AIA **Powerplant Indications Task Team Report**

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DRAFT **UNOFFICIAL**

Abstract

Airplanes, Commercial, Transport, Engines, Powerplant, Jet, Turbofan, Turboprop, Indications, Certification, Displays

Disclaimer:

The views expressed herein are endorsed by the members of the AIA Powerplant Indications Task Team (Appendix B) and do not necessarily reflect the views of the companies & agencies that they represent.

Executive Summary

The AIA Powerplant Indications Task Team was formed July 2001 in response to the FAA draft Harmonization Terms of Reference (HTOR) 25.1305. The team was subsequently sanctioned by the AIA as the Powerplant Indications Task Team. The team includes representation from several Airframe Manufacturers, Engine Manufacturers and Regulatory Agencies. The AIA PITT was an active working group from late 2001 through mid-2006. After 2006 the team gradually prepared a team report via ad hoc team telecons. The team has provided:

- A Powerplant Indications input to the Avionics Systems Harmonization Working Group (ASHWG) draft AC/AMC 25-11 Electronic Displays. Much of the AIA Powerplant Indications Task Team input was incorporated in revision AC25-11A released by the FAA in June, 2007
- A revision proposal to FAR/CS §25.1305 "Powerplant instruments". The proposed §25.1305 allows for use of the existing prescriptive list of powerplant indications (updated in some areas) or alternatively an objective-based approach for some or all powerplant indications. A notable addition to the prescriptive list is the requirement for an engine fail (sub-idle) indication.
- Recommendations for a revision to FAR/CS §25.1549 "Powerplant and auxiliary power unit instruments". §25.1549 requires revision to align with current accepted practices and to allow for alignment with crew alerting requirements of §25.1322.
- Recommendations for a revision of AC20-88A, to align with current accepted practices and to allow for alignment with crew alerting requirements of §25.1322. AC20-88A is outdated relative to current design practice (i.e. glass flight decks).
- Recommendations for a revision to FAR/CS §25.1337 "Powerplant instruments". §25.1337 is in some cases redundant to other, existing regulations and in some cases outdated relative to current technology. In addition, §25.1337 is a mix of flammable fluid requirements, indications requirements and fire safety requirements. The AIA Powerplant Indications Task Team recommends that these different types of requirements be grouped appropriately within the Code of Federal Regulations.
- A white paper intended for the FAA Engine and Propeller Directorate and EASA Engine Certification branch regarding "Engine Parameter Indication and Certification: The Integration of Engine TCDS Limits and Their Role in Aircraft Safety". This paper addresses the current practice of treating all engine certification limits as safe operating limits and therefore marking their airplane indications with redlines and, in some cases, associating flight deck warnings lights or messages. This is often inconsistent with aircraft display philosophy and airplane certification requirements.
- A response to HTOR 25.1305, and
- A Team Report, which this document comprises.

Main Contributing Individuals and Organizations

Individuals	Organizations*
Members Past & Present	
Pierre-Emmanuel Arnaud	Airbus
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Patrick Zaccaria	Airbus
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Larry Carlisle	Pratt & Whitney
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***Note:** This list reflects the organization that the individual represented at the time during which they participated in the AIA Powerplant Indications Task Team.

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1. BACKGROUND:

1.1 Team Formation

The AIA Powerplant Indications Task Team was initially formed in response to an FAA task raised at the Aviation Rulemaking Advisory Committee (ARAC) Transport Airplane and Engine Issues Group (TAEIG) Powerplant Installation Harmonization Working Group (PPIHWG) to investigate a number of concerns related to powerplant indications, including some previously raised by the AIA/AECMA Report on “Propulsion System Malfunction Plus Inappropriate Crew Response”. The specific task was documented in a draft Harmonization Terms of Reference 25.1305 (10/25/00) which is provided as Appendix A to this report. Coincidentally, an ARAC Avionic Systems Harmonization Working Group (ASHWG) was tasked to update FAA Advisory Circular AC25-11 ‘Transport Category Airplane Electronic Display Systems’ (1987). Given this, the FAA included tasking for the Powerplant team to make recommendations with regard to the powerplant portions of AC25-11 to the ASHWG.

A Powerplant Indications Task Team (PITT) was created within the ARAC TAEIG PPIHWG in preparation for the tasking. However, before the tasking could be completed, a moratorium was placed on PPIHWG activity. Recognizing the importance of this work, PITT obtained sanctioning from the Aerospace Industries Association to complete the tasking. AIA PITT includes representation from several Airframe Manufacturers, Engine Manufacturers and Regulatory Agencies. Appendix B details the AIA Powerplant Indications Task Team membership. This report documents the recommendations of that team:

- PITT is proposing changes to §25.1305 “Powerplant instruments”. The proposed §25.1305 allows for use of the existing prescriptive list of powerplant indications (updated in some areas) or alternatively an objective-based approach for some or all powerplant indications.
- PITT has provided proposed revisions to the powerplant indication guidance for the next revision to AC / AMJ 25-11. The proposal was submitted to the Avionics Systems Harmonization Working Group (ASHWG) who were responsible for drafting a proposed revision to AC / AMJ 25-11 in June 2006 and to the FAA who released the new version AC25-11A in June, 2007. Much of the PITT input was incorporated into the released version.
- PITT proposes a revision to §25.1549 “Powerplant and auxiliary power unit instruments” §25.1549 is outdated relative to current design practice i.e. glass flight decks. The continued application of §25.1549 in its current form is routinely requiring Equivalent Safety Findings be made, which is an undue burden on both the applicant and the FAA.
- PITT is also recommending that some follow on work be done regarding: Asymmetric Thrust/Power; Low Fuel Indication; Engine Surge/Stall Indication; Advisory Material for the Proposed §25.1305 Revision; and an AC20-88A Update.
- PITT is recommending that the FAA Engine & Propeller directorate and the EASA Propulsion Branch work on implementing changes to allow for improvement in the integration of the Engine limits with the aircraft powerplant displays as detailed in Appendix J of this report.

At the onset PITT created a set of Ground Rules, Assumptions and Agreements for the team effort (Appendix C). This appendix provides a two page summary of the principles that guided the team during the effort. Fuel System indications and Auxiliary Powerplant Unit indications are not addressed in this report. The ground rules created by the team are as follows:

1.2 Ground Rules

1. **Safety** Clearly define the safety issue. Regulations are driven specifically by safety requirements.
2. **Flightcrew** The team is addressing powerplant indications specifically for use by the flightcrew.

   (a) Assumes no flight engineer.

   (b) Assume the flightcrew does not have flight engineer background or training.

(c) Assume the flightcrew has no in-service experience with propulsion system malfunctions, but does have the appropriate simulator training experiences associated with major propulsion system malfunctions, e.g. loss of thrust/power events.

(d) Assume the flightcrew does not continuously monitor powerplant displays, but monitors as their recurrent operational authority training and their own operator policies require.

3. **Powerplant Indications** The existing regulations were written when powerplant indications were primarily parameter gauges and lights for flight and maintenance crews. Current generation airplanes have an increased capability to provide processed information to the flightcrew, e.g. combining parameters within a display, different display formats available to the flightcrew, text messages, electronic checklists, synoptic displays, lights, and aural alerts.

4. **Displays** For current and future airplanes assume screen-based displays and a central alerting system driven by a digital computer.

5. **FADEC** Assume EEC controlled engines, i.e. a microprocessor based system of engine parameter sensing, control and communication. Current generation EECs generally include features such as automatic rotor speed redline limiting, overboost protection, overspeed protection, surge detection/recovery, EEC-driven crew alerts, etc. Future engine control systems will likely include additional capability.

6. **New Designs** The emphasis of this HTOR is on future applications: new airplanes, new engines. The team's proposals should allow for future growth in airplane & engine systems capabilities.

7. **Boundaries**

(a) The team is limited to powerplant indications.

(b) Issues concerned with other airplane systems or areas of expertise (e.g. Pilot/Flight Test, Human Factors, and Avionics for AC/AMJ 25-11) will be forwarded to the appropriate teams covering those areas.

(c) The engine, powerplant, and the engine fuel-system (airplane spar valve and downstream) are included.

(d) The harmonized APU rule is acceptable as-is, i.e. JAR 25A1305 APU Instruments, which later was adopted as EASA CS 25J1305 APU instruments. This team needs to ensure that any proposed 1305 does not conflict with the harmonized EASA CS 25J1305 APU instruments.

(e) The Airplane Fuel System (upstream of the airplane spar valve) is excluded (e.g. Low Fuel Quantity). Note that there was no Harmonization Working Group for the Airplane Fuel System at the time that AIA PITT was active. This issue was raised to the PPIHWG Steering Committee.

- Since that time the FAA and EASA have progressed the issue of low fuel alerting:
  - FAA Amendment 25-120 (2007) CFR 25 Appendix K Section K25.1.4 Propulsion systems.(a) (3) An alert must be displayed to the flightcrew when the quantity of fuel available to the engines falls below the level required to fly to the destination. The alert must be given when there is enough fuel remaining to safely complete a diversion. This alert must account for abnormal fuel management or transfer between tanks, and possible loss of fuel. This paragraph does not apply to airplanes with a required flight engineer.
  - EASA Amendment 12 CS25.1305 Powerplant intstruments (a)(2)(iv) Provide(s) a low fuel level cockpit alert for any tank and/or collector cell that should not become depleted of fuel. Each alert is such that (A) It is provided to the flight crew when the usable quantity of fuel in the tank concerned reaches the quantity required to operate the engine(s) for 30 minutes at cruise conditions; (B) The alert and the fuel quantity indication for that tank are not adversely affected by the same single failure.

8. **Data** Document decisions and substantiate using facts & data.

1.3 Safety Issue

This team was initiated from an FAA task raised to the ARAC-TAEIG-PPIHWG to investigate a number of concerns related to Indications.

The need for this activity comes from a number of areas.

- Incidents and accidents have occurred where misinterpreted powerplant indications have played a significant role, as documented within the FAA sponsored AIA/AECMA "Propulsion System Malfunction Plus Inappropriate Crew Response" report. One recommendation of this report is as follows:

  "9.3 Powerplant Instrumentation

  A wide range of powerplant instrumentation is provided on multi-engine commercial airplanes. Some evidence is available regarding the effectiveness of the different ways in which powerplant information is presented to flight crews. It is proposed that ARAC be tasked with reviewing the requirements of FAR/JAR 23 and 25, paras 1305, 1321, 1337 and 1585, in order to produce an updated standard for powerplant instrumentation based on the information available. At this time, it is not expected, that retrospective application of a revised standard of instrumentation will be justified."

- Certification activity has found that the prescriptive requirements of §25.1305, §25.1549 and the electronic display interpretative material of AC25-11 do not adequately address present-day display systems and the improved capabilities that they offer. These requirements were created before electronic displays and FADEC systems existed. Current capabilities include displaying information only when needed via inhibits & pop-ups, prioritizing information, simplifying data, and the ability to provide computer processed display information based on integrated/interpreted parameter data.

- The regulations require that engine defined maximum/minimum safe operating limits be displayed as redlines. The colors of these limit markings are not always consistent with the color of alerts provided for exceedances of the limit. This is because the color of alerts is defined by the cockpit requirements of §25.1322, which addresses warning, caution, and advisory alerts, and the color operating limits is defined by §25.1549, which addresses engine limit markings. §25.1322 defines levels of alert based on the required flightcrew reaction (e.g. immediacy of awareness and action) and defines the color to be used by the highest level of alert (warning) as red. Some on this team have suggested that a red colored engine limit exceedance display could be a distraction from flying the aircraft, addressing the highest-level failure first and / or following flight manual defined procedures, because of the association of red color with warning level alerts. Warnings should only be displayed when immediate action by the flightcrew is required to maintain continued safe airplane operation. Exceeding an approved engine safe operating limit may, or may not, result in an unsafe malfunction of the engine. To enable a safety objective-based approach within the regulatory requirements for engine indications, the revised regulatory requirements acknowledge in effect that traditional Flight Engineer tasks are now replaced by the ability of the engine control and display systems to monitor and process engine parameter data and provide more readily understood and useful information to the flightcrew. It is important to evolve the regulations from a set of prescriptive design features to a less changeable set of design objectives to take fullest advantage of advancing monitoring and processing technology to provide the most effective displays possible. In other words, it is important that regulatory requirements do not constrain display approaches and technology that could enable a more effective flightcrew interface.

1.4 Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR)

The FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response" (PSM+ICR) concluded that improved indications of engine malfunction could potentially have prevented some PSM+ICR incidents. Particular importance was placed upon identifying the affected engine. Improved indications should have the appropriate level of alert corresponding to the urgency of flightcrew awareness of and/or response to the condition, e.g. allowing consideration of inhibiting indications during high workload time intervals. The continuous display of parametric data requires flightcrew monitoring and interpretation, and has the potential to distract the flightcrew from the prime task of flying the airplane.

The underlying safety issues being addressed in this report are documented in the AIA/AECMA Project Report on Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR), Volume 1, Aerospace Industries Association and the European Association of Aerospace Industries AECMA, 1998. The report documents 79 PSM+ICR events, 34 of which resulted in accidents, occurring between 1959 and 1996 for Western-built commercial transport airplanes heavier than 60,000 pounds [27,216 kilograms] maximum gross weight. The PSM+ICR report provides a series of conclusions and recommendations. The particular conclusions/recommendations which are addressed, at least in part, in the AIA Powerplant Indications Task Team are as follows:

> "Although the vast majority of propulsion system malfunctions are recognized and handled appropriately, there is sufficient evidence to suggest that many pilots have difficulty identifying certain propulsion system malfunctions and reacting appropriately"
>
> "The changing pilot population, coupled with reduced exposure to in-service events from increased propulsion system reliability, is resulting in large numbers of flight crews who have little or no prior experience with actual propulsion system failures"
>
> "A review of propulsion system instrumentation requirements should be completed to determine if improved engine displays or methods can be found to present engine information in a manner which would better help the pilot recognize propulsion system malfunctions"
>
> "The task group discussed the issue of whether presentation of all parameters required by the FARs/JARs regulations helps or hinders in diagnosing engine malfunctions. These parameters may help in trend monitoring, but their varying relationships at different power and atmospheric conditions make them difficult for crews to use when analyzing a problem."
>
> "An engine failure indication - e.g., "engine #_ fail" -displayed to the flight crew when the engine rolls back or runs down to a subidle condition could be beneficial."
>
> "The locations of warnings, indicators and controls should not lead to a mistaken association with a particular engine."

From the PSM+ICR report, the FAA Draft HTOR, and subsequent PITT activities, the team identified several opportunities for safety improvements:

- Provide information in a format that can be readily interpreted by the flightcrew.
- Design powerplant indications for the intended flightcrew, e.g. if there is no flight engineer continuously monitoring the engines, then the engine system and display system may need to fill some of this role and alert the pilot to conditions that require awareness/action
- Recognize that there are powerplant indications that are intended for maintenance use.
- Provide "information" rather than "data".
- Target the indication on the intended flightcrew response.
- Alert the flightcrew that a malfunction has been detected which require their awareness and/or action in a timely and appropriate manner.
- Clearly identify the malfunctioning engine.
- Use a color other than red for engine operating limit indications when immediate flightcrew response is not required (see Appendix J "The Integration of Engine Type Certificate Data Sheet Limits with Flight Deck Engine Indications and Alerts" for more details and considerations).
- Use the capabilities of electronic flight deck displays to improve the timeliness of presentation
- "Pop-up" powerplant indications automatically when needed.

- Inhibit powerplant indications or alerts when they interfere with higher priority safety displays.
- Consider whether data or information that is not used for any published procedure, normal or abnormal, should still be displayed to the flightcrew (i.e. to preserve flightcrew attention/focus on the highest priority information).

1.5 Existing Regulations

Appendix D of this document contains a list of all regulations and advisory material related to powerplant indications for transport category airplanes.

Appendix E of this document contains the text of some of the key current relative regulations for both the FAA and EASA.

The FAA and EASA regulations are considered equivalent. The only difference in interpretation is related to the means to document compliance. The FAA consider that the regulations must be interpreted as they were interpreted at the time they were drafted (i.e. electronic, smart displays did not exist) while EASA & Transport Canada have used the intent and an objective based interpretation to determine compliance. This does not result in any difference in aircraft design, but tends to result in the use of Equivalent Safety Findings in FAA airplane certifications. Note: the CS regulations do not address reciprocating engine powered transport category airplanes.

1.6 Evolution of Technology

Technology has changed significantly since these existing regulations were released:

- Two-crew flight decks with no flight engineer are the industry standard.
- Generally, a check of the propulsion system by the maintenance crew is no longer required before and after each flight.
- Engine FADEC systems are the industry standard.
- Modern indication systems automate the traditional flightcrew-monitoring task, process data, and provide more readily understood and useful information.
- Existing Powerplant regulations were based on mechanical 'instruments' (Figure 1) while modern systems typically provide powerplant indications on electronic displays (Figure 2). The electronic display guidance material was initially created when early generation displays were under development, before the capability and good reliability of these systems was understood.
- This advancement in technology allows systems to provide information as needed, rather than simply providing full-time parameter indications. Simple alerting features in dedicated flight deck display can:
    - confirm the validity of the information,
    - prioritize the conditions for response, and
    - provide attention-getting means to direct the crew to identify the problem and take the appropriate corrective action in a more timely fashion without other possible diversions (e.g. inhibiting secondary effect information)
- When an engine rotor speed is being limited by the FADEC system to an approved operating limit, the display of that rotor speed does not have to be indicated with an abnormal color or other "limit" related indication.
- Existing Powerplant regulations generally discuss indications used by the flightcrew along with those used for maintenance tasks in the same section of the regulation.

The following table summarizes some of the differences in operational and power plant indication "paradigms" from the time that the current regulatory requirements were originally released ("old paradigm") vs. those in place at the current time with current production models ("new paradigm").

Old paragigm	New pardigm
See figure 1 and 2 for examples of old vs. new paradigm	
• flight engineer monitors powerplant instruments • full-time instruments • non-adaptable • fixed scale on parameter gauges • simple alert indications • fixed instrument location on the flight deck • paper checklists • includes powerplant instruments used by flight and maintenance crews	• two-crew flight deck • no flight engineer • FADEC systems provide engine monitoring and overspeed protection • electronic displays (a.k.a. "glass cockpit") • displays driven by digital computer with ability to apply logic • conditionally adaptable formats, scales and markings on parameter gauges • powerplant indications can be moved to different display space if needed, e.g. in case of display unit failure • some indications can be part-time, i.e. "pop-up" when needed • electronic checklists • maintenance displays segregated from flightcrew displays

Figure 1 Example of prior generation (pre-glass cockpit, circa 1968) flight deck powerplant indications - Boeing 737-200 with Pratt & Whitney JT8D engine.

