded to some extent in recent certification programs by Issue Papers. Modified guidance is needed to both simplify and standardize the methods for evaluating an airplane's susceptibility to PIO. Among the non-harmonized topics related to PIO is the use of the HQRM PIO criteria as a means to assess PIO tendencies. The FAA handling quality rating system is not universally accepted within industry, nor is it accepted by EASA. However, it is worth mentioning that the FAA Issue Papers raised so far state that the applicant may propose an acceptable alternative method.
4. References (existing regulatory and guidance material, including special conditions, CRIs, etc.)
§ 25.143 (a),(b), AC 25-7C, FAA Issue Paper F-13 (Project: Dassault Aviation, Falcon 7X program), TCCA Issue Paper CM FT-25 (Project: Bombardier Inc., C-Series program). Airbus A350 F-12, FWP 599, NPA 25B-335.
5. Working method
It is envisioned that 5-6 one day face-to-face meetings will be needed to facilitate the discussion needed to complete this task. Telecons and electronic correspondence will be used to the maximum extent possible.
6. Preliminary schedule (How long?)

Recommendations to Transport Airplanes and Engines Subcommittee within 18 months of the initiation of work on these tasks.
7. Regulations/guidance affected
§ 25.143 (a),(b), AC 25-7C, NPA 25B-335
8. Additional information

Attachment 15B – Recommended Guidance Material for PIO

Font Color Explanation
Black = AC 25-7D
Red = Changes proposed in Phase 2 and Topic 18
Blue = Changes proposed in Topic 15
Green = Came from CS 25, Book 2

5.1 **General—§ 25.143~~.~~ and §25.144**

5.1.1 Explanation.

5.1.1.1 The purpose of § 25.143 is to verify that any operational maneuvers conducted within the operational envelope can be accomplished smoothly with average piloting skill and without encountering a stall warning or other characteristics that might interfere with normal maneuvering, or without exceeding any airplane structural limits. Control forces should not be so high that the pilot cannot safely maneuver the airplane. Also, the forces should not be so light that it would take exceptional skill to maneuver the airplane without over-stressing it or losing control. The airplane response to any control input should be predictable to the pilot **and pitch and roll control force sensitivity and displacement sensitivity must be compatible, so that normal inputs on one control axis will not cause significant unintentional inputs on the other. Many modern aircraft employ Envelope Protection Functions to limit excursions of one or more measured flight parameters. § 25.144 provides general regulations for such functions. The purpose of § 25.144 is to ensure that Envelope Protection Functions support safe operation and do not interfere with required maneuvering in normal and emergency operations and in foreseeable atmospheric conditions.**

5.1.1.2 The predictability of the response in attitude or flight path of the airplane to pilot control inputs is an important element in determining the handling qualities of the airplane. Inadequate predictability can lead to phenomenon referred to as Pilot Induced Oscillation (PIO) in which the airplane attitude becomes substantially out-of-phase with the pilot inputs despite the pilot's attempts to control the airplane.

5.1.1.3 Unpredictability of the airplane's response to the pilot's control input may be due to nonlinearities in the control system, actuator rate or position limiting not sensed by the pilot through the flight controls, or changing pitch response at high altitude as the airplane maneuvers into and out of Mach buffet. Systems which result in pilot control inceptors with too small a displacement and/or too light force gradients may also lead to severe over control. This is especially true in a dynamic environment of high altitude turbulence or upsets in which the autopilot disconnects. These characteristics may be hazardous and therefore would not meet the intent of §25.143(a), (b), and (k).

5.1.1.4 The requirements of §25.143(a), (b), and (k) are high level requirements on the dynamic performance of the airplane in response to pilot inputs. The requirement for smooth, safe control and maneuverability represents the integration of every element in the control systems. In evaluating the airplane's handling qualities, and in particular with regard to susceptibility to PIO, all elements in the pilot's control loop are important and contribute to the resulting dynamic response to control inputs. While §25.671(a) refers to each control's ease, smoothness, and positiveness of operation appropriate to its function, industry best practice suggests that consideration should be given to control mechanical characteristics, including the inceptors. Some of the important mechanical characteristics are

- friction and preload forces including control centering,
- deadband or freeplay in the control system displacement,
- flexibility in the control system,
- mass imbalance and inertia of the control system and resulting system dynamics,
- nonlinear gearings and control surface rate limiting.

Importantly, the combination of those elements must be compatible with flight control architecture whether mechanical or electronic including actuation, to produce:

- Acceptable dynamic response of the airplane including both force and displacement sensitivity to control inputs and;
- Display dynamics for displays the pilot will use to control the airplane attitude or path.

In particular, industry experience suggests that excessive force or displacement hysteresis, time delay and phase lag in any of those elements or in the combination of those elements can adversely affect the predictability of the airplane dynamic behavior with a pilot in the loop.

5.1.1.~~2~~5 The maximum forces given in the table in § 25.143(d) for pitch and roll control for short term application are applicable to maneuvers in which the control force is only needed for a short period. For conventional control wheels, ~~W~~where the maneuver is such that the pilot will need to use one hand to operate other controls (such as during the landing flare or a go-around, or during changes of configuration or power/thrust resulting in a change of control force that needs to be trimmed out) the single-handed maximum control forces will be applicable. In other cases (such as takeoff rotation, or maneuvering during en route flight), the two-handed maximum forces will apply.

5.1.1.~~3~~6 The maximum short term and long term forces in the table in § 25.143(d) are based upon conventional control wheel and side stick installations (with adjustable arm/elbow rest), where their location relative to the pilot Design Eye Point (DEP) and range of motion are consistent with the standard design practice for flight deck ergonomics that accommodate the full pilot population range specified by § 25.777(c). Where non-conventional control wheel or side stick installations or other controller types (e.g., center-sticks) are used, the short and long term forces in the § 25.143(d) table and the maximum and minimum control specified in Subpart B and this AC may not be appropriate.

5.1.1.~~34~~7 Short-term and long-term forces should be interpreted as follows:

5.1.1.~~34~~7.1 Short-term forces are the initial stabilized control forces that result from maintaining the intended flight path following configuration changes and normal transitions from one flight condition to another, or from regaining control following a failure. It is assumed that the pilot will take immediate action to reduce or eliminate such forces by re-trimming or changing configuration or flight conditions, and consequently short-term forces are not considered to exist for any significant duration. They do not include transient force peaks that may occur during the configuration change, change of flight conditions, or recovery of control following a failure.

5.1.1.~~34~~7.2 Long-term forces are those control forces that result from normal or failure conditions that cannot readily be trimmed out or eliminated.

5.1.1.~~45~~8 In conducting the controllability and maneuverability tests to show compliance with § 25.143 at speeds between V_{MO}/M_{MO} and V_{FC}/M_{FC}, the airplane should be trimmed at V_{MO}/M_{MO}.

5.1.1.~~56~~9 Modern wing designs can exhibit a significant reduction in maximum lift capability with increasing Mach number. The magnitude of this Mach number effect depends on the design characteristics of the particular wing. For wing designs with a large Mach number effect, the maximum bank angle that can be achieved while retaining an acceptable stall margin can be significantly reduced. Because the effect of Mach number can be significant, and because it can also vary greatly for different wing designs, the multiplying factors applied to V_{SR} may be insufficient to ensure that adequate maneuvering capability exists at the minimum operating speeds. To address this issue, § 25.143(h) was added by amendment 25-108 to require a minimum bank angle capability in a coordinated turn without encountering stall warning or any other characteristic (including the envelope protection features of fly-by-wire flight control systems or automatic power or thrust increases) that might interfere with normal maneuvering. The maneuvering requirements consist of the minimum bank angle capability the FAA deems adequate for the specified regimes of flight combined with additional bank angle capability to provide a safety margin for various operational factors. These operational factors include both potential environmental conditions (e.g., turbulence, wind gusts) and an allowance for piloting imprecision (e.g., inadvertent overshoots). The FAA considers the automatic application of power or thrust by an envelope protection feature to be a feature that might interfere with normal maneuvering because it will result in a speed increase and flight path deviation, as well as potentially increasing crew workload due to the unexpected power or thrust increase.

5.1.2 General Test Requirements.

5.1.2.1 Compliance with § 25.143 (a) through (g) and (k) is primarily a qualitative determination by the pilot during the course of the flight test program. The control forces required and airplane response should be evaluated during changes from one flight condition to another and during maneuvering flight. The forces required should be appropriate to the flight condition being evaluated. For example, during an approach for landing, the forces should be light and the airplane responsive in order that adjustments in the flight path can be accomplished with a minimum of workload. In cruise flight, the combination of control forces, ~~and~~ airplane response and any envelope protections that are included should be such that inadvertent control input does not result in exceeding limits or in undesirable maneuvers. Longitudinal control forces should be evaluated during accelerated flight to ensure a positive stick force with increasing normal acceleration. If a load factor limiting envelope protection function that prevents exceedance of design limits is not installed, pitch control forces ~~Forces~~ should be heavy enough at the limit load factor to prevent inadvertent excursions beyond the design limit. Sudden engine failures should be investigated during any flight condition or in any configuration considered critical, if not covered by another section of part 25. Control forces considered excessive should be measured to verify compliance with the maximum control force limits specified in § 25.143(d). Allowance should be made for delays in the initiation of recovery action appropriate to the situation.

5.1.2.2 Since § 25.143(h) involves a target speed, bank angle, and maximum value of thrust/power setting, not all flight test conditions to demonstrate compliance will necessarily result in a constant-altitude, thrust-limited turn. In cases with positive excess power or thrust, a climbing condition at the target bank and speed is acceptable. Alternately, if desired, the power or thrust may be reduced to less than the maximum allowed, so that compliance is shown with a completely stabilized, constant-altitude turn. With the airplane stabilized in a coordinated turn, holding power or thrust and speed, increase bank angle at constant airspeed until compliance is shown. For cases with negative excess power or thrust (e.g., the landing configuration case), a constant-altitude slow-down maneuver at the target bank angle has been shown to be a suitable technique. With the airplane descending at V_{REF} in wings-level flight on a 3° glide path, trim and throttle position are noted. The airplane is then accelerated to V_{REF} + 10 to 20 knots in level flight. The original trim and throttle conditions are reset as the airplane is rolled into a constant-altitude slow-down turn at the target bank angle. Throttles can be manipulated between idle and the marked position to vary slow-down rate as desired. Compliance is shown when the airplane decelerates through V_{REF} in the turn without encountering a stall warning or other characteristic that might interfere with normal maneuvering.

5.1.2.3 If stall warning is provided by an artificial stall warning system, the effect of production tolerances on the stall warning system should be considered when evaluating compliance with the maneuvering capability requirements of § 25.143(h). See paragraph 8.1.6.2.6 of this AC for more information.