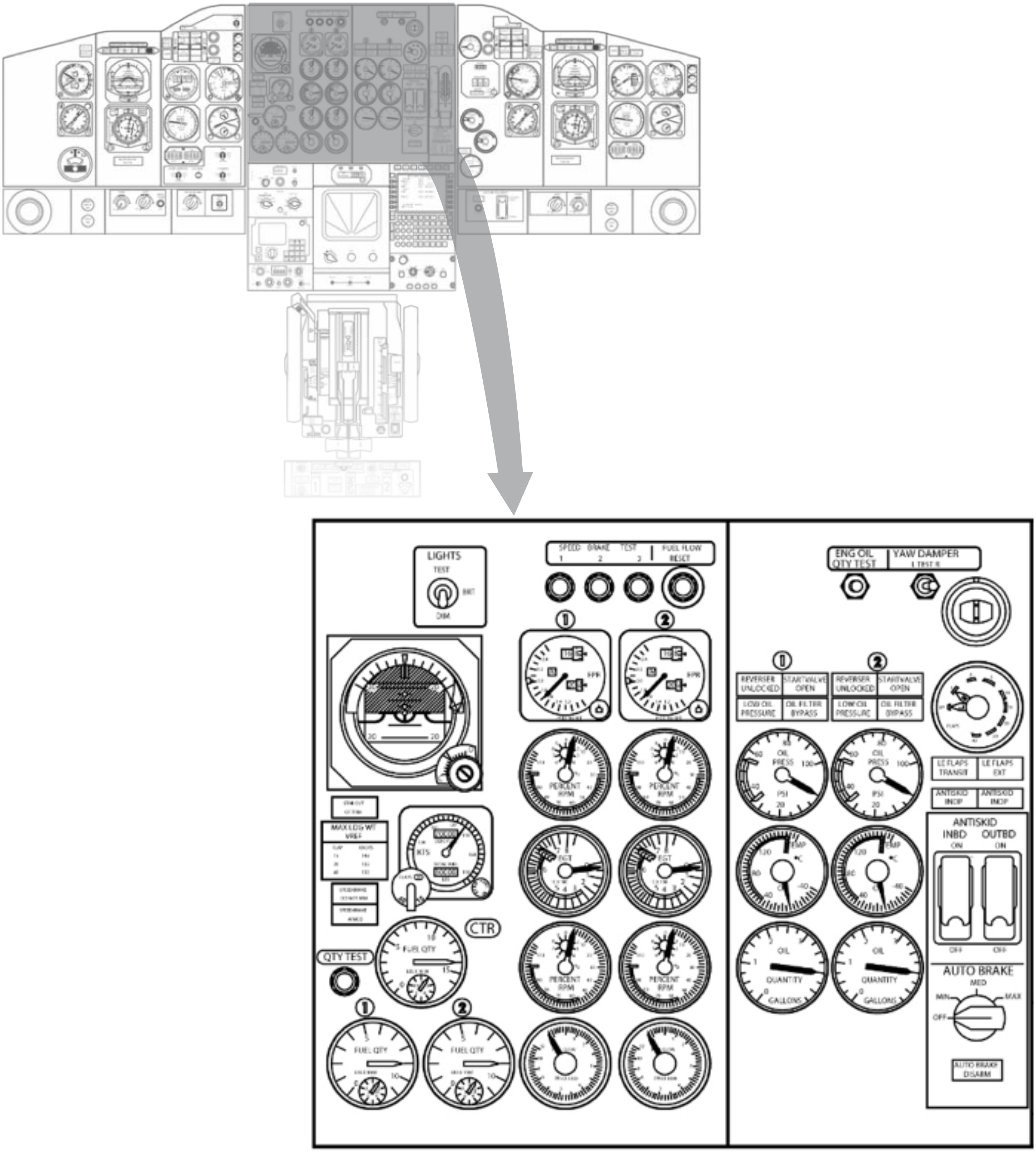
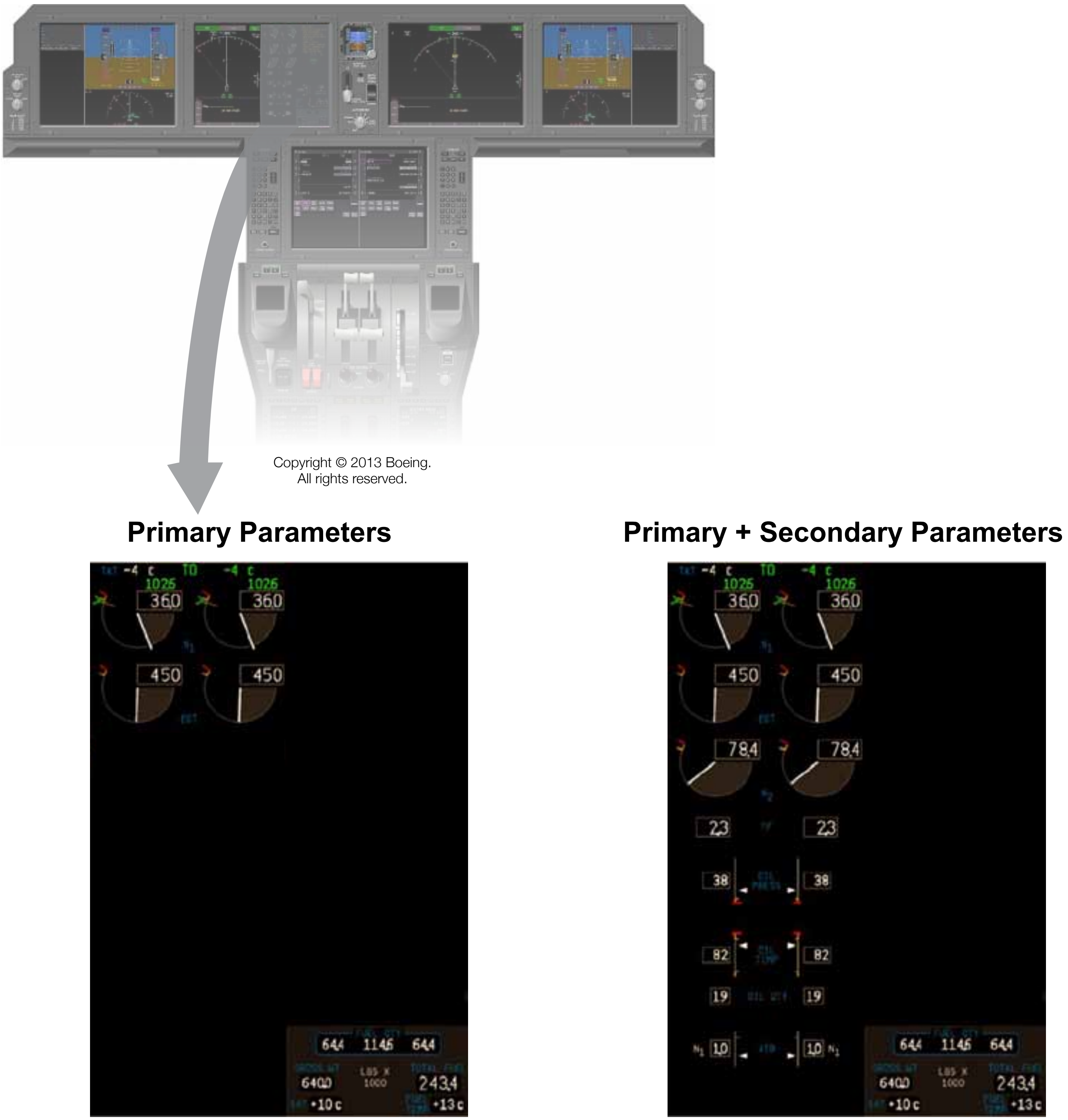


Figure 2 Example of current generation (circa 2012) flight deck powerplant indications - Boeing 787-8 with General Electric GEnx engine. During normal operation, typically only the primary parameters are displayed (see lower left).. The primary + secondary parameters (see lower right) may be displayed either manually by flightcrew selection or automatically under specific normal and non-normal operation conditions where secondary engine parameters are needed.



1.7 Recommended Strategy

The primary relevant regulations are §25.1305 'Powerplant Instruments', §25.1309(c) 'Warning Information', §25.1322 "alerting" and §25.1549 'Powerplant and auxiliary power unit instruments'.

Improvements to §25.1305 'Powerplant Instruments' are recommended herein.

A new 'objective-based' requirement, §25.1305(g) is proposed for addition to §25.1305. The intent of this objective-based requirement is to recognize the ability of electronic display systems to process data and provide more readily understood and useful information, thereby automating some of the traditional flightcrew monitoring tasks. Further, as modern engine FADEC controls generally serve as the primary means for assuring that engine operation remains within safe operating limits, the powerplant displays are now serving a backup role to the monitoring of engine operation. In accordance with sub section (g)(3), some required powerplant indications may be intended for usage other than by the flightcrew. Such indications may be located in places other than the flight deck.

The rapid evolution of engine/airplane control and display system technology will continue, which is why it is appropriate for the regulation to provide timeless design objectives rather than the prescriptive design requirements that they do today.

Requirement §25.1309(c) 'Warning Information' is considered appropriate by AIA PITT, as it is a generally applicable objective requirement ensuring that the flightcrew is alerted to any foreseeable unsafe system operating condition in an manner which enables them to take appropriate corrective action while minimizing the potential for crew error. The intent of PITT is for the new objective requirement of §25.1305(g) to identify those engine failure conditions that require 'Warning Information', have those identified engine conditions brought into the §25.1309(c) certification process, and implement any crew alerts consistently with §25.1322.

The current §25.1549 rule and AC20-88A policy are prescriptive and outdated. They often conflict with modern flight deck design objectives and sometimes even with other regulations, such as §25.1322. All too often these shortcomings must be overcome by means of formal "Equivalent Safety Findings" (ref: §21.21(b)(1)), "Exemptions" (ref: §11.15) or "Special Conditions" (ref: §21.16). Consequently, this team recommends that §25.1549 and AC20-88A be revised to make them more compatible with modern flight deck design objectives. These revisions should take full advantage of the latest AC25-11, §25.1322 rule and policy, as well as any progress made towards resolving the Part 33 Engine Limits, PSM+ICR, and other outstanding issues discussed elsewhere in this report. For more background regarding this recommendation see Section 2.2.

FAR/CS §25.1337 is titled "Powerplant instruments", however, only addresses a limited set of powerplant indications requirements, i.e. fuel flow, fuel tank quantity, fuel pressure, turboprop blade angle, and oil quantity. There are existing rules which state the requirement to have these indications, making some of the provisions of §25.1337 redundant:

- fuel flow: §25.995 and §25.1305(c)(2)
- fuel tank quantity: §25.1305(a)(2)
- fuel pressure: §25.1305(a)(1) and (b)(4)
- turboprop blade angle: §25.1305(e)(2)
- oil quantity: §25.1305(a)(3)

The remainder of §25.1337 addresses installations aspects of these indications, i.e. flammable fluid and fire safety. These aspects could be grouped more logically under existing CFR 25 sections which cover these installation requirements:

- Fuel System Design
- Oil System Design
- Powerplant Fire Protection

With regard to the propulsion flight deck indications, there is interplay among §25.1322, AC 20-88A, §25.1549, §25.1337, AC 21.101 and the associated FAA CFR 33 regulations. AIA PITT recognizes that there will be challenges during the transition period as the rules and advisory materials are updated individually, i.e. the rules and advisory materials will not all be updated simultaneously.

2. PROPOSALS

The proposed actions are to update the powerplant regulations to:

a) reflect the interpretations that have been used on modern electronic displays for many aircraft over the past 20 years,

b) offer improvements based on current understandings of safety; and

c) provide an objective based option to the existing prescriptive provisions.

2.1 Proposed FAA and CS regulation §25.1305 Powerplant Indications

Appendix F of this document contains the proposed revision to §25.1305 Powerplant Instruments.

The proposed rule change is offered to the FAA and EASA.

i. Discussion of the rule changes for §25.1305:

1) Change emphasis from 'instruments' to 'indications',
This change is considered necessary to address modern display systems where individual gauges are no longer necessarily used. The instruments referenced at the time of rule creation were those associated with individual mechanical gauges. The intent of the rule change is to maintain the requirement of providing the 'information' to the flightcrew, but removing the implied requirement for individual gauges for each parameter being displayed.

2) Standardize crew alerting terminology based upon §25.1322,
Throughout the present §25.1305 rule, wording implied a level of alerting that may not be consistent with the level of alert required in accordance with §25.1322 and accepted design practice. Many items used the term 'warning' or a 'warning means', which implies a red indication and immediate crew awareness & action, but this is not necessarily what was intended or needed, nor is it even always desirable. The term "alert" is proposed as this allows the designer to ensure the indication is consistent with the existing rules and guidance material, predominantly §25.1322.

3) Add a new requirement for an engine fail below idle indication.
AIA PITT recommends the inclusion of this requirement. This was one of the HTOR items that the team was tasked to review. This recommendation aligns with the PSM+ICR recommendations to clearly identify the malfunctioning engine. This indication improves crew awareness of a failed engine and facilitates appropriate crew action being taken on the appropriate engine, especially where such events are masked by current flight phase and/or secondary indications, such as the engine electrical generator going offline. Technology has enabled the display of such a message in a timely, reliable fashion. This message may be used as a collector message for many systems that are influenced by an engine failure.

Many of the more recent aircraft designs have incorporated such an indication, i.e. FADEC monitors engine operation and alerts the flightcrew if an engine has fallen below the engine idle setting. These existing implementations address uncommanded engine rundowns to a level below idle, but do not address inadvertent crew selected shutdown. Often the message is used as a collector to preclude multiple indications that may occur and potentially confuse the crew or delay identification of the root cause of the failure. Possible concurrent indications include: electrical power generation, engine driven hydraulics, engine bleed and anti-ice, automatic flight control, and engine oil pressure. The use of one "engine fail" alert focuses flightcrew awareness/response on the airplane effect (e.g. single engine flight, asymmetric thrust) and identify the initial malfunction (the engine) rather than secondary effects on the electrical or hydraulic systems, or the resulting low engine oil pressure. Note that standard alert inhibiting practices are required for the engine failure alert (e.g. inhibiting the attention getting features during takeoff above V1 in order to limit the potential for high energy rejected take-off).

The task team considers this indication to be current practice for new transport category aircraft, considers that it does provide improved safety, when implemented with the proper inhibits, by improving flightcrew awareness and hence considers the rule change to add this new requirement appropriate.

4) Amend §25.1305(d)(1) by deleting the requirement to indicate a change in thrust resulting from any engine malfunction, damage, or deterioration.

The requirement is proposed to be changed to: 'An indication of thrust, or a parameter that is directly related to thrust, to the flight crew. The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust.'

The first sentence of this requirement clearly states that the indicator must be based on the direct measurement of thrust or parameters directly related to thrust. No additional clarification is needed. The indicator need not provide an indication of a thrust change during an engine damage event. In fact, existing certified designs do not meet the letter of this requirement. Other indications are available for that purpose. The requirement, as written and without supporting guidance material, could unnecessarily prevent the continued use of existing proven designs and unnecessarily constrain innovation in future designs.

Other requirements within §25 provide for the intention of this sentence without putting impractical constraints on the means of compliance.

- A thrust indication system must function properly, §25.1301(d).
- A thrust indication system must perform its intended function under any foreseeable operating condition and in a safe manner, §25.1309(a & b), and §25.901(b & c).
- If in a particular application a change in thrust is considered an unsafe condition, §25.1309(c) requires an appropriate warning system, which is far more encompassing requirement than an indication of thrust change.

The justification material is contained within Appendix G to this document

5) Where applicable, segregate powerplant indications by intended use for flightcrew vs. for maintenance. Powerplant indications used strictly for maintenance need not be displayed to the flightcrew and are not subject to the rules and guidance intended for flightcrew usage. See Section "3.2.7 Maintenance Indications".

6) Add a generic requirement 'indications to support aircraft operation' to ensure that it is clear that required indications are not limited to those specifically defined in §25.1305, and to allow other indications in lieu of some or all of those specifically defined in §25.1305.

The task team spent considerable time discussing the philosophy to be used when developing these Powerplant indications changes. Two distinct approaches could be used.

1. Continue to have prescriptive requirements and add to these as required, or
2. Accept objective requirements (e.g. support procedures, crew awareness, identify unsafe conditions, etc.)

From a philosophical standpoint, the general consensus within the group was that an objective based approach was best, i.e. aligned with a top-down safety-based design. From a practical standpoint, however, the team decided that the existing prescriptive indications within §25.1305 should be retained and improved. The reason for this was to simplify certification for applicants who chose to comply with some or all the existing regulation and to make the introduction of this objective requirement less controversial by retaining most of the existing regulation. This safety objective based rule is proposed as follows:

For all airplanes. Powerplant indications as required to support safe operation of the airplane such as:

(1) Flight deck indications to support the approved operating procedures [e.g: §25.1585]

(2) Indications as required by the powerplant system safety assessments [e.g: §§25.901, 25.903 and 25.1309]

(3) Indications required to support the instructions for continued airworthiness [e.g: §25.1529]

ii. Reason for the Rule Change

The existing Powerplant regulations were based on mechanical ‘instruments’ versus powerplant indications by electronic displays.

The existing Powerplant regulations do not allow for an objective safety-based approach.

Technology has changed significantly allowing systems to provide information, versus simply data, in a more effective manner. Today’s display systems can confirm the validity of the information, prioritize the data, and provide attention-getting means to direct the crew to identify the problem and take the appropriate corrective action in a timely fashion.

The rule change proposal no longer refers to “instruments”. The proposed terminology is consistent with other rules that require alerts to be clear as to the urgency for crew awareness and response. The proposed rule clarifies that there are sources for required powerplant indications other than those specifically defined in §25.1305 (e.g. for the safety assessments or for supporting operating procedures or instructions for continued airworthiness)

Advances in engine control system and flight deck display technology can be used to reduce the requirement for flightcrew monitoring of engine parameters. This is considered inherently beneficial to airplane safety, since it allows the flightcrew to focus on the primary task of flying the airplane. Proposals to condense engine parameter data into more useful information should be encouraged, as fostering overall airplane safety.

iii Specific versus Objective Requirements

The most significant item of debate was: Should the rule contain specific requirements or would the rule be better with objective requirements?

Specific requirements would simplify certification of powerplant instrumentation, but would not necessarily provide the optimal design from a safety standpoint. The objective requirements approach would allow for a safety-based design but could pose difficulty and confusion in their initial application, and would need associated guidance material to ensure a consistent approach and rule interpretation.

The team decided on a compromise-combined approach. The proposed §25.1305 retains and improves the specific requirements but allows for an alternative objective-based approach in lieu of some or all of the specific indications. The regulations should provide adequate information to assist the design and certification of an aircraft and minimize future debates on the intent of the rule.

In support of advanced future displays/indications, the task team did support adding an introductory sentence in the rule allowing deviations to the specific indications if adequately justified.

> ‘The aircraft must be equipped with the powerplant indications listed in paragraphs (a) to (f) of this section, unless compliance with paragraph (g) can be shown without some or all of those indications.’

Also the task team considered it prudent to emphasize that other indications could be required, beyond those specified in the rule, so a further paragraph is proposed.

‘(g) *For all airplanes*. Powerplant indications as required to support safe operation of the airplane such as:

(1) Flight deck indications to support the approved operating procedures *[e.g. §25.1585]*

(2) Indications as required by the powerplant system safety assessments *[e.g. §§25.901, 25.903, and 25.1309]*

(3) Indications required to support the instructions for continued airworthiness *[e.g. §25.1529]*’

2.2 Revise FAA and CS regulation §25.1549 and FAA AC 20-88A

This material is outdated relative to technology, AC 25-11A, and the updated requirements for flightcrew alerting §25.1322 (became effective January 3, 2011). For example, per §25.1322, some alerts for limit exceedances can and should be provided as advisory or caution alerts. However, §25.1549 prescribes that limits be shown in red. As such, when implementing per these rules, an inconsistency is created within the flight deck. Revision of §25.1549 is needed to eliminate one of the requirements that results in this inconsistency. In general, engine limits and/or exceedance of engine limits must still be indicated on the flight deck. The intention of updating §25.1549 is to align with the updated requirements of §25.1322 to drive the appropriate level of alert and corresponding alerting color for engine limit exceedances, and limit marking color.