5.1.3 Controllability Following Engine Failure.
Section 25.143(b)(1) requires the airplane to be controllable following the sudden failure of the critical engine. To show compliance with this requirement, the demonstrations described in paragraphs 5.1.3.1 and 5.1.3.2 below, should be made with engine failure (simulated by fuel cuts) occurring during straight, wings level flight. To allow for likely in-service delays in initiating recovery action, no action should be taken to recover control for two seconds following pilot recognition of engine failure. The recovery action should not necessitate movement of the engine, propeller, or trim controls, and should not result in excessive control forces. Additionally, the airplane will be considered to have reached an unacceptable attitude if the bank angle exceeds 45° during the recovery. These tests may be conducted using throttle slams to idle, with actual fuel cuts repeated only for those tests found to be critical.

5.1.3.1 At each takeoff flap setting at the initial all-engine climb speed (e.g., V_2 + 10 knots) with:

5.1.3.1.1 All engines operating at maximum takeoff power or thrust prior to failure of the critical engine;

5.1.3.1.2 All propeller controls (if applicable) in the takeoff position;

5.1.3.1.3 The landing gear retracted; and

5.1.3.1.4 The airplane trimmed at the prescribed initial flight condition.

5.1.3.2 With the wing flaps retracted at a speed of 1.23 V_{SR} with:

5.1.3.2.1 All engines operating at maximum continuous power or thrust prior to failure of the critical engine;

5.1.3.2.2 All propeller controls in the en route position;

5.1.3.2.3 The landing gear retracted; and

5.1.3.2.4 The airplane trimmed at the prescribed initial flight condition.

5.1.4 Pilot Induced Oscillations (PIO) and Bio-Dynamic Coupling (BDC).

5.1.4.1 Explanation.

5.1.4.1.1 Section 25.143(a), and (b) require that the airplane be safely controllable and maneuverable without exceptional piloting skill and without danger of exceeding the airplane limiting load factor under any probable operating conditions. In addition, Section 25.143(k) requires that unsuitable pilot-in-the-loop control characteristics not be encountered during precision path control tasks, including while in expected levels of turbulence. ~~Service history events have indicated that modern transport category airplanes can be susceptible to airplane-pilot coupling under certain operating conditions and would not meet the intent of this requirement.~~

5.1.4.1.2 "Closed-loop" handling qualities phenomena can be described by a continuum of motions ranging from predictable response to control inputs to unintended airplane motions, oscillations, oscillations with divergence, and uncontrollable motions which result from anomalous interactions between the airplane and the pilot in a closed-loop (pilot flying the aircraft) flight maneuver. The pilot's movement of the cockpit controller coupled with motion of the control surface and the dynamic response of the airplane form this closed-loop or feedback system during flight maneuvers. Adverse effects often manifest themselves in situations of high "pilot gain" wherein the pilot is attempting to precisely and quickly accomplish a specified task. When the pilot's input to the control inceptor results in an unpredictable dynamic response of the airplane, the ensuing actions of the pilot may become reactions to the airplane dynamics. The closed-loop system can become unstable, and the resulting motion might be bounded (limit cycle) or unbounded (divergent). The degree to which these phenomena are detrimental to the pilot's ability to precisely perform a specific task defines the severity of an event.

5.1.4.1.3 PIOs can occur when response unpredictability is present; the pilot does not get the expected response for a given input. This condition may be due simply to overly sensitive response to controller force or position or to non-linearities in the control system, phase shifts between control input and control surface response, or actuator rate or position limiting not sensed by the pilot through the flight controls. This can develop during situations of high urgency, such as maneuvering close to the ground (as in takeoff or landing) or due to the startle incited by unexpected mode changes, autopilot disconnects, turbulence encounters, etc. in which the pilot feels a need to react very quickly and very precisely.

5.1.4.1.4 From the pilot's viewpoint, the airplane's susceptibility to PIO initiates when a "trigger" causes an input to the controller resulting in an unpredictable response. If the ensuing inputs to the controller cause sustained over-control, oscillations may develop and a PIO can occur. There is a point in this susceptibility range at which considerable compensation and increased workload by the pilot is required in controlling the airplane and a sacrifice in the task performance will dictate that the handling qualities are not acceptable.

5.1.4.1.5 The point along the continuum of motions described in 5.1.4.1.2 at which a PIO event is considered to be non-compliant with §25.143(a), (b), and (k) can be defined when all 5 of these elements are present:

- The pilot must be in the loop, actively trying to control the attitude or path of the airplane. The pilot should be flying the airplane manually, using normal piloting technique and should be trying to fly the airplane as precisely as possible.
- The response of the airplane will be substantially out of phase with the control inceptor – when compared in the time domain. If the attitude response of the airplane and the control inceptor are "substantially out

of phase", then the pilot, flying normally but with high gain, is trying to achieve precise control, but can only manage an oscillation. "Substantially" is used here because being precisely out of phase (exactly 180 degrees) is not necessary to sustain a (PIO) response which is not compliant.

- The response of the airplane will be at a frequency appropriate for a closed-loop (pilot in the loop) oscillation – The mathematics of the dynamic response dictates that there will be only one frequency at which the airplane attitude response will be out of phase with the controller. Even if the response is not precisely out of phase, the frequency should be "appropriate". This element is closely related to the phase angle element, and might be considered redundant. It is retained here because it may be easier to identify the frequency than the phase angle, depending on installed instrumentation.
- The oscillatory response must be "sustained" for more than a couple of cycles – Single bobbles may be an indication of untoward characteristics, but their existence alone does not constitute a non-compliant PIO. The concern in terms of loss of control of the airplane is an oscillatory response which the pilot is unable to arrest despite the pilot's best efforts to do so.
- The amplitude (and duration above) must be big enough to matter given the task being evaluated. As noted above, the degree to which the dynamic response interferes with the pilot's ability to precisely command attitude or flight path will define the severity of the event. Very small oscillatory responses might not be of consequence, but both the input and output amplitudes should be considered.

5.1.4.1.6 Bio-Dynamic Coupling (BDC). While PIO involves the attitude response of the airplane to deliberate, active pilot control inputs, another phenomenon, referred to as Bio-Dynamic Coupling (BDC) can arise as a result of coupling with structural modes of motion of the airplane causing unintentional pilot control inputs. These inadvertent pilot control inputs may be involuntary, driven by the motion of the airplane structure and the inertial response of the pilot. If the structural response of the motion couples with these unintentional pilot inputs, the resulting response can become very lightly damped to unstable. The presence of these tendencies can reduce the pilot's ability to precisely control the path of the airplane.

5.1.4.2 Industry Best Practices

5.1.4.2.1 The inherent characteristics of PIOs, namely, the combination of the flight control system, airplane dynamics, and pilot behavior, make seeking and identifying PIOs a challenging proposition to the applicant. Many times, PIO conditions will manifest themselves in the course of normal flying, when PIOs are not being explored. PIOs are by their nature rare events, their characteristics sometimes remaining dormant for decades before being uncovered. This makes the evaluation process challenging. For this reason, it is important to utilize lessons learned from past PIO events and available analytical tools to incorporate design features during the airplane development which would minimize the occurrence of PIOs.

5.1.4.2.2 Industry has developed and continues to refine analytical prediction methods to help in understanding those elements which contribute to unpredictability of dynamic response. While application of these techniques is not considered necessary nor sufficient for demonstrating compliance to §25.143(a), (b), and (k) in itself, their use can be helpful in design, development, diagnostics and informing critical conditions for testing. One reference is:

Development of Methods and Devices to Predict and Prevent Pilot-Induced Oscillations
David Mitchell and Roger Hoh
AFRL-VA-WP-TR-2000-3046
December, 2000

Others exist; individual OEMs may have proprietary methods.

5.1.4.2.3 Company development testing results, both in simulation and in flight can provide significant insight into the predictability of airplane response to control inputs prior to certification testing. While company test data generated during airplane development may not be suitable for showing compliance to §25.143(a), (b), and (k), they can, particularly in combination with analytical prediction techniques, prove useful in generating an efficient certification test plan and provide confidence that appropriate conditions are being tested.

5.1.4.2.4 Specialized rating scales, for both handling qualities (such as the Cooper-Harper scale) and for PIO (such as the adjectival description scale included in Cooper and Harper's NASA TN-D-5153) can be useful in facilitating communication between pilots and engineers. While their effective use requires specific training, they represent industry standards for evaluation of pilot-in-the-loop characteristics, and their proper use is encouraged in company testing. The rating scale results by themselves do not constitute demonstration of compliance to §25.143(a), (b), and (k), but their use can provide valuable insight into the characteristics of a particular airplane and contribute to the evaluating pilot's judgment of the predictability of the airplane's dynamic response.

5.1.4.2.5 The PIO assessment ~~These tasks~~ should be performed in actual flight. Notwithstanding the guidance given in paragraph 3.1.2.6 regarding use of properly-verified piloted simulation for certification and the guidance in paragraph 5.1.4.2.3 above regarding use of simulation results to support efficient certification test plans, industry experience suggests that with respect to PIO, piloted simulation results are not robust enough to support a compliance decision by themselves. Simulation results which suggest susceptibility certainly give cause for concern; results which do not show any susceptibility do not guarantee freedom from PIO in flight. ~~However, for conditions that are considered too dangerous to attempt in actual flight (i.e., certain flight conditions outside of the operational flight envelope, flight in severe atmospheric disturbances, flight with certain failure states, etc.), the closed loop evaluation tasks may be performed using a motion base high fidelity simulator if it can be validated for the flight conditions of interest.~~

~~5.1.4.1.2 The classic PIO is considered to occur when an airplane's response is approximately 180° out of phase with the pilot's control input. However, PIO events with 180° phase relationships are not the only conditions in which the airplane may exhibit closed-loop (pilot-in-the-loop) characteristics that are unacceptable for operation within the normal, operational, or limit flight envelopes. Others include unpredictability of the airplane's response to the pilot's control input. This may be due to nonlinearities in the control system, actuator rate or position limiting not sensed by the pilot through the flight controls, or changing pitch response at high altitude as the airplane maneuvers into and out of Mach buffet. Artificial trim and feel systems which produce controllers with too small a displacement and light force gradients may also lead to severe over control. This is especially true in a dynamic environment of high altitude turbulence or upsets in which the autopilot disconnects. This places the airplane in the hands of the unsuspecting pilot in conditions of only a small g or airspeed margin to buffet onset and with very low aerodynamic damping. These characteristics, while not a classic 180° out of phase PIO per se, may be hazardous and should be considered under the more general description of airplane-pilot coupling tendencies.~~

~~5.1.4.1.3 Some of the PIO tendency characteristics described in paragraph 5.1.4.1.2 above are attributes of transport airplanes (e.g., low frequency short period, large response lags) that are recognized by part 25. Limits are placed on some of these individual attributes by part 25 (e.g., stick force per g, heavily damped short period) to assure satisfactory open-loop characteristics. However, service reports from recent years have indicated that certain operating envelope conditions, combined with triggering events, can result in airplane-pilot coupling incidents. Some of the conditions that have led to these PIOs include fuel management systems that permit extended operations with a CG at or near the aft limit, operating at weight/speed/altitude conditions that result in reduced margins to buffet onset combined with tracking tasks such as not exceeding speed limitations and severe buffet due to load factor following an upset, and control surface rate or position limiting.~~