While the PITT recommendation to revise §25.1549 is intended to allow for flight deck implementations to be consistent with the updated requirements of the §25.1322, PITT makes this recommendation with the understanding that engine limit indications consistent with existing practice may need to be allowed for some time. Specifically, the best and safest course of action would need to be determined for a particular airframe application - whether to be consistent with the long established practice (e.g. operating limits are “red lines”, as originally required per §25.1549) or to depart from the legacy approach and provide engine limit indications consistent with the crew alerting requirements of §25.1322.

PITT recommends the following guidelines for the revision of §25.1549 and AC 20-88A:

§25.1549:

- In general, any revision to 25.1549 should consider what the result will look like in the flight deck -- and whether it will convey clear, correct information to the flightcrew regarding conditions related to engine parameter limits. The result should be at least as clear as the current established practice. If not, then the current established practice should still be allowed per the rule.
- The revised rule should allow for continuing established design practice if this represents the best and safest course of action for a particular application.
- Align 25.1549 with 25.1322 – i.e. revise requirements of 25.1549 that result in engine indication implementations that are inconsistent with alerts implemented as required by 25.1322.
- Address the issue of alerts for exceeding safe operating limits (see Appendix J).
- 25.1322 specifically addresses “alerts” while 25.1549 addresses the display of safe operating limits. 25.1549 should continue to provide for crew awareness of safe operating limits as warranted. Note that this does not imply that full-time display of the limits are required, rather other means for providing crew awareness of safe operating limits can be considered. Engine controls often provided automatic control to prevent engine limit exceedances.
- Use “indication” instead of “instrument” for consistency with AC25-11A.
- Generalize yellow to “yellow/amber”.
- Remove the requirements 25.1549(b) to mark “normal operating range”.

AC 20-88A:

- Determine if a unique Part 25 AC should be created in lieu of AC 20-88A or whether this information be incorporated into a revision to AC25-11.
- Align AC20-88A with AC25-11A. Much of the AC20-88A content is now addressed by AC25-11A and some by 25.1322. Eliminate that which is already addressed elsewhere.
- Align AC20-88A with 25.1322, e.g. the guidelines for the use of the colors red and yellow/amber.
- Use “indication” instead of “instrument” for consistency with AC25-11A

- Use "safe operating limits" rather than the term "authorized" for consistency with 25.1549.
- Generalize yellow to "yellow/amber" for consistency with AC25-11A and §25.1322.
- Align AC20-88A with 25.1549 as revised. If 25.1549 or 25.1549(b) is deleted, then allow the use of green, white or other non-alerting colors for indication of normal operation .Remove the reference to "findings of equivalency" for using means other than green operating ranges.

2.3 Revise FAA and CS regulation §25.1337 Powerplant indications

AIA Powerplant Indications Task Team recommends that §25.1337 be revised per the following strategy:

1. Remove requirements which are already adequately addressed in other, existing regulations, e.g. §25.995 and §25.1305.
2. Update the requirements based on current technology.
3. For those aspects which remain; move them to sections of the regulations where they are more logically grouped, i.e. under "Fuel System", "Oil System" or "Powerplant Fire Protection".
4. If there are any requirements remaining under the §25.1337 heading, then revise §25.1337 accordingly. If no requirements remain under the §25.1337 heading, then delete §25.1337.

2.4 Powerplant input to AC / AMC 25-11 'Electronic Displays'

As requested by the originating FAA HTOR, AIA PITT worked in conjunction with the Avionics Systems Harmonization Working Group (ASHWG), who were tasked to update AC25-11 'Transport Category Airplane Electronic Display Systems' (1987). The existing material was considerably out of date, had inconsistencies and conflicting information, and required display reliability levels which were not always commensurate with the potential failure effects. AIA PITT provided to ASHWG revised Powerplant guidance for the draft AC /AMC and made additional recommendations in other areas where the team considered the draft document could be improved. Meetings were held between representatives from the two teams to coordinate the Powerplant input. Much of the team recommendation was included by the AVHWG in their letter to ARAC which became the recommendation to the FAA. The FAA revision to the advisory material: AC25-11A, released in June, 2007, incorporates AIA PITT input, including some input which was not incorporated by ASHWG/TAEIG. One item that needs further improvement is the definition of "indication". This improvement should be included in any future update to AC / AMC 25-11:

Intended:

Indication Any visual information intended for use by the flight crew, e.g. gauges, graphical representations, numeric data, messages, lights, symbols, and synoptics.

AC 25-11A, Appendix 3, Definitions

"**Indication** Any visual information representing the status of graphical gauges, other graphical representations, numeric data messages, lights, symbols, synoptics, etc. to the flightcrew."

The recommendations made to ASHWG are discussed throughout this report and can be found as an Appendix to this report: Appendix H 'Recommendations to the Avionics Systems Harmonization Working Group [re: AC/AMC 25-11]'.

2.5 Engine Limits and the Engine Type Certification Data Sheet (ETCDS)

AIA PITT recommends that the FAA Engine & Propeller Directorate (EPD) align the CFR Part 33 certification of engine limits with CFR Part 25 airplane certification. Specifically AIA PITT recommends that engine limits in the Engine Type Certificate Data Sheet (ETCDS) be defined such that they may be implemented into the aircraft in a manner that is consistent with §25.1322.

Presently engine limits are treated as "maximum safe operating limits" and as such under §25.1549 those limits must be marked in "red", often implemented as a "redline" on the airplane powerplant indication. This report includes a proposal to revise §25.1549, however, should the engine manufacturer(s) continue to refer to these as "maximum safe operating limits", the airframer(s) installing the powerplant must provide the indications to ensure the flightcrew takes immediate action to keep the engines operating below those limits.

PITT is concerned that the exceedance of some certified engine limits is more relevant to long-term damage, or economic considerations, than to requiring immediate flightcrew action to maintain safe airplane operation.

There have been incidents where the display of an engine redline exceedance, which was actually not urgent, distracted the flightcrew from the prime task of maintaining safe airplane operation. The source of confusion is the grouping together in the ETCDS of two different concepts in one requirement - continued operation (which is what the manufacturers write the limits around) and safe operation.

AIA PITT met with representatives of FAA EPD in October 2004 at the FAA EPD Burlington, MA offices. The intent was to establish the link between engine regulations and airplane flight deck design, and to discuss potential improvements. One of the items discussed was engine limits and the potential aircraft hazard when an engine limit is exceeded. The following points were noted during the discussion:

1. PSM+ICR is a leading cause of propulsion related incidents and accidents, for both the first and second CAAM (Continued Airworthiness Assessment Methodologies) studies.
    a. Propulsion displays are contributing to PSM+ICR events, in that these pilots appear to have difficulty interpreting the state of the engine under high workload conditions and in particular respond too quickly to exceedances.
    b. There are cases where pilots are reluctant to allow exceedances (engine indications in red) even if the safety of the airplane is at risk due to other conditions.
2. The current display implementation (data, show ETCDS limit in red color, turn engine indications red for limit exceedance) is driven by many FAA CFR 25 regulations. These refer back to the limits in the ETCDS.
    a. There is an airplane-level default assumption that exceeding any TCDS limit is unsafe.
    b. There is great variation in interpretation of the current rules by both manufacturers and regulators, leading to great display inconsistencies.
3. Engine manufacturers state that exceeding a limit in the ETCDS is not inherently unsafe.
    a. The ETCDS limits indicate normal operation limits; exceedance indicates a possible need for maintenance action.
    b. With FADEC systems protecting engine rotor speeds, an exceedance of another engine parameter limit rarely warrants immediate action by the pilot. Action when other duties permit would be generally appropriate. Delayed action may result in economic damage but is unlikely to affect airplane safety.
    c. Generally, an exceedance would be better conveyed to the flightcrew as a caution or advisory message than a warning.

4. It was proposed that one or more of the following suggestions might be practicable and desirable:
   a. Give parameters an amber band (corresponding to an advisory message) to permit crew action in a reasonable timescale.
   b. Provide notes in the ETCDS, explaining in standardized wording the consequence of an exceedance, and recommending a time frame for crew response. Examples:
      i. Requires immediate crew response.
      ii. Does not require immediate crew response, take action at first reasonable opportunity
      iii. Maintenance action required.

The EPD representatives took an action to consider whether they would permit such notes in the ETCDS, and what standard of substantiation would be required. The airplane/Transport Aircraft Directorate representatives stated that these approaches would allow a more appropriate flight deck implementation.

It is recognized that the progression of engine failures varies from case to case, and that individual crew response also vary. Absolute proof that the indication approach is the best possible for every failure case is not expected, no more than such proof was required to justify the original regulation and Methods of Compliance (MOCs). Analysis should be used to show that the indication approach is effective for the most serious failures generally encountered, for which a timely and effective crew response could reasonably mitigate the failure.

This area of work has not been completed at this time.

PITT recommendations are detailed in Appendix J of this report. In particular, PITT recommends that the engine Specific Operating Instructions include the level of flightcrew response required - per §25.1322 - when any given certified engine operating limit is exceeded. Reference to the SOIs shall be permitted for compliance with this aspect of the FAR/CS Part 25 regulations.

Appendix I, 'AIA PITT Meeting with FAA EPD, September 2004' is a record of the discussions that took place between the FAA EPD and AIA PITT

Appendix J, 'The Integration of Engine Type Certificate Data Sheet Limits with Flight Deck Engine Indications and Alerts', provides historical certification and event data in support of the above PITT position.

3. Recommendations

3.1 Response to FAA draft HTOR 25.1305

The FAA draft Harmonization Terms of Reference 25.1305 which was the genesis for this team is provided in Appendix A. The draft HTOR listed 6 "specific tasks". The following is a summary of the AIA PITT response to each task item.

3.1.1 Low Fuel Indication

The FAA requested that the team consider additional fuel indication, to address low fuel to complete a mission, fuel system quantity independence to the low fuel indication and means to identify a fuel leak or trapped fuel in a timely manner. The task team did not have adequate fuel system knowledge and experience to address these items. The FAA representatives within AIA PITT are pursuing other avenues to have these items addressed.

3.1.2 Engine Failure Indication

The team included a prescriptive indication for Engine Failure (Sub-Idle) Indication in the proposed revision to regulation §25.1305. See Appendix F:

> "(c) *For turbine engine-powered airplanes.* In addition to the powerplant indications required by paragraph (a) of this section, the following powerplant indications are required: ...
>
> (9) For each engine, a means to alert the flightcrew when an engine fails to a below idle condition."

3.1.3 Asymmetric Thrust/Power Indication

The AIA/AECMA PSM+ICR Report and the draft FAA HTOR 25.1305 recommended consideration of a regulatory requirement for a thrust asymmetry indication. The PSM+ICR reports states "An asymmetric thrust indication displayed to the flight crew when the thrust asymmetry exceeds a predetermined value could be beneficial."

AIA PITT views the issue of thrust asymmetry detection and annunciation as one which could potentially yield safety improvements and therefore recommends that this issue be tasked for further work. The issue needs to be tasked at an airplane level rather than at a powerplant level to ensure a system level solution that integrates flightcrew human factors, aircraft dynamic response, and propulsion integration. Representation is recommended from avionics, flightcrews, autoflight/autothrust, flight controls, human factors and propulsion. Any follow-on tasking should include consideration of:

1. All flight phases including landing and reverse operation
2. All dispatchable configurations
3. Thrust lever design and operation
4. The role of powerplant indications, including alerts
5. The potential effect of Thrust or Thrust Lever asymmetry on other airplane systems such as Autothrust/Autothrottle, Autoflight/Autopilot, Autobrakes and automatic spoiler deployment.

Another consideration is whether it is most effective to annunciate/focus crew attention on the source of the asymmetry (e.g. the PSM), the thrust asymmetry itself, or the airplane effects of thrust asymmetry (e.g. low airspeed, potential loss of control). There are relative risks and unique challenges associated with each of the aforementioned approaches that need to be identified and evaluated; i.e. annunciating the asymmetry itself may or may not be the most effective.

Existing regulatory and guidance material related to thrust asymmetry:

Existing regulatory and advisory material already addresses thrust asymmetry conditions either implicitly or explicitly and therefore the team does not believe that a requirement for a dedicated asymmetric thrust message should be mandated by regulations:

- 25.1305(d)(1) – thrust indication (Note that the proposed revision to §25.1305 within this report includes an objective based item proposed under §25.1305, item (g), which implicitly addresses the issue by linking powerplant indication requirements back to the airplane systems safety assessment.
- 25.901(c) – no single failure or malfunction or probable combination of failures will jeopardize the safe operation of the airplane
- 25.1309(c) - Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action.
- AMC 25.901(c) – Powerplant Safety Assessment – See Undetected Thrust Loss, validation of detectable thrust loss including impact on aircraft handling, and loss of thrust control including asymmetric thrust.
- FAA AC 25.1329-1B: Asymmetric Thrust during Autothrust Operation:

  The Flight Guidance Harmonization Working Group has previously recommended an alert for asymmetric thrust during auto-thrust operation which was incorporated in FAA AC 25.1329-1B (July 17th, 2006):

  "Asymmetric Thrust during Autothrust Operation

During autothrust operation, it is possible that a failure (e.g., engine failure, throttle lever jam, or thrust control cable jam) could result in significant asymmetric thrust failure condition that may be aggravated by the continued use of the autothrust system. Because the FGS could potentially compensate for the asymmetric condition with roll (and possibly yaw) control, the pilot may not immediately be aware of the developing situation. Therefore, an alert should be considered as a means of mitigation to draw the pilot's attention to an asymmetric thrust condition during FGS operation."

- Thrust Control Malfunction (TCM) / Uncontrolled High Thrust (UHT) Accommodation

  The specific subset of thrust asymmetry, that due to the loss of thrust control, has been addressed through the AIA / AECMA Project Report on Strategies for Protection from Thrust Control System Malfunctions (1 July 2002). Subsequently, the regulatory authorities have issued Issue Papers regarding §25.901(c) compliance which require Thrust Control Malfunction (TCM) a.k.a. Uncontrolled High Thrust (UHT) issues to be addressed. This has already resulted in design changes to address through automatic systems TCM/UHT conditions where the airplane is not deemed to be controllable by the flightcrew.

Additional considerations regarding thrust asymmetry:

- Identify the Malfunctioning Engine

  The PSM+ICR report stresses the importance of clearly identifying the malfunctioning engine to the flightcrew. In cases where the malfunction results in a thrust change which is identifiable from displayed engine parameters this then also identifies an uncommanded thrust asymmetry.

  Clearly identifying the malfunctioning engine offers two advantages over simply displaying a thrust asymmetry alert:

  - It relieves the flightcrew from having to diagnose a malfunctioning engine among multiple engines. This avoids the potential for detracting from safe airplane operation.
  - Eliminates the possibility that the flightcrew misdiagnoses, i.e. reduces thrust on, or shuts down, the "good" engine.

  There are, however, malfunctions where it may not be possible to automatically identify the affected engine to the flightcrew, e.g. thrust lever system failures where the engine continues to follow the thrust command.

- Thrust Indication

  The design of the flight deck powerplant thrust/power setting parameter display should facilitate easy comparison of the thrust indication for all engines. Thrust indications for multiple engines should be horizontally aligned and should include a graphical representation. The graphical representation should be commonly scaled across the engines so as to allow direct visual comparison between the engines.

  Thrust can also be asymmetric due to non-symmetric electrical, hydraulic or pneumatic bleed loads.

  There are times where the flightcrew may elect to set thrust asymmetrically among the engines (during turns on the ground, when one engine has a failure which requires reduced thrust operation).

3.1.4 Additional Prescriptive Indications as Required by §25.1309(c)

The team did not recommend any additional prescriptive indications other than the Engine Fail (Sub-Idle) item discussed above. The team recommended a combined prescriptive/objective based approach in the proposed revision to §25.1305. The team retained most of the existing prescriptive indications but offered an alternative objective-based approach which focused on the intent of flight deck powerplant indications:

"(g) *For all airplanes*. Powerplant indications as required to support safe operation of the airplane such as:

(1) Flight deck indications to support the approved operating procedures *[e.g.: §25.1585],*

(2) Indications as required by the powerplant system safety assessments *[e.g.: §25.1309*]

(3) Indications required to support the instructions for continued airworthiness *[e.g.: §25.1529]*

See also the discussion under similar HTOR task item 6 below in Section 3.1.6.

3.1.5 Engine Surge/Stall Indication

Although there is some potential benefit to such an indication, the team does not recommend mandating an Engine Surge/Stall Indication in the regulations at this time due to considerations such as:

- technology maturity with regard to detecting engine surge/stall – The message would need to be reliably implemented such that there would be no nuisance messages, otherwise its potential benefit would be compromised.
- modern FADEC engines typically include automatic surge/stall recovery – The team does not believe there is a requirement to indicate an automatically recovered surge/stall to the flightcrew, though an indication to maintenance is appropriate.
- the pros and cons of surge/stall indication near airplane takeoff decision speed – Actually making the crew aware that what they just experienced was an engine surge/stall and the airplane is safe to fly would be very beneficial, especially when the surge/stall occurs near V1. However, given that the time available between such a surge/stall and when the decision to abort or continue the takeoff should be made is so short, actually achieving that awareness is unlikely. Instead, any indication or annunciation in conjunction with the inherent indications of the surge/stall could just increase the likelihood that the crew will perform an unnecessary reactive abort, perhaps even above V1. Add to that shortcoming the potential for nuisance indications and there may be more potential to do harm than to do good with such an indication during takeoff phase of flight.

Engine Surge/Stall Indication has been partially addressed by the FAA Research Project "Indications of Propulsion System Malfunction" (see references below). AIA PITT recommends that further research be undertaken to evaluate the potential for integrating engine health data in real-time with the goal of providing information useable by the flightcrew to facilitate appropriate action (e.g. engine surge/stall indication).

FAA Research Project: Indications of Propulsion System Malfunctions – Reports:

(1) DOT/FAA/AR-03/72, Indications of Propulsion System Malfunctions, S.T. Clark, R.E. Iverson, R.J. Mumaw, J.A. Sikora, J.L. Vian, and V.J. Winters, The Boeing Company, P.O. Box 3707, Seattle, WA 98124

(2) DOT/FAA/AR-06/15, Indications of Propulsion System Malfunctions—Sustained Thrust Anomaly Study, Grace Balut Ostrom, Jeanne Mason, Sam Clark, and Steve Clark, The Boeing Company, P.O. Box 3707, Seattle, WA 98124

(3) DOT/FAA/AR-08/24, Engine Damage-Related Propulsion System Malfunctions, Steve Clark, Grace Balut Ostrom, and Sam Clark, The Boeing Company, P.O. Box 3707, Seattle, WA 98124

3.1.6 General, Modernization, and AC25-11"Electronic Displays" (1987)

The team addressed this item primarily in three ways:

a. Provided the Powerplant expertise for the FAA revised AC25-11A released in June, 2007. See Appendix H.

b. Provided a proposal to revise regulation §25.1305 including the following objective-based item:

(1) Flight deck indications to support the approved operating procedures [e.g: §25.1585],

(2) Indications as required by the powerplant system safety assessments [e.g.: §25.1309]

(3) Indications required to support the instructions for continued airworthiness [e.g: §25.1529]

c. Proposing a revision to regulation §25.1549 to address inconsistencies within the flight deck given the requirements of §25.1322.

Several other topics which fall under this general/modernization category were raised and discussed by the team. These are addressed in the following section.

3.2 Other Discussion Items

3.2.1 Auxiliary Power Unit Indications

AIA PITT did not consider it necessary to address the APU, as this topic was addressed by the ARAC PPIHWG APU task team. The APU team produced technically harmonized requirements for the Part 25 APU Installation that introduced an objective, versus prescriptive, approach to APU indication requirements. AIA PITT reviewed the proposal of the APU team and used their objective based approach as a model when working on §25.1305(g) and our AC/AMC 25-11 input.

EASA has issued these agreed requirements as a revision to subpart J, CS-25 at amendment 1 (2005): CS 25J1305 APU instruments.

The FAA introduction of this material into the FAR is pending.

3.2.2 Oil System Health

PITT Position: If an applicant elects to demonstrate that any specific oil system parameter is not required, then the applicant must either (a) show that there is no airplane level hazard, requiring crew awareness or crew action associated with this specific parameter, or (b) show that there are alternative means to provide the crew awareness or crew action required to address the airplane level hazard related to this specific parameter. In some cases an alert indication may be an appropriate substitute for a parameter display indication. An example could be an alert based on a combination of data (e.g. oil pressure, temperature, debris detection, vibration) or the system design is such that another related indication will prompt the appropriate crew response.

It is recognized that the progression of engine failures varies from case to case, and that individual crew responses also vary. Absolute proof that the indication approach is the best possible for every failure case is not expected, no more than such proof was required to justify the original regulation and Methods of Compliance (MOCs). Analysis should be used to show that the indication approach is effective for the most serious failures generally encountered, for which a timely and effective crew response could reasonably mitigate the failure.

The proposed rule change to §25.1305 allows for aircraft not to be equipped with the prescriptive powerplant indication if ‘compliance to paragraph (g) can be shown without some or all of those indications’.

For example, the flight deck alerts for the engine oil system could potentially be driven by integrated information, e.g. sensor fusion logic which includes Oil Pressure, and Oil Temperature, etc. before setting an Oil System Failure alert, providing crew awareness and potential action, rather than making a decision based solely on one parameter.

There are differences between the oil systems among engine manufacturers, and differences between the oil systems for turbofan, turboprop and geared fan engines. There can be different oil system failure modes and hazard classifications for the failures. These differences must be considered when designing and evaluating oil system indications.

The level of alert for an oil message (temperature, pressure, quantity, bypass, chip detection, etc.) must be commensurate with the required crew awareness and action.

Inhibiting any or all of the oil system health messages should be considered during the critical flight time intervals (take-off & landing).

There has been inconsistent interpretation of the oil pressure indication and low oil pressure alert. There is no specific requirement that these must be from independent sources, or that there be sensor redundancy. However, to minimize nuisance messages and ensure reliable operation, acceptable design practice has generally been to provide a level of redundancy in the oil pressure indication and alert design.

There has been inconsistent interpretation of the oil quantity indication requirement. There must be a means to determine oil quantity for each oil tank, but it does not necessarily need to be on the flight deck, nor available to the flightcrew during flight, though flight operational requirements may make this mandatory (e.g. ETOPS).

3.2.3 Engine Start Progression

AIA PITT does not recommend a new prescriptive item under §25.1305 regarding "START IN PROGRESS" or other indication to indicate engine starting progress. This item was not part of the initiating FAA HTOR, but the impetus comes from the AIA working draft advisory material to §25.903(e) and new aircraft certification discussions. Modern engine in-flight start characteristics often have very slow engine acceleration characteristics during the early portion of a start, the engine temperature may not consistently increase during the start and a start can take in excess of two minutes.

The concern is that visual cues to the flightcrew are insufficient to determine that a start is progressing appropriately. This situation could cause a flightcrew to abort a potentially successful start, or result in delayed flightcrew reaction to an unsuccessful start attempt. §25.1309 (c) does contain non-specific requirements '*Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.'* Numerous FAA Issue Papers and EASA Certification Review Items (CRIs) specifically address this concern, e.g. 'Time to relight should not exceed… *A longer spool-up time may be acceptable if a positive indication is available to the crew that a start is progressing normally' and 'The FAA flight test branch will determine the acceptability of engine starts which are demonstrated to show compliance with the above requirements based on indication of a clear progression of the start when the procedures to be contained in the manual are followed.'*

As per any crew alerting feature, an engine start system alert must be tied to the desired flightcrew action, and must be tied to published procedures and training. For an engine with auto-start, the desired crew action may be 'monitor' (an advisory) or if no pilot awareness or action is required then there may be no need for an alert.

As discussed within AC / AMC 25-11 on part-time displays and 'pop-ups' (see Appendix H on the specific Powerplant comments to ASHWG) system parameters essential for determining the health and operational status of the engines and for taking appropriate corrective action, including engine restart, must be automatically displayed after a failure, including consideration of the loss of normal electrical power. Should an engine IFSD, or an all engine out event occur, all necessary information for the crew to take action or monitor the engine restart must be available.

3.2.4 Inhibiting of Alerts

AIA PITT position: No additional action is deemed necessary as the proposed AC/AMC 25-11, which includes input from AIA PITT, adequately addresses this item.

Due to the concern for pilot distraction during the critical flight phases, notably take-off, landing and go-around; crew alerts or automatic pop-up type of instrument displays should be inhibited unless immediate crew action is required to maintain safe airplane operation (per the guidance of AC/AMC 25-11).

Modern aircraft generally inhibit the attention getting features of crew alerts (e.g. lights, aurals,):

- During takeoff power setting speed, or just prior to 'high speed' (e.g. 60 knots) to a minimum of 400 ft. AGL,
- During landing from 400 ft AGL to some seconds (e.g. 30) after touch down
- During a go-around at altitudes under 400 ft AGL

There is often a maximum time limit on any inhibit (whether specific to an alert, or general system maximum time) to preclude a potential dormant failure condition and /or limit potential exposure.

3.2.5 Use of Numeric Readouts

AIA PITT provided input regarding powerplant concerns and criteria for the use of numeric readouts (also referred to as digital displays) to the ASHWG AC/AMC 25-11 team. Not all of this material was incorporated in their proposed advisory material, so it is provided here.

The following was forwarded to ASHWG:

For a given application the powerplant indications may include the display of particular parameters. For the display of parameters, combined numeric and graphical display format is generally an acceptable means of compliance.

The numeric-only display of a parameter may be an acceptable means of compliance for cases where:

- The parameter is **not a control parameter** i.e. the flightcrew is not required to “close the loop” i.e. manually control the engine such that the parameter achieves a given target or command value, e.g. thrust setting in non auto-thrust mode.
- The flightcrew **does not have the nominal task of maintaining the parameter within certified limits**, e.g. there is a control system, which performs this function.
- Procedurally, the flightcrew is not required to determine the margin relative to a certified limit, or comparison against the same parameter on other powerplants. (This excludes airmanship type procedures requiring visual scans and comparisons.)

The graphical-only display of a parameter may be an acceptable method of compliance where:

- No published normal or abnormal procedures require the flightcrew to control to a specific numerical value for that parameter.

In general, the graphical representation of a setting or “commanded” value with another representation for the actual level has been found an acceptable means to allow flightcrew control and indication.

A numeric-only or graphical-only display format may be acceptable means of compliance in other scenarios not covered above provided that:

- The display format is shown to be suitable for the intended function of the parameter
- The display format is shown to support all published normal and abnormal procedures associated with that parameter.

3.2.6 Rotor Speed Indication

PITT position: No additional specific action is required beyond what is contained within both AC/AMC 25-11A and the general requirements change made to §25.1305 as proposed within this document.

Rotor speed was often used for discussion purposes during this rulemaking proposal activity, as

- There is a prescriptive requirement, ref: §25.1305(c)(3),
- Certification issue papers have been raised to address numeric display only,
- Core speed indication may be necessary as an indication of engine start progression
- It was debated whether exceeding an engine speed limit is a safety issue by definition
- For some engines, engine speeds have certified operating limits that are variable, e.g. accounting for time at speed before crew alerting is required.
- Confirming a margin to the certification limit was historically a flightcrew responsibility

PITT arrived at the above noted conclusion based on there being suitable requirements and guidance in the proposed §25.1305 and AC/AMC 25-11A to allow design flexibility when substantiated.

It is noted that

- Many modern aircraft only have numeric display of the engine core speeds.
- FADEC engines have the capability to monitor rotor speeds, identify deterioration or faults to maintenance, and alert the crew when awareness or action is required
- FADEC engines or aircraft avionics can incorporate variable limits to account for time at speed before alerting the crew

- FADEC engines can take all engine information and make a determination if an engine start is progressing and alert the crew if / as required

The emphasis should be on abnormal rotor speeds (e.g. exceeding established limits, speeds/behavior indicative of a failure condition, etc.) and / or aircraft /engine safety limits rather than full-time display of the rotor speed(s).

3.2.7 Maintenance Indications

§25. 1305 as it exists today is not restricted to powerplant indications on the flight deck. In specific sub-parts there are certain instruments that specifically state "for the flight crew". PITT did delete a specific mention of "maintenance" from early drafts, but after much discussion agreed to leave in the reference to "as required to support the instructions for continued airworthiness." The intent here is simply that if the ICA written by the Airframer requires that a particular powerplant item needs to be checked via an indication on the airplane, then there needs to be an airplane indication. The intent is no more than that. The team recognizes the risk that an uninformed person could misapply this and insist that an indication intended strictly for maintenance use is made a full-time flight deck display. PITT believes this can easily be refuted:

- The new (g)(3) does not say "flight deck".
- The new (g)(3) says "as required by the instructions for continued airworthiness"… so when the instructions for continued airworthiness mentions a maintenance indication for use by maintenance, then it is clear that it is not a flight deck indication for the flightcrew.

3.2.8 Part-time Display

AIA PITT provided related input to ASHWG regarding the proposed revision to AC/AMJ 25-11. This is reflected in the FAA AC25-11A adopted June 21, 2007. This subject is covered under "Full-time vs. Part-time Display of Information." and "Pop-up Display of Information". The "Full-time vs. Part-time Display" is repeated here:

"Full-time vs. Part-time Display of Information. Some airplane parameters or status indications are required to be displayed by the regulations (for example, powerplant information required by §25.1305), yet they may only be necessary or required in certain phases of flight. If it is desired to inhibit some parameters from full-time display, an equivalent level of safety to a full-time display should be demonstrated.

When determining if information on a display should be part-time consider the following criteria:

- Continuous display of the parameter is not required for safety of flight in all normal flight phases.
- The parameter is automatically displayed in flight phases where it is required or when it would be relevant information during a failure condition.
- Display of the inhibited parameter can be manually selected by the flightcrew without interfering with the display of other required information.
- If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of all applicable regulations (for example §25.1309).
- The automatic or requested display of the inhibited parameter should not create unacceptable clutter on the display. Also, simultaneous multiple 'pop-ups' should not create unacceptable clutter on the display.
- If the presence of a new parameter is not sufficiently self-evident, suitable alerting should accompany the automatic presentation of the parameter."

In addition, the draft AC25-11 includes the following, modified from the original AC by AIA PITT:

> "For engine indications that are required during engine re-start, the indications should be readily available after an engine out event. (See §§25.901(b)(2), 25.901(c) 25.903(d)(2), 25.903(e), 25.1301, 25.1305, 25.1309 and Chapter 6, paragraph 36c(3) of this AC).

3.3 Summary of Recommendations for Further Action

- **Asymmetric Thrust/Power** This issue needs to be tasked at an airplane level rather than at a powerplant level. Representation is recommended from avionics, flightcrews, autoflight/autothrust, flight controls, human factors and propulsion. See RECOMMENDATIONS Section 3.1.3 "Asymmetric Thrust/Power Indication" in this report for further details regarding this recommendation.
- **Low Fuel Indication** This item was out of scope for the AIA Powerplant Indications Task Team. The team recommended to the ARAC Powerplant Installations Harmonization Working Group that this item be tasked to a Fuels team. As of the date of release of this report, no such team has been formed to address the issue. See Appendix A HTOR 25.1305 item 1 for further details.
- **Engine Surge/Stall Indication** The team recommends that further research be undertaken to evaluate the potential for integrating engine health data in real-time with the goal of providing information useable by the flight-crew to facilitate appropriate action (e.g. engine surge/stall indication). See Section 3.1.5 for further details.
- **Advisory Material for the Proposed §25.1305 Revision** The team does not believe that advisory material is required at this time. If, however, the rule is adopted and experience shows that advisory material would be beneficial, then this should be tasked to a joint regulatory/industry team.
- **AC 20-88 Update** This guidance should be updated. The update should integrate the updated §25.1322 and AIA PITT recommendations relative to §25.1549. Recommendations toward this revision are provided in Section 2.2.
- **25.1549** The team suggests that §25.1549 is outdated relative to current design practice and needs to be updated. Recommendations toward this revision are provided in Section (1)(g.) and Section 2.2.
- **25.1337** The team suggests that §25.1337 is outdated relative to current design practice and needs to be updated. Recommendations toward this revision are provided in Section (1)(g.) and Section 2.3.
- **Engine Certificate Data Sheet treatment of Engine Limits** The team recommends that the FAA EPD undertake a review of the certification and documentation of engine limits in the Engine Type Certificate Data Sheet. See Section 2.5 and Appendices I & J for detailed recommendation

4. Discussion of Regulatory Advisory Material

AIA PITT has contributed to the ASHWG draft AC/AMJ25-11 which was approved by ARAC-TAEIG and forwarded to the FAA. The FAA revision AC25-11A released in June, 2007 incorporates AIA PITT input, including some input which was not incorporated by ASHWG/TAEIG.

In addition, material associated with §25.901(c), technically harmonized and released as AMC 901(c), §25.1322, and §25.1309 provide additional guidance.

PITT recommends that AC20-88A be updated to reflect the state of practice regarding the use of electronic displays in Part 25 aircraft.

There is no FAA advisory material for §25.1305, the basic powerplant indications regulations. The JAA, no longer in existence, had an AMJ for §25.1305(d)(1) which clarified the acceptability of certain thrust setting parameters. The intent of JAA AMJ25.1305(d)(1) has been incorporated into the AIA PITT proposed revision to §25.1305.

AIA PITT believes that the proposed revision to §25.1305, in combination with the other material above, provides sufficient information for the certification of powerplant indications. AIA PITT believes that interpretive material would assist in establishing compliance to the existing and the proposed rule revision, but considered that the additional time to create and release such material was not warranted for this team.

PITT recommends that this issue be reviewed by the AIA based on experience with applying the new rule.

5. Impact of the Proposed Changes on the Industry

All Part 25 aircraft manufacturers will be affected by this rule change for new products. This will provide rules terminology that is more applicable to the current state of design practice and future designs.

Aircraft manufacturers may be required to submit specific system safety assessments for parameters and display systems certified under the new rule. This could result in some incremental cost increases in the preparation of system safety assessments owing to the need to provide additional detail.

Engine manufacturers may be requested to define safety-related limits on parameters versus long-term operating limits on parameters. This could result in significant cost increases to engine certification, especially if the safety-related limits are held to a higher standard of proof than the limits published historically. Typical means of developing certification limits include the following:

- Similarity to previous products. For example, a temperature which has had the same limit for a series of certification programs may have the same limit applied on the next, rather than analysis being used to derive a new limit from first principles.
- Observation of development testing. A temperature observed during development testing without resulting distress to engine parts may form the basis of a “limit”.
- Intentional demonstration by development testing. Development tests may be run specifically to demonstrate engine capability with a certain parameter value, as in CFR 33.27, 33.87 and elsewhere.
- Experienced engineering judgment. For instance, if oil pressure drops too low, the engine bearings will not be cooled and damage will result. It is not considered necessary to demonstrate that this will happen.

These certification limits provide parameter values for which the engine will operate. They do not provide any information about the parameter values at which it will not operate.

The additional requirements, the generic catchall paragraph (g) and the engine sub-idle fail indication are indications that are being implemented on today’s aircraft designs.

The clarifications provided should reduce the need for ‘equivalent safety’ findings which tend to require a significant man-hour effort and paperwork for both the applicant and the regulatory agency, therefore this change should be beneficial to the industry.

Date: 10/25/00

Title of Initiative

Design Requirements and Advisory Material for Powerplant Indications

Affected Far Section Number(s):

§25.1305, 25.1309(c), §25.1321, §25.1322, §25.1337, §25.1549 and §25.1585

Affected Jar Paragraph Number(s):

25.1305

NPA/NPRM Number:

NPRM 87-3

Advisory Material Number(s):

AC20-88A, AC 25-11 and AMJ 25-11

Specific Tasks:

This HTOR covers several distinct tasks related to powerplant indications as follows:

1) provide recommendations regarding a new §25.1305(a)(9) regulatory requirement and advisory material for “a low fuel indication” displayed to the flight crew at any point during a flight where crew awareness is required to avoid fuel starvation for any main engine. This low fuel indication should be capable of annunciating inappropriate fuel loading or utilization, leaking or trapped fuel, or any other fuel system condition where flight crew awareness is expected to be required to avoid fuel starvation for one or more main engines, including when the fuel available for main engine fuel feed is below that required to safely complete the flight with adequate fuel reserves. No malfunction should affect both this indication and any fuel quantity indicator.

2) provide recommendations regarding a new §25.1305(a)(10) regulatory requirement and advisory material for “an engine failure indication for each engine”, e.g. “ENG#_ FAIL”, displayed to the flight crew when the engine rolls-back or runs down to a sub-idle condition.

3) provide recommendations regarding a new §25.1305(a)(11) regulatory requirement and advisory material for “an asymmetric thrust/power indication” displayed to the flight crew whenever thrust/power asymmetry is abnormal.

4) provide recommendations regarding a new §25.1305(a)(12) regulatory requirement and advisory material for “any additional powerplant instruments or indications required for the powerplant installation to comply with §25.1309(c)”.

5) provide recommendations regarding a new §25.1305(c)(9) regulatory requirement and advisory material for “an engine surge indicator for each engine”, e.g. “ENG#_ SURGE”, displayed to the flight crew within one second of a detectable engine surge. This indication should not be inhibited during takeoff or go-around, as that is when it would be most beneficial.

6) perform a review of the powerplant installation instrumentation and procedural requirements and guidance associated with §25.1305, §25.1309(c), §25.1321, §25.1322, §25.1337,§25.1549 and §25.1585 to:

   a) determine if additional prescriptive powerplant instruments or indications should be proposed;

   b) determine if additional prescriptive powerplant related operating procedures should be proposed;

   c) determine if improved engine, propeller, APU and/or fuel system displays or presentation methods can be recommended which would improve pilot recognition, identification and response to powerplant installation malfunctions; and

   d) make recommendations regarding modernizing and improving both these regulations and the associated advisory material. For example:

i. accommodation of display color changes in lieu of the arc's or lines required by §25.1549;

ii. guidance for the use of digital only displays;

iii. guidance regarding shared and part time displays;

iv. guidance to replace Paragraph 4a(3)(ix) of current AC25-11 "Transport Category Airplane Electronic Display Systems", dated 7/16/87; and

v. guidance regarding the typical use and requirement for display accuracy.

The recommendations associated with these tasks should cover the need for, as well as the content of each proposed rule and/or policy change. These recommendations should be consistent with the existing and/or recommended regulations and policies for §§25.1309(c), 25.1321, 25.1322, and any other applicable companion regulations. These tasks may result in recommendations for additional research or other follow on tasks. Any recommendation conditional upon or calling for additional research and development should provide a clear recommended specification for each study.

For each of the above tasks, the ARAC working group will present their recommendations to the FAA in the form of a report. Reports covering tasks 1 through 4 will be due to the FAA within one year from tasking. Reports covering tasks 5 & 6 will be due to the FAA within two years from tasking.

Proposed HWG Assignment:

Power Plant Installation Harmonization Working Group(PPIHWG) will serve as the focal working group. PPIHWG will develop and coordinate these recommendations in cooperation with the Flight Test Harmonization Working Group(FTHWG), Human Factors Harmonization Working Group(HFHWG), and Avionics Systems Harmonization Working Group(ASHWG).