~~5.1.4.1.4 This service experience has shown that compliance with only the quantitative, open-loop (pilot-out-of-the loop) requirements does not guarantee that the required levels of flying qualities are achieved. Therefore, in order to ensure that the airplane has achieved the flying qualities required by § 25.143(a), (b), and (bk), the airplane should be evaluated by test pilots conducting high-gain (wide-bandwidth), closed-loop tasks to determine that the potential of encountering adverse PIO tendencies is minimal. .~~

5.1.4.3 Special Considerations for Test Planning.

5.1.4.3.1The certification flight test program should be tailored to the specific airplane design. This tailoring may be aided by knowledge of the findings during the company testing and any PIO analytical assessment. To do so:

- The certification team should understand the flight control system and airplane design.
- The applicant should explain what has been done during the development flight test experience.

- The applicant should explain why the design is not conducive to a PIO problem and how this is to be shown in certification flight tests.

~~5.1.4.2 Special Considerations.~~
~~5.1.4.2.1 The certification team should understand the flight control system and airplane design.~~

~~5.1.4.2.2 The applicant should explain why the design is not conducive to a PIO problem and how this is to be shown in both developmental and certification flight tests.~~

~~5.1.4.2.3 The applicant should explain what has been done during the development flight test experience and any design changes that were required for PIO problems.~~

~~5.1.4.2.4 The certification flight test program should be tailored to the specific airplane design and to evaluate the airplane in conditions that were found to be critical during its development program and PIO analytical assessment.~~

~~5.1.4.2.5 The FAA flight test pilots should also continuously evaluate the airplane for PIO tendencies during the certification program in both the airplane and simulator. This evaluation should include both normal and malfunction states; all certification flight test points; transitions between and recoveries from these flight test points; and normal, crosswind, and offset landing task evaluations.~~

~~5.1.4.2.6~~5.1.4.3.2 Since the evaluation of flying qualities under § 25.143(a), (b), and (~~b~~k) is basically qualitative, especially evaluations of PIO susceptibility, ~~the high gain tasks~~ dedicated attitude captures and offset landings discussed herein should be accomplished by at least three test pilots. Use of other pilots can provide additional insights into the airplane handling qualities, but for the purpose of demonstrating compliance with this requirement the evaluation pilots should be trained test pilots.

5.1.4.~~3~~4 **Procedures: Flight Test.**
5.1.4.4.1 Qualitative PIO assessment with "heightened awareness" should be continuously conducted and documented throughout the certification test campaign. Engineering evaluations based on the criteria specified in paragraph 5.1.4.1.5 and PIO specific flight test maneuvers should be conducted at any test condition where pilot assessment surfaces PIO tendencies. If no PIO tendencies are discovered throughout the certification flight test program, then only a minimum set of PIO specific test maneuvers, outlined in paragraph 5.1.4.4.5.2 below, will be considered sufficient.

5.1.4.4.2 The evaluation for PIO could be included in the flight test procedures used when testing the basic airplane handling and flight characteristics. This would include all closed-loop (pilot-in-the-loop) test procedures selected for a specific certification project. Test conditions should include manual flight and any control law transition states or mode changes, transitions from autoflight to manual flight, and atmospheric disturbances which will be normally encountered in the course of a certification flight test campaign. For general evaluation during the course of the test program some level of atmospheric turbulence is expected to be experienced, however, the targeted, specific PIO maneuvers detailed in paragraph 5.1.4.4.5.2 are not expected to be conducted in turbulent conditions.

5.1.4.4.3 The objective of high gain should not be confused with being overly aggressive on the controls. High pilot gain is associated with accomplishing high precision with high urgency. What this means is that the pilot reacts to observed error in attitude or path as quickly as possible and in a way to try to drive the error to zero as quickly as possible. Many times, this will result in large inputs at high frequency, but these should be the result of the pilot trying to fly the prescribed task and should not be confused with large, *open loop* oscillatory inputs. While it is certainly possible to make large oscillatory open loop inputs, the proper evaluation of handling with respect to PIO involves focus on the precise control of attitude or flight path, not artificial inputs simply to "stir up" the airplane response.

5.1.4.~~3~~4.~~1~~4 Quantitative ~~E~~evaluation of the actual task performance achieved, ~~e.g., flight technical error,~~ is not recommended as a measure of proof of compliance. Only the pilot's ~~rating~~ evaluation of the PIO characteristics, or if necessary, application of the definition in paragraph 5.1.4.1.5 is needed ~~as described in paragraph 5.1.4.6~~. The PIO-specific tasks in paragraph 5.1.4.4.5.2 are used only to increase the pilot's gain, which is a prerequisite for exposing PIO tendencies. Although task performance is not used as proof of compliance, task performance should be recorded and analyzed to insure that all pilots seem to be attempting to achieve the same level of performance.