Contacts:

FAA .... Mike McRae

JAA .... Robin Boning

U.S. .... Andrew Lewis-Smith

European Industry .... Jean Paillet

Remarks:

Task 1 is a continuation of the "low fuel warning" FAA rulemaking initiative originally proposed in NPRM 87-3 to mitigate the threat of fuel starvation. Fuel starvation has been one of the top ten causes of fatalities. As a result of this adverse service experience, public comments on the NPRM and further internal FAA coordination, the objective of this rulemaking has broadened and now is simply to highlight and prescribe how §25.1309(c) will be met for this particular unsafe fuel system operating condition. An acceptable means of compliance is foreseen as providing a continuous automated way point and fuel system monitoring capability which replaces or supplements the manual methods currently in use to avoid fuel starvation.

Task 2 has been a rulemaking initiative under consideration within the FAA for over a decade. This initiative was part of the motivation behind the FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response". The AIA/AECMA report from this project recommended consideration of the proposed indication. An acceptable means of compliance is foreseen as providing reliable detection and indication while minimizing false warnings. §§ 25.901(c) & 25.903(b) would require that hazardously misleading information, such as erroneously displaying failure of one engine as failure of a different engine, not be anticipated to occur.

Task 3 has been a rulemaking initiative under consideration within the FAA since the China Southern B737-300 accident in 1992. Several subsequent accidents and incidents, such as the Air France B747-400 accident in 1993 and the Tarom A310-300 accident in 1995 have reinforced the need for such a requirement. A recently released SAE ARP on "Autopilot, Flight Director & Autothrust Systems states: *"failure cases that result in asymmetric thrust shall be detected and annunciated"*. A recent ARAC recommendation for AC25.901-1 states: *"Automated thrust management features, such as autothrottles and target rating displays, traditionally have been certified on the basis that they are only conveniences to reduce crew workload and do not relieve the crew of any responsibility for assuring proper thrust management. In some cases, malfunctions of* *these systems can be considered to be minor, at most. However, for this to be valid, even when the crew is no longer directly involved in performing a given thrust management function, the crew must be provided with information concerning unsafe system operating conditions to enable them to take appropriate corrective action."* This initiative was also part of the motivation behind the FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response". The AIA/AECMA report from this project also recommended consideration of the proposed indication. An acceptable means of compliance is foreseen as providing reliable detection and indication of any asymmetry that if not accommodated could result in a hazardous or catastrophic outcome. This indication should be provided in a manner enabling the crew to take appropriate corrective action, while minimizing false warnings. §§ 25.901(c) & 25.903(b) would require that hazardously misleading information, such as erroneous directional information, not be anticipated to occur.

Task 4 is a logical extension of the fact that tasks 1, 2, 3 & 5 propose requirements that simply highlight and prescribe how §25.1309(c) will be met for a particular foreseeable powerplant installation operating condition. A detailed assessment of the propulsion system relative to the requirements of §25.1309(c) would likely have resulted in cockpit indications for these and other conditions on past airplane programs. This proposed general requirement is intended to highlight the need for any unsafe powerplant installation operating condition to meet the intent of §25.1309(c), even when a specific prescriptive indication requirement does not exist for that particular condition.

Task 5 is a rulemaking initiative under consideration within the FAA as a result of the FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response". The AIA/AECMA report from this project recommended consideration of the proposed indication. Since the benefits and other implications of this new requirement have not been under consideration as long as those of the other proposals, the FAA has decided to allow an additional year for this task.

Task 6.a is in part a logical extension of the fact that tasks 1, 2, 3 & 5 propose requirements that simply highlight and prescribe how §25.1309(c) will be met for a particular powerplant installation operating condition. This task is intended to facilitate formal consideration of whether or not there are other operating conditions deserving of similar specific treatment within the regulations.

Task 6.b is the "procedures" counterpart to Task 6.a.

Task 6.c is a general initiative under consideration within the FAA as a result of the FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response". The AIA/AECMA report from this project recommended consideration of the proposed review. This is a task that impacts multiple disciplines and should involve close coordination and cooperation of all affected parties. This task may well result in recommendations for additional research or other follow on tasks.

Task 6.d is a general review task under consideration within the FAA as a result of:

1) ongoing experience with dated rules and advisory material, especially in the areas highlighted within the examples. The FAA will supply Generic Issue Papers that provide FAA Positions regarding 6.d.i, 6.d.ii, 6.d.iii, and 6.d.iv; and

2) a recommendation in the report from the FAA sponsored AIA/AECMA Project on "Propulsion System Malfunction Plus Inappropriate Crew Response".

It should be noted that the ARAC Avionics Systems Harmonization Working Group has the overall task to revise AC25-11. Consequently, task 6.d.iv should simply provide supplemental recommendations for powerplant instruments to the ASHWG for their consideration and incorporation into an overall ARAC AC25-11 recommendation.

Benefits of Harmonization:

Qualitative benefits:

There have been numerous powerplant installation malfunction plus inappropriate crew response related accidents and incidents. The FAA is committed to improving crew awareness and responses wherever practicable. The subject indications and procedures regulations and the associated policies are harmonized, or will be through other tasking. Consequently, any unilateral changes to these regulations or policies by the FAA would result in disharmony. Such disharmony usually results in unwarranted certification and continued airworthiness costs for applicant that need to comply with both the FAR and the JAR.

Quantitative benefits: TBD

Draft Completed by Harmonization Focal Point on: TBD

Name	Representing*
Members Past & Present	
Pierre-Emmanuel Arnaud	Airbus
Arnaud Bonnet	Airbus
Patrick Zaccaria	Airbus
John Doherty	Boeing Commercial Airplane
Joseph Sikora	Boeing Commercial Airplane
Geof Armstrong	Bombardier
Braulio Medeiros	Embraer
Jairo Scherrer	Embraer
Sarah Knife	General Electric
Vladimir Lozovsky	IAC AR
Larry Carlisle	Pratt & Whitney
William Fletcher	Rolls-Royce
Barry Rohm (now retired)	Rolls-Royce
Yves Cousineau	Transport Canada
Robin Boning (now retired)	UK Civil Aviation Authority
Ann Azevedo	US Federal Aviation Administration
Bill Emmerling	US Federal Aviation Administration
Gary Horan	US Federal Aviation Administration
Hals Larsen (now retired)	US Federal Aviation Administration
Mike McRae (now retired)	US Federal Aviation Administration
Chip Queitzsch	US Federal Aviation Administration
Consultations	
Mike Young	Pratt & Whitney
Laurent Gruz	European Aviation Safety Agency
Ken Fontaine	UK Civil Aviation Authority

***Note:** This list reflects the organization that each individual represented at the time during which they participated in the AIA Powerplant Indications Task Team.

Ground Rules & Assumptions

(30 January 2003)

1. **Safety** Clearly define the safety issue. Regulations are driven specifically by safety requirements.

2. **Flight Crew** The team is addressing powerplant indications specifically for use by the flight crew.
   a) Assume a two-crew flight deck, i.e. no flight engineer.
   b) Assume the flight crew does not have flight engineer background or training.
   c) Assume the flight crew has no in-service experience with engine malfunctions.
   d) Assume the flight crew does not continuously monitor powerplant displays.

3. **Powerplant Indications** The existing regulations were written when powerplant indications were primarily parameter gauges and lights. Current generation airplanes have an increased capability to provide processed information to the flight crew, e.g. combining parameters within a display, different displays formats available to the flight crew, text messages, electronic checklists, synoptic displays, lights, aural alerts.

4. **Displays** For current and future airplanes assume screen-based displays and a central alerting system driven by a digital computer.

5. **FADEC** Assume EEC controlled engines, i.e. a microprocessor based system of engine parameter sensing, control and communication. Current generation EECs generally include features such as automatic rotor speed redline limiting, overboost protection, overspeed protection, surge detection/recovery, EEC-driven crew alerts, etc. Future engine control systems will likely include additional capability (e.g. thrust control malfunction accommodation).

6. **New Designs** The emphasis of this HTOR is on future applications: new airplanes, new engines. The team's proposals should allow for future growth in airplane & engine systems capabilities.

7. **Boundaries**

   (a) The team is limited to powerplant indications.

   (b) Issues concerned with other airplane systems or areas of expertise (e.g. Pilot/Flight Test, Human Factors, Avionics for AC/AMJ 25-11) will be forwarded to the appropriate teams covering those areas. Team Boundaries:

   (c) The engine, powerplant, propeller, APU and the engine Fuel System (airplane spar valve and downstream) are included.

   (d) The harmonized APU rule is acceptable as-is. JAR 25A1305 APU Instruments. This team needs to ensure that any proposed 1305 does not conflict with the harmonized JAR APU for 1305.

   (e) The Airplane Fuel System (upstream of the airplane spar valve) is excluded (e.g. Low Fuel Quantity). Note that there is currently no Harmonization Working Group for the Airplane Fuel System. This issue has been raised to the PPIHWG Steering Committee.

8. **Data** Document decisions and substantiate using facts & data.

Agreements

(30 January 2003)

1. The team believes that a new objective-based regulation should replace or supplement the existing prescriptive regulation.

2. The intent of the new objective-based regulation is to allow for other means of compliance in lieu of the existing 25.1305 instrumentation list. The existing 25.1305 prescriptive instrumentation list, however, will be maintained as an acceptable means of compliance. This could be accomplished by inclusion in the associated advisory material.

3. A new regulation will only be effective if accepted by Flight Deck, Pilots and Human Factors.

4. The team believes that safety and the flight crew will be better served by the display of processed "information" rather than "parameter data" which must then be interpreted by the flight crew. In some cases retaining parameter data may be useful.

5. Powerplant indications should be directed at the intended flight crew response.

6. The unintended consequences of any new display must be carefully considered.

7. AC/AMJ 25-11 needs to be revised for the following reasons:
   - Rulemaking by AC, which is contrary to the intent of the AC process.
   - Assumes today's first generation glass displays (e.g. pop-ups).
   - The probability numbers used for powerplant indication failures are not explained by, referenced to, or validated by, a hazard classification
   - Currently, the material is too restrictive with respect to powerplant displays.
   - The powerplant display terminology is confusing.

8. The new rule should allow for new display concepts or technology not currently implemented or considered or conceived (i.e. should not prescribe or assume a particular implementation.

9. There is no need for a regulation that all ETCDS engine parameter limits must have a corresponding airplane flight deck powerplant indication. Instead, each ETCDS item should be evaluated with regard to safety implications and the intended flight crew response. This will determine whether a flight deck powerplant indication is required and when it should be displayed.

10. The team will provide input to the FAA funded research request via the FAA research sponsors who are on the task team.

FAR/JAR-25 Powerplant Indications

10 April 2008

Part 25 Requirement	Comments
25.33	Propeller limitations set; may need indication of Maximum Np, propeller low pitch limiting angle, maximum torque. Although this is a compliance requirement, confirmation that low pitch setting (or power setting) has not altered may be needed.
25.107 and others	Implies need for pilot to be able: to confirm that the engine is producing the correct power, torque, etc, to recognise an engine failure, so that the crew can take the appropriate action, during take-off and landing
25.147 and others	The pilot needs to know if the propeller is (or is not) in the minimum drag position.
25.149	The pilot may need to recognise the state of the propeller of an inoperative engine - windmilling, most probable position or feathered.
25.903(e)	Windmilling speed may need to be known so that the proper restart procedure can be implemented.
25.905(b)	Engine power and speed limits to be observed for propellers.
25.929	Propeller de-icing may need means to determine when de-icing is to be selected.
25.991	Some indication may be needed to advise the flight crew that the emergency pump needs to be started.
25.1001	Indications may be needed to enable the use of auxiliary jettison controls.
25.1019(a)(3)	Oil filter contamination indication, usually considered to be at the filter itself e.g. ‘pop-up’ indication.
25.1019(a)(5)	Oil filter contamination indication to be shown on the flight deck.
25.1025	Oil valve position indication specified. Consider revision to be equivalent to the proposed new wording for 25.1141(f)
25.1043(b)	Indication may be needed for the flight crew to determine if the ‘winterisation’ installation can be used. See also FAR 25.1521(d)
25.1093	Means to determine falling and blowing snow limitations, criteria.
25.1141(f)	Valve position indications. Harmonised proposal has been made.
25.1199(c)	Provides the need for the discharge indication
25.1203	Provides the need for fire indication (see also 25.1305) and for failure indications.
25.1305	Provides a comprehensive list of necessary powerplant instruments (and indicators). Would be useful to clarify that these instruments (and indications) are to be visible to the flight crew. See also 25.1321.
25.1321	General instrument requirements.
25.1337	Surprisingly also called ‘Powerplant instrument’, as 25.1305. Some of this material requires ‘instruments’; other material appears to be advisory in nature.
25.1521, 1522	Requires ability to observe limits; may require new instrument to be provided. The APU paragraph could be deleted in favour of the new proposed APU Subpart/Appendix.
25.1549	Marking Requirements

25.1551	Advisory material for oil quantity?
25.1553	Advisory material for fuel quantity?
25.1555	Specific fuel valve control markings.
25.1583(b)	Additional information about instrument markings and powerplant limitations.
25.1585(d), (e)	Additional information about the FQIS indications.

FAR Part 25, Amdt 25-1 through 25-115 (25.1322at Amdt 131)	CS 25 Amendment 1 (2005)
Subpart F-Equipment	**Subpart F-Equipment**
§ 25.1305 Powerplant Instruments. The following are required powerplant instruments: (a) *For all airplanes.* (1) A fuel pressure warning means for each engine, or a master warning means for all engines with provision for isolating the individual warning means from the master warning means. (2) A fuel quantity indicator for each fuel tank. (3) An oil quantity indicator for each oil tank. (4) An oil pressure indicator for each independent pressure oil system of each engine. (5) An oil pressure warning means for each engine, or a master warning means for all engines with provision for isolating the individual warning means from the master warning means. (6) An oil temperature indicator for each engine. [(7) Fire-warning devices that provide visual and audible warning.] (8) An augmentation liquid quantity indicator (appropriate for the manner in which the liquid is to be used in operation) for each tank. (b) *For reciprocating engine-powered airplanes.* In addition to the powerplant instruments required by paragraph (a) of this section, the following powerplant instruments are required: (1) A carburetor air temperature indicator for each engine. (2) A cylinder head temperature indicator for each air-cooled engine. (3) A manifold pressure indicator for each engine. (4) A fuel pressure indicator (to indicate the pressure at which the fuel is supplied) for each engine.	**CS 25.1305 Powerplant instruments** The following are required powerplant instruments: (a) *For all aeroplanes* (1) A fuel pressure warning means for each engine, or a master warning means for all engines with provision for isolating the individual warning means from the master warning means. (2) A fuel quantity indicator for each fuel tank. (3) An oil quantity indicator for each oil tank (4) An oil pressure indicator for each independent pressure oil system of each engine. (5) An oil pressure warning means for each engine, or a master warning means for all engines with provision for isolating the individual warning means from the master warning means. (6) An oil temperature indicator for each engine. (7) Fire-warning devices that provide visual and audible warning. (8) An augmentation liquid quantity indicator (appropriate for the manner in which the liquid is to be used in operation) for each tank. (b) Reserved

Continued

FAR Part 25, Amdt 25-1 through 25-115 (25.1322at Amdt 131)	**CS 25 Amendment 1 (2005)**
Subpart F-Equipment	**Subpart F-Equipment**
(5) A fuel flowmeter, or fuel mixture indicator, for each engine without an automatic altitude mixture control. (6) A tachometer for each engine. A device that indicates, to the flight crew (during flight), any change in the power output, for each engine with (i) An automatic propeller feathering system, whose operation is initiated by a power output measuring system; or (ii) A total engine piston displacement of 2,000 cubic inches or more. (8) A means to indicate to the pilot when the propeller is in reverse pitch, for each reversing propeller.	
(c) For turbine engine-powered airplanes. In addition to the powerplant instruments required by paragraph (a) of this section, the following powerplant instruments are required: (1) A gas temperature indicator for each engine. (2) A fuel flowmeter indicator for each engine. (3) A tachometer (to indicate the speed of the rotors with established limiting speeds) for each engine. (4) A means to indicate, to the flight crew, the operation of each engine starter that can be operated continuously but that is neither designed for continuous operation nor designed to prevent hazard if it failed. (5) An indicator to indicate the functioning of the powerplant ice protection system for each engine. (6) An indicator for the fuel strainer or filter required by § 25.997 to indicate the occurrence of contamination of the strainer or filter before it reaches the capacity established in accordance with § 25.997(d).	(c) For turbine engine-powered aeroplanes. In addition to the powerplant instruments required by sub-paragraph (a) of this paragraph, the following powerplant instruments are required: (1) A gas temperature indicator for each ngine. (2) A fuel flowmeter indicator for each engine. (3) A tachometer (to indicate the speed of the rotors with established limiting speeds) for each engine. (4) A means to indicate, to the flight crew, the operation of each engine starter that can be operated continuously but that is neither designed for continuous operation nor designed to prevent hazard if it failed. (5) An indicator to indicate the functioning of the powerplant ice protection system for each engine (6) An indicator for the fuel strainer or filter required by CS 25.997 to indicate the occurrence of contamination of the strainer or filter before it reaches the capacity established in accordance with CS 25.997(d).

Continued

FAR Part 25, Amdt 25-1 through 25-115 (25.1322at Amdt 131)	**CS 25 Amendment 1 (2005)**
Subpart F-Equipment	**Subpart F-Equipment**
(7) A warning means for the oil strainer or filter required by § 25.1019, if it has no bypass, to warn the pilot of the occurrence of contamination of the strainer or filter screen before it reaches the capacity established in accordance with § 25.1019(a)(2). (8) An indicator to indicate the proper functioning of any heater used to prevent ice clogging of fuel system components.	(7) A warning means for the oil strainer or filter required by CS 25.1019, if it has no bypass, to warn the pilot of the occurrence of contamination of the strainer or filter screen before it reaches the capacity established in accordance with CS 25.1019(a)(2). (8) An indicator to indicate the proper functioning of any heater used to prevent ice clogging of fuel system components.
(d) *For turbojet engine powered airplanes.* In addition to the powerplant instruments required by paragraphs (a) and (c) of this section, the following powerplant instruments are required: (1) An indicator to indicate thrust, or a parameter that is directly related to thrust, to the pilot. The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust. The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration. [(2) A position indicating means to indicate to the flight crew when the thrust reversing device – (i) Is not in the selected position, and (ii) Is in the reverse thrust position, for each engine using a thrust reversing device.] (3) An indicator to indicate rotor system unbalance. (e) *For turbopropeller-powered airplanes.* In addition to the powerplant instruments required by paragraphs (a) and (c) of this section, the following powerplant instruments are required: (1) A torque indicator for each engine. (2) Position indicating means to indicate to the flight crew when the propeller blade angle is below the flight low pitch position, for each propeller. (3) [Removed]	d) For turbo-jet engine-powered aeroplanes. In addition to the powerplant instruments required by sub-paragraphs (a) and (c) of this paragraph, the following powerplant instruments are required: (1) An indicator to indicate thrust, or a parameter that is directly related to thrust, to the pilot. The indication must be based on the direct measurement of thrust or of the parameters that are directly related to thrust. The indicator must indicate a change in thrust resulting from any engine malfunction, damage or deterioration. (See AMC 25.1305 (d)(1).) (2) A means to indicate to the flight crew when the thrust reversing device — (i) Is not in the selected position, and (ii) Is in the reverse thrust position, for each engine using a thrust reversing device. (3) An indicator to indicate rotor system unbalance. (e) For turbo-propeller-powered aeroplanes. In addition to the powerplant instruments required by sub-paragraphs (a) and (c) of this paragraph, the following powerplant instruments are required: (1) A torque indicator for each engine. (2) Position indicating means to indicate to the flight crew when the propeller blade angle is below the flight low pitch position, for each propeller. (3) Reserved

Continued

FAR Part 25, Amdt 25-1 through 25-115 (25.1322at Amdt 131)	CS 25 Amendment 1 (2005)
Subpart F-Equipment	**Subpart F-Equipment**
(f) For airplanes equipped with fluid systems (other than fuel) for thrust or power augmentation, an approved means must be provided to indicate the proper functioning of that system to the flight crew.	(f) For aeroplanes equipped with fluid systems (other than fuel) for thrust or power augmentation, an approved means must be provided to indicate the proper functioning of that system to the flight crew.
§ 25.1309 Equipment, Systems, and Installations. (c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.	**CS 25.1309 Equipment, Systems and Installations** (c) Information concerning unsafe system operating conditions must be provided to the crew to enable them to take appropriate corrective action. A warning indication must be provided if immediate corrective action is required. Systems and controls, including indications and annunciations must be designed to minimise crew errors, which could create additional hazards.
Instruments: Installations	**Instruments: Installations**
§ 25.1321 Arrangement and Visibility. (a) Each flight, navigation, and powerplant instrument for use by any pilot must be plainly visible to him from his station with the minimum practicable deviation from his normal position and line of vision when he is looking forward along the flight path. (c) Required powerplant instruments must be closely grouped on the instrument panel. In addition (1) The location of identical powerplant instruments for the engines must prevent confusion as to which engine each instrument relates; and (2) Powerplant instruments vital to the safe operation of the airplane must be plainly visible to the appropriate crewmembers.	**CS 25.1321 Arrangement and visibility** (a) Each flight, navigation, and powerplant instrument for use by any pilot must be plainly visible to him from his station with the minimum practicable deviation from his normal position and line of vision when he is looking forward along the flight path. (c) Required powerplant instruments must be closely grouped on the instrument panel. In addition — (1) The location of identical powerplant instruments for the engines must prevent confusion as to which engine each instrument relates; and (2) Powerplant instruments vital to the safe operation of the aeroplane must be plainly visible to the appropriate crewmembers.

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Instruments: Installations	Instruments: Installations
§ 25.1322 Flightcrew Alerting. (a) Flightcrew alerts must: (1) Provide the flightcrew with the information needed to: (i) Identify non-normal operation or airplane system conditions, and (ii) Determine the appropriate actions, if any. (2) Be readily and easily detectable and intelligible by the flightcrew under all foreseeable operating conditions, including conditions where multiple alerts are provided. (3) Be removed when the alerting condition no longer exists. (b) Alerts must conform to the following prioritization hierarchy based on the urgency of flightcrew awareness and response. (1) Warning: For conditions that require immediate flightcrew awareness and immediate flightcrew response. (2) Caution: For conditions that require immediate flightcrew awareness and subsequent flightcrew response. (3) Advisory: For conditions that require flightcrew awareness and may require subsequent flightcrew response. (c) Warning and caution alerts must: (1) Be prioritized within each category, when necessary. (2) Provide timely attention-getting cues through at least two different senses by a combination of aural, visual, or tactile indications. (3) Permit each occurrence of the attention-getting cues required by paragraph (c)(2) of this section to be acknowledged and suppressed, unless they are required to be continuous.	**CS 25.1322 Warning, caution, and advisory lights** *(See AMC 25.1322)* If warning, caution, or advisory lights are installed in the cockpit, they must, unless otherwise approved by the Agency, be-- (a) Red, for warning lights (lights indicating a hazard which may require immediate corrective action); (b) Amber, for caution lights (lights indicating the possible need for future corrective action); (c) Green, for safe operation lights; and (d) Any other colour, including white, for lights not described in sub-paragraphs (a) to (c) of this paragraph, provided the colour differs sufficiently from the colours prescribed in sub-paragraphs (a) to (c) of this paragraph to avoid possible confusion.

Continued

Instruments: Installations	Instruments: Installations
(d) The alert function must be designed to minimize the effects of false and nuisance alerts. In particular, it must be designed to: (1) Prevent the presentation of an alert that is inappropriate or unnecessary. (2) Provide a means to suppress an attention-getting component of an alert caused by a failure of the alerting function that interferes with the flightcrew's ability to safely operate the airplane. This means must not be readily available to the flightcrew so that it could be operated inadvertently or by habitual reflexive action. When an alert is suppressed, there must be a clear and unmistakable annunciation to the flightcrew that the alert has been suppressed. (e) Visual alert indications must: (1) Conform to the following color convention: (i) Red for warning alert indications. (ii) Amber or yellow for caution alert indications. (iii) Any color except red or green for advisory alert indications. (2) Use visual coding techniques, together with other alerting function elements on the flight deck, to distinguish between warning, caution, and advisory alert indications, if they are presented on monochromatic displays that are not capable of conforming to the color convention in paragraph (e)(1) of this section. (f) Use of the colors red, amber, and yellow on the flight deck for functions other than flightcrew alerting must be limited and must not adversely affect flightcrew alerting.	
§ 25.1337 Powerplant Instruments. (a) Instruments and instrument lines. (1) Each powerplant and auxiliary power unit instrument line must meet the requirements of §§ 25.993 and 25.1183. (2) Each line carrying flammable fluids under pressure must (i) Have restricting orifices or other safety devices at the source of pressure to prevent the escape of excessive fluid if the line fails; and	**CS 25.1337 Powerplant instruments** (a) Instruments and instrument lines (1) Each powerplant instrument line must meet the requirements of CS 25.993 and CS 25.1183. (2) Each line carrying flammable fluids under pressure must- (i) Have restricting orifices or other safety devices at the source of pressure to prevent the escape of excessive fluid if the line fails; and

Continued

Instruments: Installations	Instruments: Installations
(ii) Be installed and located so that the escape of fluids would not create a hazard. (3) Each powerplant and auxiliary power unit instrument that utilizes flammable fluids must be installed and located so that the escape of fluid would not create a hazard.	(ii) Be installed and located so that the escape of fluids would not create a hazard. (3) Each powerplant instrument that utilises flammable fluids must be installed and located so that the escape of fluid would not create a hazard.
(b) *Fuel quantity indicator.* There must be means to indicate to the flight crewmembers, the quantity, in gallons or equivalent units, of usable fuel in each tank during flight. In addition (1) Each fuel quantity indicator must be calibrated to read ``zero" during level flight when the quantity of fuel remaining in the tank is equal to the unusable fuel supply determined under § 25.959; (2) Tanks with interconnected outlets and airspaces may be treated as one tank and need not have separate indicators; and (3) Each exposed sight gauge, used as a fuel quantity indicator, must be protected against damage.	(b) Fuel quantity indicator. There must be means to indicate to the flight-crew members, the quantity, in litres, (gallons), or equivalent units, of usable fuel in each tank during flight. In addition — (1) Each fuel quantity indicator must be calibrated to read 'zero' during level flight when the quantity of fuel remaining in the tank is equal to the unusable fuel supply determined under CS 25.959; (2) Tanks with interconnected outlets and airspaces may be treated as one tank and need not have separate indicators; and (3) Each exposed sight gauge, used as a fuel quantity indicator, must be protected against damage.
(c) *Fuel flowmeter system*. If a fuel flowmeter system is installed, each metering component must have a means for bypassing the fuel supply if malfunction of that component severely restricts fuel flow. (d) *Oil quantity indicator.* There must be a stick gauge or equivalent means to indicate the quantity of oil in each tank. If an oil transfer or reserve oil supply system is installed, there must be a means to indicate to the flight crew, in flight, the quantity of oil in each tank.	(c) *Fuel flowmeter system.* If a fuel flowmeter system is installed, each metering component must have a means for bypassing the fuel supply if malfunction of that component severely restricts fuel flow. (d) *Oil quantity indicator.* There must be a stick gauge or equivalent means to indicate the quantity of oil in each tank. If an oil transfer or reserve oil supply system is installed, there must be a means to indicate to the flight crew, in flight, the quantity of oil in each tank.
(e) *Turbopropeller blade position indicator.* Required turbopropeller blade position indicators must begin indicating before the blade moves more than eight degrees below the flight low pitch stop. The source of indication must directly sense the blade position.	(e) *Turbo-propeller blade position indicator.* Required turbo-propeller blade position indicators must begin indicating before the blade moves more than 8º below the flight low pitch stop. The source of indication must directly sense the blade position.

Continued

Instruments: Installations	Instruments: Installations
f) Fuel pressure indicator. There must be means to measure fuel pressure, in each system supplying reciprocating engines, at a point downstream of any fuel pump except fuel injection pumps. In addition (1) If necessary for the maintenance of proper fuel delivery pressure, there must be a connection to transmit the carburetor air intake static pressure to the proper pump relief valve connection; and (2) If a connection is required under subparagraph (1) of this section, the gauge balance lines must be independently connected to the carburetor inlet pressure to avoid erroneous readings.	
§ 25.1521 Powerplant Limitations. (a) *General*. The powerplant limitations prescribed in this section must be established so that they do not exceed the corresponding limits for which the engines or propellers are type certificated and do not exceed the values on which compliance with any other requirement of this part is based. (b) *Reciprocating engine installations*. Operating limitations relating to the following must be established for reciprocating engine installations: (1) Horsepower or torque, r.p.m., manifold pressure, and time at critical pressure altitude and sea level pressure altitude for (i) Maximum continuous power (relating to unsupercharged operation or to operation in each supercharger mode as applicable); and (ii) Takeoff power (relating to unsupercharged operation or to operation in each supercharger mode as applicable). (2) Fuel grade or specification. (3) Cylinder head and oil temperatures. (4) Any other parameter for which a limitation has been established as part of the engine type certificate except that a limitation need not be established for a parameter that cannot be exceeded during normal operation due to the design of the installation or to another established limitation.	**CS 25.1521 Powerplant limitations (See AMC 25.1521)** (a) *General*. The powerplant limitations prescribed in this paragraph must be established so that they do not exceed the corresponding limits for which the engines or propellers are type certificated and do not exceed the values on which compliance with any other requirement of this Code is based. (b) Reserved.

Continued

<table>
<tr><th>Instruments: Installations</th><th>Instruments: Installations</th></tr>
<tr><td>(c) Turbine engine installations. Operating limitations relating to the following must be established for turbine engine installations:

(1) Horsepower, torque or thrust, r.p.m., gas temperature, and time for

(i) Maximum continuous power or thrust (relating to augmented or unaugmented operation as applicable).

(ii) Takeoff power or thrust (relating to augmented or unaugmented operation as applicable).

(2) Fuel designation or specification.

(3) Any other parameter for which a limitation has been established as part of the engine type certificate except that a limitation need not be established for a parameter that cannot be exceeded during normal operation due to the design of the installation or to another established limitation.

(d) Ambient temperature. An ambient temperature limitation (including limitations for winterization installations, if applicable) must be established as the maximum ambient atmospheric temperature established in accordance with § 25.1043(b).</td><td>(c) Turbine engine installations. Operating limitations relating to the following must be established for turbine engine installations:

(1) Horsepower, torque or thrust, rpm, gas temperature, and time for —

(i) Maximum continuous power or thrust (relating to augmented or unaugmented operation as applicable).

(ii) Take-off power or thrust (relating to augmented or unaugmented operation as applicable).

(2) Fuel designation or specification.

(3) Any other parameter for which a limitation has been established as part of the engine type certificate except that a limitation need not be established for a parameter that cannot be exceeded during normal operation due to the design of the installation or to another established limitation.

(d) Ambient temperature. An ambient temperature limitation (including limitations for winterization installations, if applicable) must be established as the maximum ambient atmospheric temperature established in accordance with CS 25.1043(b).</td></tr>
<tr><td>§ 25.1522 Auxiliary Power Unit Limitations.

If an auxiliary power unit is installed in the airplane, limitations established for the auxiliary power unit, including categories of operation, must be specified as operating limitations for the airplane.</td><td>[CS 25.1522 removed at Amdt No.:25/1]</td></tr>
<tr><td>§ 25.1549 Powerplant and Auxiliary Power Unit Instruments.

For each required powerplant and auxiliary power unit instrument, as appropriate to the type of instrument

(a) Each maximum and, if applicable, minimum safe operating limit must be marked with a red radial or a red line;

(b) Each normal operating range must be marked with a green arc or green line, not extending beyond the maximum and minimum safe limits;</td><td>CS 25.1549 Powerplant instruments
(See AMC 25.1549)

For each required powerplant instrument, as appropriate to the type of instrument:

(a) Each maximum and, if applicable, minimum safe operating limit must be marked with a red radial or a red line;

(b) Each normal operating range must be marked with a green arc or green line, not extending beyond the maximum and minimum safe limits;</td></tr>
</table>

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Instruments: Installations	Instruments: Installations
(c) Each takeoff and precautionary range must be marked with a yellow arc or a yellow line; and (d) Each engine, auxiliary power unit, or propeller speed range that is restricted because of excessive vibration stresses must be marked with red arcs or red lines.	(c) Each take-off and precautionary range must be marked with a yellow arc or a yellow line; and (d) Each engine or propeller speed range that is restricted because of excessive vibration stresses must be marked with red arcs or red lines
§ 25.1551 Oil Quantity Indication. Each oil quantity indicating means must be marked to indicate the quantity of oil readily and accurately.	**CS 25.1551 Oil quantity indicator** Each oil quantity indicating means must be marked to indicate the quantity of oil readily and accurately.
§ 25.1553 Fuel Quantity Indicator. If the unusable fuel supply for any tank exceeds one gallon, or five percent of the tank capacity, whichever is greater, a red arc must be marked on its indicator extending from the calibrated zero reading to the lowest reading obtainable in level flight.	**CS 25.1553 Fuel quantity indicator** If the unusable fuel supply for any tank exceeds 3.8 l (one gallon), or 5% of the tank capacity, whichever is greater, a red arc must be marked on its indicator extending from the calibrated zero reading to the lowest reading obtainable in level flight.
§ 25.1583 Operating Limitations. (b) *Powerplant limitations.* The following information must be furnished: (1) Limitations required by § 25.1521 and § 25.1522. (2) Explanation of the limitations, when appropriate. (3) Information necessary for marking the instruments required by § 25.1549 through 25.1553.	**CS 25.1583 Operating limitations** (b) *Powerplant limitations*. The following information must be furnished: [(1) Limitations required by CS 25.1521.] (2) Explanation of the limitations, when appropriate. (3) Information necessary for marking the instruments required by CS 25.1549 to 25.1553.
§ 25.1585 Operating Procedures. (c) Information identifying each operating condition in which the fuel system independence prescribed in § 25.953 is necessary for safety must be furnished, together with instructions for placing the fuel system in a configuration used to show compliance with that section. (e) Information must be furnished which indicates that when the fuel quantity indicator reads 'zero' in level flight, any fuel remaining in the fuel tank cannot be used safely in flight. (f) Information on the total quantity of usable fuel for each fuel tank must be furnished.	**CS 25.1585 Operating procedures** (c) Information identifying each operating condition in which the fuel system independence prescribed in CS 25.953 is necessary for safety must be furnished, together with instructions for placing the fuel system in a configuration used to show compliance with that section. (e) Information must be furnished which indicates that when the fuel quantity indicator reads 'zero' in level flight, any fuel remaining in the fuel tank cannot be used safely in flight. (f) Information on the total quantity of usable fuel for each fuel tank must be furnished.

§ 25.1305 Powerplant indications.

The aircraft must be equipped with the powerplant indications listed in paragraphs (a) to (f) of this section, unless compliance with paragraph (g) can be shown without some or all of those indications.

(a) ***For all airplanes***.

(1) A means to alert the flight crew of low fuel pressure for each engine, or a master alert means for all engines with provision for isolating the individual engine status from the master alert.

(2) A fuel quantity indication for each fuel tank.

(3) An oil quantity indication for each oil tank.

(4) An oil pressure indication for each independent pressure oil system of each engine.

(5) In addition to (4), a means to alert the flight crew of low oil pressure for each engine, or a master alert means for all engines with provision for isolating the individual engine status from the master alert.

(6) An oil temperature indication for each engine.

(7) Visual and audible fire alert indication(s).

(8) An augmentation liquid quantity indication (appropriate for the manner in which the liquid is to be used in operation) for each tank.

(b) ***For reciprocating engine-powered airplanes.*** In addition to the powerplant indications required by paragraph (a) of this section, the following powerplant indications are required:

(1) A carburetor air temperature indication for each engine.

(2) A cylinder head temperature indication for each air-cooled engine.

(3) A manifold pressure indication for each engine.

(4) A fuel pressure indication (to indicate the pressure at which the fuel is supplied) for each engine.

(5) A fuel flowmeter, or fuel mixture indication, for each engine without an automatic altitude mixture control.

(6) A tachometer for each engine.

(7) A device that indicates, to the flight crew (during flight), any change in the power output, for each engine with—

(i) An automatic propeller feathering system, whose operation is initiated by a power output measuring system; or

(ii) A total engine piston displacement of 2,000 cubic inches or more.

(8) A means to indicate to the pilot when the propeller is in reverse pitch, for each reversing propeller.

(c) ***For turbine engine-powered airplanes.*** In addition to the powerplant indications required by paragraph (a) of this section, the following powerplant indications are required:

(1) A gas temperature indication for each engine.

(2) A fuel flowmeter indication for each engine.

(3) Rotor speed indication(s) for each engine.

(4) A means to indicate, to the flight crew, the operation of each engine starter that can be operated continuously but that is neither designed for continuous operation nor designed to prevent hazard if it failed.

(5) An indication of the functioning of the powerplant ice protection system for each engine.

(6) An indication for the fuel strainer or filter required by §25.997 to alert the flight crew of contamination of the strainer or filter before it reaches the capacity established in accordance with §25.997(d).

(7) An alert means for the oil strainer or filter required by §25.1019, if it has no bypass, to alert the flight crew of contamination of the strainer or filter screen before it reaches the capacity established in accordance with §25.1019(a)(2).

(8) An indication of the proper functioning of any heater used to prevent ice clogging of fuel system components.

(9) For each engine, a means to alert the flight crew when an engine fails to a below idle condition.

(d) ***For turbojet engine powered airplanes.*** In addition to the powerplant indications required by paragraphs (a) and (c) of this section, the following powerplant indications are required:

(1) An indication of thrust, or a parameter that is directly related to thrust, to the flight crew. The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust.

(2) For each engine using a thrust reversing device, indication to the flight crew when the thrust reversing device is either – Not in the selected position, or In the reverse thrust position.

(3) An indication of rotor system unbalance.

(e) ***For turbopropeller-powered airplanes***. In addition to the powerplant indications required by paragraphs (a) and (c) of this section, the following powerplant indications are required:

(1) A torque indication for each engine.

(2) ndication to the flight crew when the propeller blade angle is below the flight low pitch position, for each propeller.

(f) For airplanes equipped with fluid systems (other than fuel) for thrust or power augmentation, an approved means must be provided to indicate the proper functioning of that system to the flight crew.

(g) ***For all airplanes***. Powerplant indications as required to support safe operation of the airplane such as:

(1) Flight deck indications to support the approved operating procedures

(2) Indications as required by the system safety assessments

(3) Indications required to support the instructions for continued airworthiness

A version with the changes indicated follows below.

§ 25.1305 Powerplant ~~instruments~~ **indications.**

~~The following are required powerplant instruments:~~

The aircraft must be equipped with the powerplant indications listed in paragraphs (a) to (f) of this section, unless compliance with paragraph (g) can be shown without some or all of those indications.

(a) *For all airplanes.*

(1) A ~~fuel pressure warning~~ means **to alert the flight crew of low fuel pressure** for each engine, or a master ~~warning~~ **alert** means for all engines with provision for isolating the individual ~~warning means~~ **engine status** from the master ~~warning means~~ **alert.**

(2) A fuel quantity ~~indicator~~ **indication** for each fuel tank.