~~5.1.4.3.2 Tasks for a specific certification project should be based on operational situations, flight testing maneuvers, or service difficulties that have produced PIO events. Task requirements for a specific project will be dictated by the particular airplane and its specific areas of interest as determined by the tailored flight test program mentioned above. Some of these include high altitude upset maneuvers, encounters with turbulence at high altitude in which the autopilot disconnects, crosswind/crossed control landings with and without one engine inoperative, and offset landings to simulate the operational case in which the airplane breaks out of instrument meteorological conditions (IMC) offset from the glideslope and/or localizer beam and the pilot makes a rapid alignment correction. Tests should be conducted at or near the critical altitude/weight/CG combinations.~~

~~5.1.4.3.3 Tasks described here may be useful in any given evaluation and have proven to be operationally significant in the past. It is not intended that these are the only tasks that may be used or may be required depending on the scope and focus of the individual evaluation being conducted. Other tasks may be developed and used as appropriate. For example, some manufacturers have used formation tracking tasks successfully in the investigation of these tendencies. For all selected tasks, a build-up approach should be used and all end points should be approached with caution. Capture tasks and fine tracking tasks share many common characteristics but serve to highlight different aspects of any PIO problem areas that may exist. In some cases, depending on individual airplane characteristics, it may be prudent to look at capture tasks first and then proceed to fine tracking tasks or combined gross acquisition (capture) and fine tracking tasks as appropriate.~~

5.1.4.4.5 Compliance with the general requirements of §25.143(a), (b), and (k) with respect to PIO may be conducted and determined in the following manner:

5.1.4.4.5.1 All relevant closed-loop (pilot-in-the-loop) test procedures that pertain to handling qualities and flight characteristic should be considered for evaluating an airplane's susceptibility to PIO, including but not limited to the Standard Subpart B test procedures contained in Chapters 4 through 10 and 42 of this AC that are appropriate for the specific type of airworthiness certification. Closed-loop test procedures specific to operational tasks typically conducted within a certification program. (e.g. crosswind landings) represent good candidates.

5.1.4.4.5.2 The following test procedures specifically related to PIO's should be conducted:

a. Pitch, roll, and heading capture and tracking maneuvers: From a steady flight condition, the pilot makes an aggressive angle capture (e.g. 30 degrees bank, 5 degrees pitch, 10 degrees heading (using recommended aircraft control)). Once the capture target is reached, the pilot tracks the target with best possible precision or accuracy (minimum error) until another capture angle is requested. Pitch, roll, and heading targets can be given verbally to the pilot, or by using a specific guidance device (flight director, HUD, etc.). Applicants should propose a test plan which will accomplish the above considering critical flight conditions, relevant tests and relevant configurations during takeoff, climb, cruise, descent, approach, landing, and go-around which could trigger PIOs.
b. Precision Offset Landing Procedure: The precision offset landing has been identified as one of the best maneuvers to detect PIO tendencies. The aircraft begins the approach phase mis-aligned with the runway (in horizontal runway alignment). The pilot may either use visual ground references (a taxiway, a given point on the airfield, etc.) or ILS references (e.g 2 dots aside). The offset lateral alignment and height for correcting to the centerline will depend on the size and maneuverability of the airplane. At a predetermined position, the pilot makes an aggressive runway alignment recovery in order to land on the runway and in the touchdown box. During this alignment phase the pilot will achieve capture and fine tracking tasks which will identify PIO tendencies.

5.1.4.4.5.3 Compliance with Section §25.143(a), (b), and (k)with respect to PIO's shall be established by accomplishing the requisite maneuvers identified in 5.1.4.4.5 without exhibiting a non-compliant PIO as defined in 5.1.4.1.5 above.

5.1.4.4.5.4 When conducting maneuvers in icing conditions according to AC 25-25A/AMC 25.21(g), pilots should use the same consideration of "heightened awareness" as recommended for non-icing conditions.

5.1.4.5 Bio-dynamic Coupling:
In showing compliance with the requirements of §25.143(a), (b), and (k), account should be taken of aeroelastic effects and structural dynamics (including ~~aeroplane~~ airplane response to rough runways and water waves) which may influence the ~~aeroplane~~ airplane handling qualities in flight and on the surface. The oscillation characteristics of the flight deck, in likely atmospheric and runway/water surface conditions, should be such that there is no reduction in ability to control and ~~manoeuvre~~ maneuver the ~~aeroplane~~ airplane safely. In general, no dedicated tests are needed and this evaluation could be concurrent with other testing for §25.143(a), (b), and (k) noted above.

~~5.1.4.4 Capture Tasks.~~
~~5.1.4.4.1 Capture tasks are intended to evaluate handling qualities for gross acquisition as opposed to continuous tracking. A wide variety of captures can be done provided the necessary cues are available to the pilot. Pitch attitude, bank angle, heading, flight path angle, angle-of-attack, and g captures can be done to evaluate different aspects of the airplane response. These capture tasks can give the pilot a general impression of the handling qualities of the airplane, but because they do not involve closed-loop fine tracking, they do not expose all of the problems that may arise in fine tracking tasks. Capture tasks should not be used as the only evaluation tasks.~~

~~5.1.4.4.2 For pitch captures, the airplane is trimmed for a specified flight condition. The pilot aggressively captures 5° pitch attitude (or 10° if the airplane is already trimmed above 5°). The pilot then makes a series of aggressive pitch captures of 5° increments in both directions, and then continues this procedure with 10° increments in both directions. An airplane with more capability can continue the procedure with larger pitch excursions. If possible, the initial conditions for each maneuver should be such that the airplane will remain within ±1,000 feet and ±10 knots of the specified flight condition during the maneuver; however, large angle captures at high-speed conditions will inevitably produce larger speed and altitude changes. If the airplane should get too far from the specified condition during a task, it should be re-trimmed for the specified condition before starting the next maneuver.~~

~~5.1.4.4.3 The other kinds of captures are usually done in a similar manner, with some minor differences. G captures can be done from a constant-g turn or pull ups and pushovers using ±0.2 g and ±0.5 g. Heading captures can be used to evaluate the yaw controller alone (usually small heading changes of 5° or less).~~