(3) An oil quantity ~~indicator~~ **indication** for each oil tank.

(4) An oil pressure ~~indicator~~ **indication** for each independent pressure oil system of each engine.

(5) ~~An oil pressure warning means~~ **In addition to (4), a means to alert the flight crew of low oil pressure** for each engine, or a master ~~warning~~ **alert** means for all engines with provision for isolating the individual ~~warning means~~ **engine status** from the master ~~warning~~ **alert**.

(6) An oil temperature ~~indicator~~ **indication** for each engine.

(7) ~~Fire-warning devices that provide~~ Visual and audible fire ~~warning~~ **alert indication(s).**

(8) An augmentation liquid quantity ~~indicator~~ **indication** (appropriate for the manner in which the liquid is to be used in operation) for each tank.

(b) *For reciprocating engine-powered airplanes.* In addition to the powerplant ~~instruments~~ **indications** required by paragraph (a) of this section, the following powerplant ~~instruments~~ **indications** are required:

(1) A carburetor air temperature ~~indicator~~ **indication** for each engine.

(2) A cylinder head temperature ~~indicator~~ **indication** for each air-cooled engine.

(3) A manifold pressure ~~indicator~~ **indication** for each engine.

(4) A fuel pressure ~~indicator~~ **indication** (to indicate the pressure at which the fuel is supplied) for each engine.

(5) A fuel flowmeter, or fuel mixture ~~indicator~~ **indication**, for each engine without an automatic altitude mixture control.

(6) A tachometer for each engine.

(7) A device that indicates, to the flight crew (during flight), any change in the power output, for each engine with—

(i) An automatic propeller feathering system, whose operation is initiated by a power output measuring system; or

(ii) A total engine piston displacement of 2,000 cubic inches or more.

(8) A means to indicate to the pilot when the propeller is in reverse pitch, for each reversing propeller.

(c) *For turbine engine-powered airplanes.* In addition to the powerplant ~~instruments~~ **indications** required by paragraph (a) of this section, the following powerplant ~~instruments~~ **indications** are required:

(1) A gas temperature ~~indicator~~ **indication** for each engine.

(2) A fuel flowmeter indicator **indication** for each engine.

(3) ~~A tachometer (to indicate the speed of the rotors with established limiting speeds)~~ **Rotor speed indication(s)** for each engine.

(4) A means to indicate, to the flight crew, the operation of each engine starter that can be operated continuously but that is neither designed for continuous operation nor designed to prevent hazard if it failed.

(5) An ~~indicator to indicate~~ **indication** of the functioning of the powerplant ice protection system for each engine.

(6) An ~~indicator~~ **indication** for the fuel strainer or filter required by §25.997 to ~~indicate the occurrence~~ **alert the flight crew** of contamination of the strainer or filter before it reaches the capacity established in accordance with §25.997(d).

(7) ~~A warning~~ **An alert** means for the oil strainer or filter required by §25.1019, if it has no bypass, to ~~warn the pilot of the occurrence~~ **alert the flight crew** of contamination of the strainer or filter screen before it reaches the capacity established in accordance with §25.1019(a)(2).

(8) An ~~indicator to indicate~~ **indication of** the proper functioning of any heater used to prevent ice clogging of fuel system components.

(9) For each engine, a means to alert the flight crew when an engine fails to a below idle condition.

(d) *For turbojet engine powered airplanes.* In addition to the powerplant ~~instruments~~ **indications** required by paragraphs (a) and (c) of this section, the following powerplant ~~instruments~~ **indications** are required:

(1) An ~~indicator to indicate~~ **indication** of thrust, or a parameter that is directly related to thrust, to the ~~pilot~~ **flight crew**. The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust. ~~The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration.~~

(2) **For each engine using a thrust reversing device,** ~~A position indicating means to indicate~~ **indication** to the flight crew when the thrust reversing device **is either –**

~~Is~~ **not** in the selected position, and or

~~Is~~ **in the reverse thrust position**~~, for each engine using a thrust reversing device.~~

(3) An ~~indicator~~ **indication** of rotor system unbalance.

(e) *For turbopropeller-powered airplanes.* In addition to the powerplant ~~instruments~~ **indications** required by paragraphs (a) and (c) of this section, the following powerplant ~~instruments~~ **indications** are required:

(1) A torque ~~indicator~~ **indication** for each engine.

(2) ~~Position indicating means to indicate~~ **Indication** to the flight crew when the propeller blade angle is below the flight low pitch position, for each propeller.

(f) For airplanes equipped with fluid systems (other than fuel) for thrust or power augmentation, an approved means must be provided to indicate the proper functioning of that system to the flight crew.

(g) *For all airplanes.* **Powerplant indications as required to support safe operation of the airplane such as:**

(1) Flight deck indications to support the approved operating procedures

(2) Indications as required by the system safety assessments

(3) Indications required to support the instructions for continued airworthiness

Background

During development of PITT recommendations for changes to §25.1305, questions were raised about compliance with §25.1305(d)(1). Specifically the last sentence that reads: “The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration”. The questions concern the need for a rule that clarifies just one aspect (thrust change) of the thrust indication system, overlap with other regulations, the prescriptive nature of this requirement hampering innovation in flight deck display systems and changes in control systems architecture to parameters that are directly related to thrust which negate the original concerns being addressed when the rule was first adopted. In addition the EASA CS provides advisory material for this regulation which allows existing thrust setting parameters which has provided safe operation, but do not meet the literal interpretation of the last sentence.

History of current regulation

The original rule was introduced in 1964, and then moved with minor editorial changes to a separate paragraph (d) for turbojet engine indications in 1974.

> **Sec. 25.1305 Powerplant instruments.**
> (r) An indicator to indicate a change in thrust resulting from any deficiency in the engine, or to indicate a gas stream pressure that can be related to thrust, for each turbojet engine.
> **–Final Rule. Docket No. 5066; Issued on 11/03/64.**
>
> **Sec. 25.1305 Powerplant instruments.**
> * * * * *
> (d) * * *
> (1) An indicator to indicate a change in thrust resulting form any deficiency in the engine, or to indicate a gas stream pressure that can be related to thrust, for each engine.
> **–Amdt. 25-36, Eff. 10/31/74**

In 1975, the FAA proposed a significant revision to this rule. The proposed rule includes the concept that the thrust indication is based on the direct measurement of thrust.

> Proposal 8-50. By adding a new Sec. 25.1305(c)(9) and revising Sec. 25.1305(d)(1) to read as follows:
>
> **Sec. 25.1305 Powerplant instruments**
> * * * * *
> (d) * * *
> (1) An indicator to indicate thrust to the pilot. The indication must be based on the direct measurement of thrust or of a parameter that is directly related to thrust except that a parameter may not be used if the accuracy of the indication based on that parameter will be adversely affected by any engine malfunction, damage, or deterioration.
>
> *Explanation.*
> In addition, the proposal for Sec. 25.1305(d)(1) would revise the current requirement to more clearly indicate the kinds of engine deficiencies to be considered, and would require a direct measurement either of thrust or of a parameter that is related to thrust. The use of gas stream pressure as a parameter would no longer be permitted for all engines since for some engines it does not provide an adequate indication of a change in thrust caused by all engine malfunctions, damage, or deterioration.
> **–Ref. Proposal No. 785; Sec. 25.1305(d)(1); Agenda Item N-78 (Committee IV).**
>
> **–Notice of Airworthiness Review Program No. 8; Notice No. 75-31; Issued on 6/30/75. [Federal Register: July 11, 1975] [Page 29410]**

Industry offered comments on the proposed rule; the FAA disposition of these comments was published along with the final rule in 1980.

> Proposal 8-50: … One commenter objects to revising Sec. 25.1305(d)(1), stating that significant aerodynamic forces acting on the powerplant nacelle make the direct measurement of thrust impractical. The FAA agrees that such forces may be significant. This commenter further objects to the revision, stating that it is beyond the state of the art to prohibit a parameter from being used if the accuracy of the indication will be adversely affected by any engine malfunction or damage. The FAA agrees that precise values of thrust provided by a malfunctioning, damaged, or deteriorated engine are unnecessary, provided that any changes in thrust due to engine malfunction, damage, or deterioration are indicated to the pilot. The paragraph is revised to require that the indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust.
>
> Although concurring with Sec. 25.1305(d)(1), one commenter states that he would prefer to retain the existing requirements and delete the words ", or to indicate a gas stream pressure that can be related to thrust,". The FAA does not agree. The change suggested by this commenter would eliminate the requirement for thrust information and would retain the requirement for change-of-thrust information only. It also would provide a lower level of safety than the adopted paragraph.
>
> This commenter also states that Sec. 25.1305(d)(1) should be complementary to a similar requirement in Part 33 of this chapter. The FAA does not agree. In current practice, the airframe manufacturer determines how performance should be met. The choice of a means to indicate thrust is negotiated between the airplane manufacturer and the engine manufacturer. The factors which influence the final choice are substantial and may vary among airplane designs. These factors may not be known to the engine manufacturer at the time of engine type certification. Another commenter states that the need for an actual value of thrust is not obvious, whereas indication of a loss of thrust would satisfy the original proposal. The FAA agrees that the actual value of thrust is of little value to the pilot. Sec. 25.1305(d)(1) is revised to specify that the indicator indicate thrust, or a parameter related to thrust, to the pilot.
>
> **–Final Rule. Docket No 14779, 14324; Issued. on 8/27/80.**

This is the final rule that was adopted in October of 1980 after disposition of the above comments.

> **Sec. 25.1305 Powerplant instruments.**
>
> * * * * *
>
> (d) * * *
>
> (1) An indicator to indicate thrust, or a parameter that is directly related to thrust, to the pilot. The indication must be based on the direct measurement of thrust or parameters that are directly related to thrust. The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration.
>
> **–Amdt. 25-54, Eff. 10/14/80**

While a portion of 25.1305 concerning thrust reversers was revised in 2004, this section remains unchanged in the current amendment.

> **Sec. 25.1305 Powerplant instruments**
>
> * * * * *
>
> (d) * * *
>
> (1) An indicator to indicate thrust, or a parameter that is directly related to thrust, to the pilot. The indication must be based on the direct measurement of thrust or parameters that are directly related to thrust. The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration.
>
> **–Amdt. 25-115, Eff. 8/2/2004**

Current EASA regulation

The current EASA regulation is harmonized with the FAA regulation, but adds a direct reference to the EASA advisory material.

CS 25.1305 Instruments
* * * * *
d) * * *
(1) An indicator to indicate thrust, or a parameter that is directly related to thrust, to the pilot. The indication must be based on the direct measurement of thrust or of the parameters that are directly related to thrust. The indicator must indicate a change in thrust resulting from any engine malfunction, damage or deterioration. (See AMC 25.1305 (d)(1).)
–CS-25 Amendment 1

EASA Advisory material

The EASA advisory material reference establishes at least 3 possible methods for compliance with this requirement.

AMC 25.1305(d)(1)
Instruments
The following are examples of parameters, which are considered to be directly related to thrust; fan RPM(N1), integrated engine pressure ratio (IEPR) and engine pressure ratio (EPR), depending on engine type.

Observations

Indicator: 1 –s: a: one that indicates as: a: an index hand (as on a dial): POINTER b (1): a pressure gauge (2): an instrument for automatically making a diagram that indicates the pressure in and volume of a working fluid of an engine throughout the cycle so that the horsepower and other characteristics may be deduced c: a speed counter for an engine d: a registering dial (as on a dial telegraph) e: ANNUNCIATOR…
–Webster's Third New International Dictionary unabridged

Indicate: to point out or point to or toward with more or less exactness: show or make known with a fair degree of certainty: a (1): to show the probable presence or existence or nature or course of: give fair evidence of: be a fairly certain sign or symptom or: reveal in a fairly clear way … b: to act as a more or less exact index of: show or suggest the probable extent or degree of… d: to show the general position or direction of: direct attention to with more or less preciseness: point at…
–Webster's Third New International Dictionary unabridged

Based on the above material, the following conclusions can be made about the 25.1305(d)(1) rule.

- The rule concerns an indicator, a gage, or an index, that notifies the pilot when thrust changes due to an engine malfunction, damage, or deterioration.
- The ability of the indicator, gage, or index, to accurately measure thrust measurement with an engine malfunction is not required.
- Absolute accuracy in thrust measurement in not required. The use of word “indicate” though implies that the gage should have a fair degree of certainty, or that it should be a more or less exact index of thrust. This implies that some level of of uncertainty in the thrust indication is acceptable. This position is reflected by the disposition comments when the FAA states, “that the actual value of thrust is of little value to the pilot.”

Question

If accuracy in thrust measurement is not required, what then is required under this rule?

Response

The rule requires a graduated reading (i.e. an indication) of thrust.

> Indication: 1: the action of indicating 2a: something (as a signal, sign, suggestion) that serves to indicate… : a symptom or particular circumstance that indicates the advisability or necessity of (as a specific medical treatment or procedure)… b: something that is indicated as advisable or necessary… 3: the degree indicated in a specific instance or at a specific time on a graduated physical instrument (as a thermometer): READING 4: suggestion (as by the use of conventionalized techniques or symbols) of architectural features (as in a drawing) rather than detailed representation of such features…
>
> **–Webster's Third New International Dictionary unabridged**

PITT proposed changes

Proposed

(1) An indication of thrust, or a parameter that is directly related to thrust, to the flight crew. The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust.

Proposed (with emphasize and changes)

(1) An ~~indicator to indicate~~ **indication** of thrust, or a parameter that is directly related to thrust~~, to the pilot~~ **to the flight crew.** The indication must be based on the direct measurement of thrust or of parameters that are directly related to thrust. ~~The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration.~~

Explanation

Change 1: delete "indicator to indicate" and replace with "indication".

The term indicator is prescriptive in that it implies the presence of a physical index on a dial, a gage, a diagram, or a counter. Current and future systems are moving away from such literal devices to systems that present the flight crew with parameters (processed data) and information that the flight crew uses to make judgments or decisions. The term indication implies the act of indicating, is more general, and will allow for representations that are more symbolic verses detailed representations of gages or indexes.

Change 2: delete "to the pilot" and replace with "to the flight crew".

This is an editorial change to recognize that cockpit indications are intended for display to the flight crew, and not just the pilot flying.

Change 3: delete the sentence "The indicator must indicate a change in thrust resulting from any engine malfunction, damage, or deterioration".

The first sentence of this requirement clearly states that the indictor must be based on the direct measurement of thrust or parameters directly related to thrust. No additional clarification that the indicator must show a change in thrust resulting from any engine malfunction is necessary since the indication is based on thrust, if thrust changes it is only logical to conclude that the indication will also change.

Other requirements within §25 provide for the intention of this sentence without describing the means of compliance. Firstly, a thrust indication system must function properly, §25.1301(d). In order to meet this requirement a thrust indication system should be able to indicate changes in thrust as part of its proper function. Secondly, a thrust indication system must perform its intended function under any foreseeable operating condition and in a safe manner, §25.1309(a), and §25.901(c). Thus, the concepts of engine malfunction, damage, or deterioration are already implicit in the regulations since these are foreseeable conditions. In addition, §25.1309(a), and §25.901(c), add additional requirements to consider since failures of the thrust indication system (sensors, displays, etc) and not just engine malfunction are part of the safety properties.

EASA and it's predecessor, the JAA, recognized that existing thrust setting parameters (a) did not meet the requirements of the last sentence yet (b) provided safe airplane operation. They addressed this conflict by providing ACJ 25.1305(d)(1) which circumvented any discussion of the detailed requirements of the last sentence by allowing existing thrust setting parameters such as N1 , EPR and IEPR.

The requirement is overly prescriptive in that it limits the possible methods of compliance for indication of thrust changes to a gage or index. The requirements of §25.901(c), §25.1301(d), and§25.1309(a), already make provision for the indications required by the flight crew to operate the aircraft. For current and future systems, it is possible to envision systems where a traditional thrust gage representation is augmented by visual or aural warning messages on the thrust status of the aircraft. Thus the intention of rule for a thrust change indication would be shifted from the physical gage indication to an aircraft level caution/warning system[1]. Depending on the level of abstraction for the thrust indication it may not be clear that such a caution/warning system could comply with the literal intent of the rule for a physical gage.

Finally, changes in control system architecture from indirect control of thrust to direct control of thrust have mitigated the need for an explicit requirement on thrust change indication. During the period in which this rule was adopted engine control systems that operated on a parameter directly related to thrust were atypical. For example, systems of the period moved a physical throttle that controlled setting on an N2 speed. The resulting thrust was in effect a secondary result of the engine running at a particular N2 speed. In such a system, it was important to monitor for changes in thrust, because thrust was not under direct control and differences between requested thrust and actual thrust were expected. Hence, the explicit requirement for an indication of changes in thrust in order to allow for this comparison was an important aspect of the regulation in that time period. Modern systems are now using a primary parameter such as N1, or EPR that is directly related to thrust for control, and the comparison between requested thrust and actual thrust is a function of the control system and not the flight crew.

[1] Systems have already been certified that warn the flight crew of thrust reductions during takeoff. These systems use the aircraft master warning system and a warning message, not changes in the thrust setting display to initiate flight crew action for an engine failure aborted takeoff. In the future increases in computing power may make continuous aircraft and engine performance calculations possible. This would enable aircraft performance calculations to be crosschecked with engine performance calculations. Rather waiting for the flightcrew to notice a gage change such a system can provide warnings for thrust/drag disagreement or performance disagreement.

The following recommendations were forwarded by J. Doherty, AIA PITT Chair to C. Badie Co-chair ASHWG in June 2006.

The following is presented as edits to the original AC/AMC 25-11.

Draft	Date	Description of Changes
K	Apr 2006	Includes changes made from the AVHWG meeting, April 2006
	Jun 2006	AIA Powerplant Indications Team input as noted by gray highlight

6.2 Effects of Failure Conditions

Fully understanding the effects of failures of a Display System is difficult because the effects are highly dependent on the flight crew proficiency, flight deck procedures, phase of flight, the type of operations being conducted, instrumental or visual meteorological conditions, and other system protections.

The Failure Condition definition is complete when the effects resulting from "failure" are identified. A complete definition of the Failure Condition and its effect will then support the subsequent Failure Condition classification.

Based on experience of previous airplane certification programs, section 6.5 sets safety objectives for some Failure Conditions. These safety objectives do not preclude the assessment of the actual effects of these failures, which may be more or less severe depending on the design. Therefore the classifications for these Failure Conditions will also need to be agreed with the authority during the FAR/CS-25.1309 safety assessment process.

a. When assessing the effects that result from a display failure, the following effects should be considered, accounting for phases of flight when relevant:

- Effects on the flight crew's control of the airplane in terms of attitude, speed, accelerations, flight path, potentially resulting in: (reformatted to address CAST recommendations)
    - controlled flight into terrain (CFIT)
    - loss of control
    - loss of obstacle clearance capability
    - exceeding takeoff or landing field length

      [AIA PITT: These two items are in lieu of the much-discussed "Note 1", i.e. enables removal of Note 1 from Section 6.5.7, the version that discussed undetected thrust loss vs. airplane performance cert.]

    - exceeding the flight envelope
    - exceeding the structural integrity of the airplane
    - exciting structural modes.
- Effects on the flight crew's ability to control the engines, such as
    - those effects resulting in shutting down a non-failed engine in response to failure of a different engine
    - undetected, significant thrust loss.
    - Effects on the flight crew's management of the aircraft systems
    - Effects on the flight crew's performance, workload and ability to cope with adverse operating conditions
    - Effects on situation awareness (e.g. related to navigation, system status)

When the display system is used as a control device for other airplane systems, assessment of the failure of the display system as a control device has to consider the cumulative effect on all the controlled systems.