~~5.1.4.4.4 Bank angle captures are also commonly done using bank-to-bank rolls. Starting from a 15° bank angle, the pilot aggressively rolls and captures the opposite 15° bank angle (total bank angle change of 30°). The pilot then rolls back and captures 15° bank in the original direction. This procedure should continue for a few cycles. The procedure is then repeated using 30° bank angles, and then repeated again using 45° bank angles. A variation of this is to capture wings-level from the initial bank condition.~~

~~5.1.4.4.5 Where suitable, combined conditions could be used as described in the task shown in paragraph 5.1.4.4.6 below, in which a target g and bank angle are tightly tracked until the target pitch attitude and heading are captured.~~

~~5.1.4.4.6 The following upset and/or collision avoidance maneuvers have been found to be effective in evaluating PIO susceptibility when the airplane is flying at high altitude under conditions of low g to buffet onset, typically 0.3 g. This emphasis on cruise susceptibility stems from operational experiences, but should not be interpreted as placing less emphasis on other flight phases.~~
~~1. Trim for level flight at long range cruise Mach number. Initiate a slight climb and slow the aircraft while leaving power/thrust set. Push the nose over and set up a descending turn with 30° to 40° of bank and approximately 10° nose below the horizon, or as appropriate, to accelerate to the initial trim speed. At the initial~~

trim airspeed initiate a 1.5 g to 1.67 g (not to exceed deterrent buffet) pull up and establish a turn in the opposite direction to a heading which will intercept the initial course on which the airplane was trimmed. Establish a pitch attitude which will provide a stabilized climb back to the initial trim altitude. The pilot may use the throttles as desired during this maneuver and should pick a target g, bank angle, heading, and pitch attitude to be used prior to starting the maneuver. The target g and bank angle should be set and tightly tracked until the target pitch attitude and heading are obtained respectively. The stabilized steady heading climb should be tightly tracked for an adequate amount of time to allow the pilot to assess handling qualities, even through the initial trim altitude and course if required. The pilot should qualitatively evaluate the airplane during both the gross acquisition and fine tracking portions of this task while looking for any tendency towards PIO in accordance with the criteria in paragraph 5.1.4.6.

2. This maneuver should be repeated in the nose-down direction by accelerating to M_{MO} from the trim condition 10° nose down and then recover as above.

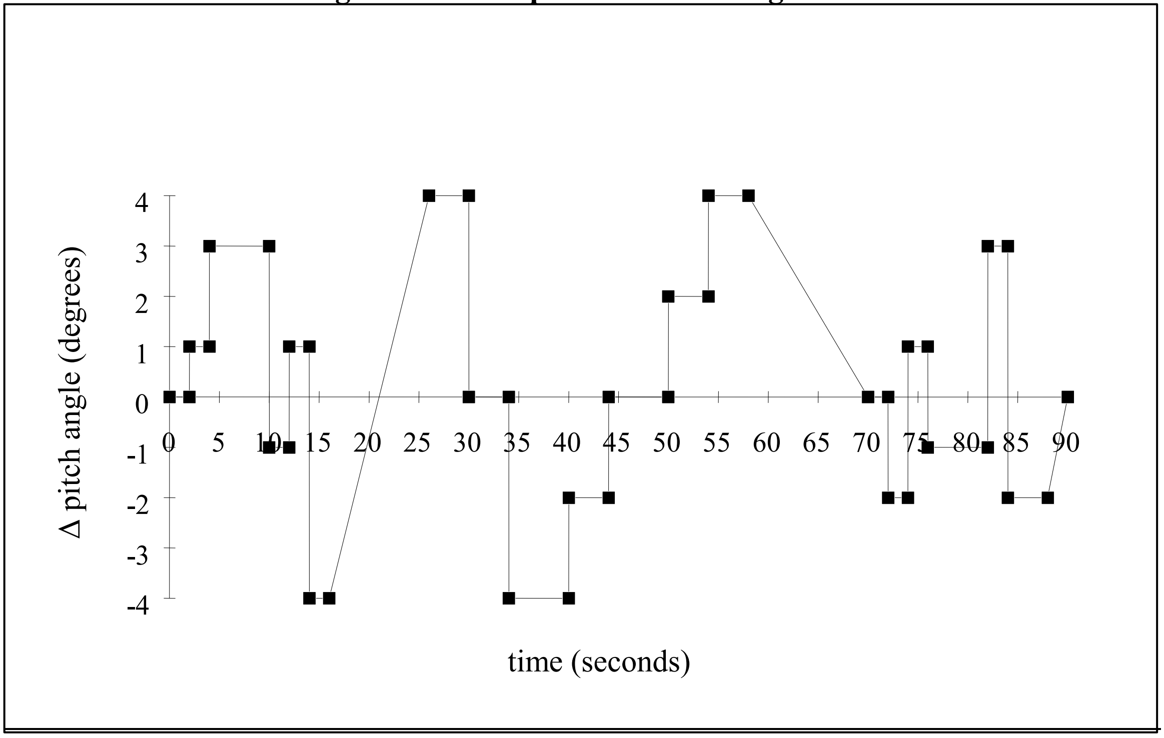
3. Trim for level flight as above. Initiate a 1.5 g to 1.67 g (not to exceed deterrent buffet) pull-up and approximately a 30° bank turn. Once the target g is set, transition the aircraft to approximately a 0.5 g pushover and reverse the turn to establish an intercept heading to the initial course. Using power or thrust as required, set up a stabilized steady heading descent to intercept the initial course and altitude used for the trimmed condition. The pilot may continue the heading and descent through the initial conditions to allow more tracking time if needed. Attempt to precisely set and track bank angle, g, heading, and pitch attitude as appropriate. The pilot should qualitatively evaluate the airplane during both the gross acquisition and fine tracking portions of this task while looking for a PIO tendency in accordance with paragraph 5.1.4.6.

5.1.4.5 Fine Tracking Tasks.
5.1.4.5.1 These tasks may be used to assess the airplane's PIO susceptibility when flying in turbulent atmospheric conditions. In this task, a tracking target is displayed which commands pitch and roll changes for the evaluation pilot to follow. Whatever visual cue is used (e.g., head up display (HUD), flight director, etc.), it should present the tracking task without filtering, smoothing, or bias. The pitch and roll commands should be combinations of steps and ramps. The sequence of pitch and roll commands should be designed so as to keep the airplane within ±1,000 feet of the test altitude and within ±10 knots of the test airspeed. The sequence should be long enough and complex enough that the pilot cannot learn to anticipate the commands. The unfamiliarity is intended to help keep the test pilot's gain high and to preclude inadvertent pilot compensation while accomplishing the task. Such compensation, along with reduced gains, could mask any PIO tendencies.

5.1.4.5.2 Even though these fine tracking tasks will provide insight into PIO susceptibility of a conventional airplane when flying in turbulence, other considerations apply to augmented airplane types. For example, structural load alleviation systems that use the same flight control surface as the pilot will limit the pilot's control authority in turbulent atmospheric conditions. Under these circumstances of rate or position limiting, PIO tendencies will be more critical as previously discussed. Therefore, specific evaluations for turbulent atmospheric conditions with these systems operating are necessary for these airplane types.

5.1.4.5.3 For single axis tasks, it has been found that aural commands given in a timed sequence provide an adequate cue in the event it is not possible to modify the flight director to display the pitch commands.
5.1.4.5.4 Based on PIO events seen in service, high altitude tracking tasks (with up to approximately ±4° pitch excursions from trim occurring at varying intervals of approximately 2 to 5 seconds) have been effective in evaluating PIO susceptibility. These tasks have been used where the airplane is flying under conditions of low g margin to buffet onset. The time history in figure 5-1 below is a pictorial representation of a sample task in MIL-STD-1797A that has the desired attributes for high altitude PIO evaluations.

Figure 5.1. Sample Pitch Tracking Task



5.1.4.6 PIO Assessment Criteria.

5.1.4.6.1 The evaluation of an airplane for PIO susceptibility will be conducted using the FAA handling qualities rating method (HQRM). (See appendix E of this AC for more information on the HQRM). Tasks should be designed to focus on any PIO tendencies that may exist. Table 5-1 below contains the descriptive material associated with PIO characteristics and its relationship to the PIO Rating Scale called out in the U.S. Military Standard.

Table 5.1 PIO Rating Criteria and Comparison to MIL Standard

FAA HQ Rating	PIO Characteristics Description	MIL-STD-1797A PIO Rating Scale
SAT	No tendency for pilot to induce undesired motion.	1
	Undesirable motions (overshoots) *tend to occur* when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated by pilot technique. (*No more than minimal pilot compensation is required*.)	2
ADQ	Undesirable motions (unpredictability or over control) easily *induced* when pilot initiates abrupt maneuvers or attempts tight control. These motions can be prevented or eliminated but only at sacrifice to task performance or through considerable pilot attention and effort. (*No more than extensive pilot compensation is required*.)	3
CON	*Oscillations tend to develop* when pilot initiates abrupt maneuvers or attempts tight control. Adequate performance is not attainable and pilot has to reduce gain to recover. (Pilot can recover y merely reducing gain.)	4
UNSAT	*Divergent oscillations* tend to develop when pilot initiates *abrupt*	5

	maneuvers or attempts tight control. Pilot has to open control loop by releasing or freezing the controller.)	
	Disturbance or *normal pilot control* may cause divergent oscillation. Pilot has to open control loop by releasing or freezing the controller.	6

SAT= Satisfactory CON = Controllable
ADQ = Adequate UNSAT = Unsatisfactory or Failed

5.1.4.6.2 Table 5-1 above provides the FAA handling qualities (HQ) rating descriptions of airplane motions that may be seen during the conduct of specific PIO tasks or during tests throughout the entire certification flight test program. The italicized phrases highlight major differences between rating categories in the table.

5.1.4.6.3 The acceptable HQ ratings for PIO tendencies is shown in Table E-2 of appendix E. criteria, varies with flight envelope, atmospheric disturbance considered, and failure state. For example, Table 5-2 below shows a handling qualities matrix for a tracking task with the airplane at aft CG trimmed in flight conditions giving 1.3 g to buffet onset.

Table 5.2 Example of acceptable HQ Rating for PIO tendencies

Airspeed	M_{LRC}	M_{LRC}	M_{LRC}	M_{LRC}
Load Factor Range	0.8 to 1.3	-1.0 to 2.5	0.8 to 1.3	-1.0 to 2.5
Buffet Level	Onset	Deterrent	Onset	Deterrent
Turbulence	Light	Light	Light	Light
Failure	None	None	Improbable failure of SAS	Improbable failure of SAS
Flight Envelope	NFE	LFE	NFE	LFE
Minimum Permitted HQ Rating	SAT	ADQ	ADQ	CON

SAT = Satisfactory ADQ = Adequate CON = Controllable

NFE = Normal Flight Envelope LFE = Limit Flight Envelope

SAS = Stability augmentation System LRC = Long range cruise Mach number