6.5.7 Engine

Safety objectives for engine display related failure conditions are as follows: The term "required engine indications" refers specifically to the engine thrust/power setting parameter (e.g. Engine Pressure Ratio, fan speed, torque) and any other engine indications that may be required by the flight crew to maintain the engine within safe operating limits (e.g. rotor speeds, Exhaust Gas Temperature)

This table assumes the display failure occurs while operating in an autonomous engine control mode. Autonomous engine control modes, such as those nominally provided by Full Authority Digital Engine Controls (FADECs), protect continued safe operation of the engine at any thrust lever setting. Hence, the flight deck indications and associated flight crew actions are not the nominal means of protecting safe engine operation.

Failure Condition	Safety objective
Loss of one or more required engine indications on a single engine	Remote
Misleading display of one or more required engine indications on a single engine.	Remote
Loss of one or more required engine indications on more than one engine.	Extremely Remote
Misleading display of any required engine indications on more than one engine	Extremely Improbable

[AIA PITT:
"Note 1", both the original AIA PITT and AVHWG version, is deleted.
The autonomous control paragraph is a necessary lead-in qualifier for the table.
As was discussed 30 May 06 between AVHWG & AIA PITT reps @ FAA Seattle Office:

- *As for non-autonomous engine controls, firstly we don't expect any other than STCs, and secondly they are adequately covered by the provisos above in Section 6, e.g. each application requires a SSA.*
- *Extremely Remote is consistent with the most severe anticipated Functional Hazard Classification.]*

7.2.4.2 Scales, Dials, and Tapes

Scales, dials and tapes with fixed or moving pointers have been shown to effectively improve crew interpretation of numeric data,

The displayed range should be sufficient to perform the intended function. If the entire operational range is not shown at any given time, the transition to the other portions of the range should not be distracting or confusing.

Scale resolution should be sufficient to perform the intended task. Delimiters such as tick marks should allow rapid interpretation without adding unnecessary clutter. Markings and labels should be positioned such that their meaning is clear yet they do not hinder interpretation.

Pointers and indexes should be unambiguous and readily identifiable. They should not obscure the scales or delimiters such that they can no longer be interpreted. They should be positioned with sufficient accuracy at all times. Accuracy includes effects due to data resolution, latency, graphical positioning, etc.

When numeric readouts are used in conjunction with scales, tapes or dials, they should be located close enough to ensure proper association yet not detract from the interpretation of the graphic.

[AIA PITT: Minor item, as discussed 30 May 06 meeting with AVHWG reps. AIA PITT pointed out that this paragraph seems to unintentionally omit the possibility of graphic-only representations.]

7.7 Consistency

[Move to Chapter 8.2.3] The following information should be placed in the same relative position whenever shown: [Need to re-write for consistency, clarity, and to ensure that the "relative to what" is specified]

- Real time sensor data (e.g. localizer deviation, radio altitude, traffic), airplane position, and menus
- Airplane system information (relative to actual airplane position and to other graphics for that system) such as powerplant indications
- Map features (relative to current position)
- Failure flags (relative to the indications they replace)
- Segment of flight information (relative to similar information for other segments)
- Bugs, limits and associated data (relative to the information they support) such as tape markings
- Data messages (relative to other related messages) such as crew alerts or data links
- Image reference point, unless the flight crew takes action to alter the reference point

8.2 Types and Arrangement of Display Information

This section provides guidance for the arrangement and location of categories of information. The categories of information include:

1. Primary Flight Information (PFI) including attitude, airspeed, altitude and heading.
2. Powerplant Information (PI) which covers functions relating to propulsion.
3. Other Information

Information on the Basic T and Powerplant information is covered below.

8.2.2 Powerplant Information

This section provides guidance for location and arrangement of required powerplant information. Parameters necessary to set and monitor engine thrust or power should be continuously displayed in the flight crew's primary field of view unless the applicant can demonstrate that this is not necessary (see Appendix B). The automatic or manually selected display of powerplant information should not suppress other information that requires flight crew awareness.

§ Generally, place parameter indications in order of importance with the most important at the top.

Powerplant information must be closely grouped (in accordance with 25.1321) in an easily identifiable and logical arrangement which allows the flight crew to clearly and quickly identify the displayed information and associate it with the corresponding engine. Typically, it is considered to be acceptable to arrange parameters related to one powerplant in a vertical manner and, according to powerplant position, next to the parameters related to another powerplant in such a way that identical powerplant parameters are horizontally aligned.

[AIA PITT: Please either define closely grouped or adopt what was already proposed by AIA PITT: "Generally, engine information should be grouped on the same display unless there are compelling reasons to separate them to different displays, e.g. "primary" and "secondary" displays, or the manner in which the displays are used (i.e. display space as limited by flight deck configuration, flight crew vs. maintenance, pre-flight vs. operation)."]

8.3.3 Full-time vs. Part-time Displays

Some airplane parameters or status indications are required by the regulations to be displayed, yet they may only be necessary or required in certain phases of flight. If it is desired to inhibit some parameters from

full-time display, an equivalent level of safety to full-time display must be demonstrated. Criteria to be considered include the following:

- Continuous display of the parameter is not required for safety of flight in all normal flight phases.
- The parameter is automatically displayed in flight phases where it is required.
- The inhibited parameter is automatically displayed when its value indicates an abnormal condition, or when the parameter reaches an abnormal value.
- Display of the inhibited parameter can be manually selected by the crew without interfering with the display of other required information.
- If the parameter fails to be displayed when required, the failure effect and compounding effects must meet the requirements of 25.1309.
- The automatic, or requested, display of the inhibited parameter should not create unacceptable clutter on the display; simultaneous multiple "pop-ups" must be considered.
- If the presence of the new parameter is not sufficiently self-evident, suitable alerting must accompany the automatic presentation.

13 Glossary of Acronyms/Abbreviations

EICAS –Engine Indicating and Crew Alerting System [AIA PITT: Delete? Not used anywhere in the AC] PI-Powerplant Information

14 Definitions

Indication–Any visual information intended for use by the flight crew, e.g. gauges, graphical representations, numeric data, messages, lights, symbols, and synoptics. [Updated 4/2014]

[**Note**: The definition above was misinterpreted in the released AC revision and written as follows:

"**Indication** - Any visual information representing the status of graphical gauges, other graphical representations, numeric data messages, lights, symbols, synoptics, etc. to the flightcrew."

AIA PITT prefers the recommended definition of "indication" above. If the AC is further revised, this improvement should be included.]

Misleading Information: Misleading information is incorrect information that is not detected by the flight crew because it appears as correct and credible information under the given circumstances.

> *[AIA PITT: As "misleading" is used throughout this document, particularly in the safety objectives, this definition is insufficient. It does not differentiate misleading information that leads to no consequence from misleading information which could impact safe airplane operation. Please add to the definition something such as "when the misleading display results in inappropriate flight crew perception or action which could have safety significant consequences". We note that elsewhere the AVHWG draft states: "Erroneous display of data, that could be: .... Difficult to detect by the crew or not detectable and assumed to be correct (e.g. 'Dangerously incorrect display of …')"]*

Required Powerplant Parameters – The information whose presentation is required by 25.1305.

Appendix B: Powerplant Indications

This section provides additional compliance guidance for powerplant indications.

[AIA PITT: We reviewed the AVHWG re-write and as discussed at the 30 May 06 meeting between AVHWG and AIA PITT reps at the Seattle FAA office, re-instituted the required portions of our previous input, with improvements as suggested by AVHWG.]

B.1 Required Powerplant Indications

To comply with a provision of §25.1305 a display should provide all the instrument functionality of a full time dedicated analog type instrument as intended when the rule was adopted (ref. AC20-88A). The design flexibility and conditional adaptability of modern displays were not envisioned when §25.1305 "Powerplant instruments" and §25.1549 "Powerplant and auxiliary power unit instruments" were initially adopted. In addition, the capabilities of modern control systems to automate and complement flight crew functions were not envisioned. In some cases these system capabilities obviate the need for a dedicated full-time analog type instrument.

When making a finding, all uses of the affected displays should be taken into consideration, including:

(1) Flight deck indications to support the approved operating procedures [re: §25.1585],

(2) Indications as required by the powerplant system safety assessments [re: §25.1309]

(3) Indications required in support of the instructions for continued airworthiness [re: §25.1529]

Example:

Compliance with §25.1305(c)(3) for the engine N2 rotor was originally achieved by means of a dedicated full time analog instrument. This provided the continuous monitoring capability required to:

- support engine starting (e.g. typically used to identify fuel on point);
- support power setting (e.g. sometimes used as primary or back up parameter);
- "give reasonable assurance that those engine operating limitations that adversely affect turbine rotor structural integrity will not be exceeded in service" as required by §25.903(d)(2);
- provide the indication of normal, precautionary and limit operating values required by §25.1549; as well as
- support detection of unacceptable deterioration in the margin to operating limits and other abnormal engine operating conditions as required to comply with §§25.901, 25.1309, etc.

As technology evolved Full Authority Digital Engine Controls (FADECs) were introduced. FADECs were designed with the ability to monitor and control engine N2 rotor speed as required to comply with §25.903(d)(2). Additionally, engine condition monitoring programs were introduced and used to detect unacceptable engine deterioration. Flight deck technology evolved such that indications could be displayed automatically to cover abnormal engine operating conditions. The combination of these developments obviated the need for a full time analog N2 rotor speed indication.

B.2 Additional Design Guidelines

[AIA PITT acknowledges the importance of these two items, however, they are being covered via other means. Requiring a "clear annunciation of… significant thrust loss" would be rulemaking by AC. For significant thrust loss the existing regs such as 1309(b)(c) & 901(c) may be met by annunciations or other means at the discretion of the applicant. Significant undetected thrust loss is addressed in Section 6. As regards Engine Limit Exceedances, this is a 1322 issue, as mentioned, AIA PITT recommend the deletion of 1549. There are ongoing initiatives to improve the compatibility of P33/CS-E engine limits with the intent 1322 by clarifying the safety significance of each limits. AIA PITT conducted a meeting @ FAA EPD on this subject in October 2005.]

The following design guidelines are to be considered in addition to the failure conditions listed in Section 6.5.7:

1) No single failure may cause misleading indications on more than one engine. [ref., §25.903(b)].
2) No single failure should cause the loss of all thrust setting parameters on more than one engine [ref. §25.901(b)(2), §25.901(c), §25.1301, §25.1305 §25.1309].
3) For single failures leading to the partial loss of indications on an engine, sufficient indications should remain to allow continued safe operation of the engine [ref. §25.901(b)(2), §25.901(c), §25.903(d)(2)]
4) Indications required for engine re-start should be automatically displayed when required after an engine out event. (ref. §25.901(b)(2), §25.901(c) §25.903(d)(2), §25.903(e), §25.1301, §25.1305 §25.1309).
5) Indications required for continued safe operation of the engines, including engine restart, should be displayed after the loss of normal electrical power.

[AIA PITT agrees to removed the 1st two items from the previous version. The remaining items are developed from the existing AC25-11 and are required, but have been improved and simplified.]

Summary

In September 2004 the Powerplant Indications Task Team (PITT) met with FAA Engine and Propeller Directorate (EPD) staff members to discuss the linkage between the engine Type Certificate Data Sheet (TCDS) and cockpit display requirements for turbofan equipped transport aircraft. The historical evidence indicates that red warning messages due to engine malfunction cause pilots to take unnecessary immediate action, rather than delaying action and performing higher priority tasks first, such as flying the airplane. The nature of most turbofan malfunctions[1] (excluding fire warning indications) is such that a small time delay in pilot response will have no adverse safety effect with respect to the engine. The delay time would allow the flight crew the opportunity (re)establish/maintain aircraft control (possible in an OEI configuration) and should improve aircraft safety by reducing the PSM+ICR rate.

The TCDS limits are defined by the engine manufacturer as allowing "continued safe operation" of the engine. There is no current approach in place for distinguishing between those providing 'continued operation" (i.e. reliability) and those protecting "safe operation" (which might include safe shutdown).Under the current regulatory interpretation the TCDS limits define the safe operating range of the engine. This along with red warning displays requirements for TCDS parameters mandate immediate flight crew action to bring operation of the engine back within limits. Due to the historical conflict between gage marking and crew alerting requirements the engine installer has no (or limited) ability to implement a consistent system of engine gage markings and engine exceedence message i.e. today we have examples of red exceedance indications on gages, accompanied by amber caution messages on Crew Alerting System. It has been suggested that a change in the TCDS to provide a clarification of which limit exceedances require which level of flight crew awareness and action to assure acceptable safety (e.g. immediate action = warning, immediate awareness and possible future action = caution, awareness only = advisory, action before next flight = status), or a policy position from the Engine and Propeller Directorate will be required to provide the engine installer the ability to implement a consistent system of engine indications and caution or warning messages based on powerplant safety assessments.

Personnel from the EPD did offer the clarification that the engine limits are selected by the applicant and then verified by the applicant as part of certification under 14 CFR 33. Since the engine manufacturer understands the margin between TCDS limits and unsafe operation, the FAA accepts these limits as the safe operating limits. Thus it should be possible for the engine manufacturer to provide the needed clarification on the TCDS.

Following the EPD meeting an additional discussion on this subject was held within the PITT. A sample TCDS entry was reviewed and possibility for an EPD policy letter on this subject was discussed. Also following the meeting, the PITT received an informal communication from EPD indicating support for the proposed approach, but clarifying that an actual engine certification program would be needed first, in order for the EPD to establish a precedent followed then by general policy making and advisory material. This information stands in contrast to the PITT who felt that sufficient historical data exists to allow for the discussion and policy making to occur at the industry level, thus alleviating the need for discussion on individual engine makes/models.

Presentation Summaries and Ensuing Discussion Points

The following section reviews some of the discussion points from the meeting along with summaries of the presentation materials. Copies of the presentations follow this section. Please note that these summaries like a newspaper article have been prepared from the notes of one individual. The statements attributed to the FAA are intended to capture the essential thinking, and do not represent the statements of one individual, nor the policy of the FAA.

Presentation 1 – Discusses the engine TCDS, and the conclusion that all engine TCDS entries are taken by default to be the safe operating limit for the engine.

Industry - The overall objective is to reduce the PSM+ICR rate through improved displays. The perceptions within elements of the regulatory community that any TCDS limit and associated exceedence require red warning displays along with immediate pilot action will limit possible solutions. Industry would like to reach a common understanding of the FAA's intent in publishing engine limits in TCDS, how those limits relate to flight deck displays based on safety assessment, and how to implement new solutions for engine exceedence displays.

[1] *Examples include small high oil pressures or temperatures, small EGT exceedences.*

Industry - Which TCDS limits imply safety (when based on a system safety assessment) and what should the aircraft manufacturer do in response to the TCDS limits?

Presentation 2 – Discusses the aircraft regulations relating to powerplant displays, requirements for red warning displays for parameters from the engine TCDS, provides examples of service events and flight crew responses to engine exceedences, and discusses the need for improved display integration in modern flight deck design.

All – Across multiple models and manufacturer's the approach to transient limits is very inconsistent.

FAA - The applicant pick the limits, and the FAA then accepts them as the safe operating limits. The engine applicant is the expert who best understands the margin between TCDS limits and unsafe operation.

Industry - While the applicant does pick the limit value, the FAA specifies that certain parameters be required to have limits regardless of the safety assessment. Then at the aircraft the FAA requires that the TCDS limits drive display and action priorities.

Industry - How does an engine manufacturer inform the installer which limits are related to safe engine operation and which are related to long-term reliability. Under the current system all limits are safe operation limits, and not just the ones listed in the system safety assessment with a 14 CFR 33.75 effect.

Industry – One aircraft manufacturer's prior practice was to have the engine oil temperature display green for normal operation, and amber above the TCDS limit. The regulatory community requested that the display be change to have green and red above the TCDS limit on the basis that this would be consistent with the TCDS. The manufacturer had to perform a study with each of the installed engine marks to show that exceedence of this limit was not safety related before being able to retain the desired green/amber display. One evaluation of high oil temperature indications covering 10 years, and 14 million cycles found approximately 90 high oil temperature indication events, with no reports of oil fire, or internal fire associated with high oil temperature.

FAA - A limit is needed, because otherwise how do you know where to stop. In addition, information is needed to indicate the effect of exceeding a limit.

All - We really want the pilot to fly the aircraft, but the need to action an engine procedure needs to be weighted against the urgency and the timeframe so as to not distract the pilot.

FAA - The engine manufacturer proposes the engine limits, and understands where margin exists. The FAA does not know how much margin exists; we know based on experience that the engine will operate safely within the demonstrated area and that is considered the safe operating limit.

FAA - Past experience shows that engine limit exceedences have inherent margin and we generally have no adverse outcome from an engine exceedence. New engine models, or design changes in the future may remove this margin, as the FAA does not dictate margin. This concern may increase as today's environment says that margin is extra cost and should be designed out of the system.

FAA - the manufacturers have done more than anyone to increase reliability of engines compared to historic levels, economics drives them to do this. Designing with "zero margin" would result in an economically unacceptable engine, so it isn't likely to happen.

Ending - The engine may fail during the exceedence, but this will not be worse than having a PSM+ICR event. Engines need to have demonstrated margin, akin to the over-temperature test, and it should be acceptable to address the margin question by test, design, analysis, or approved process.

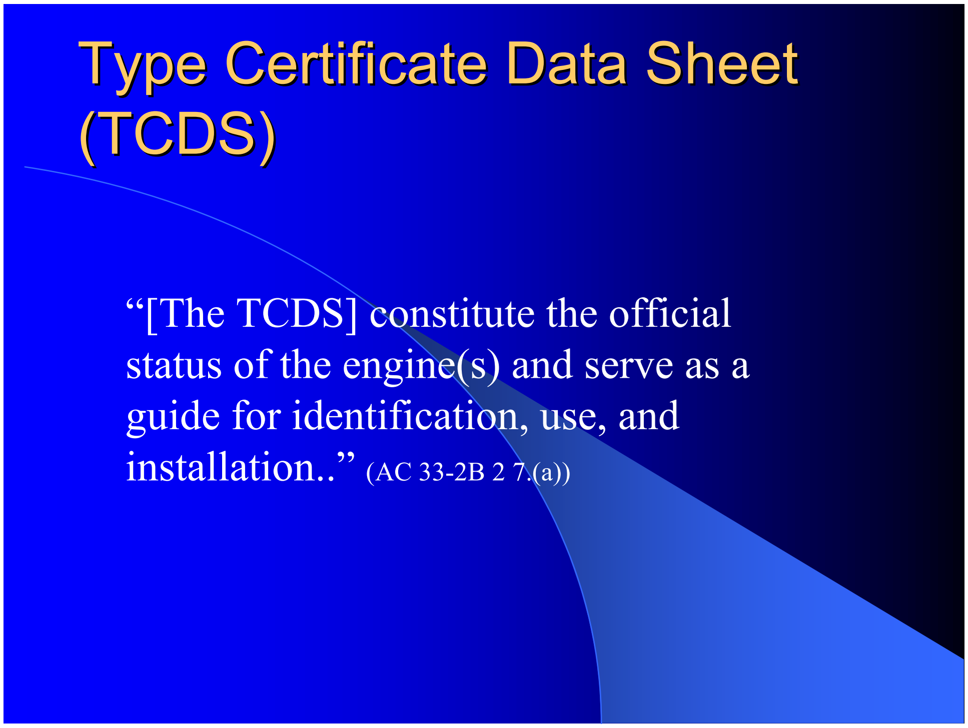
From the follow-up discussion

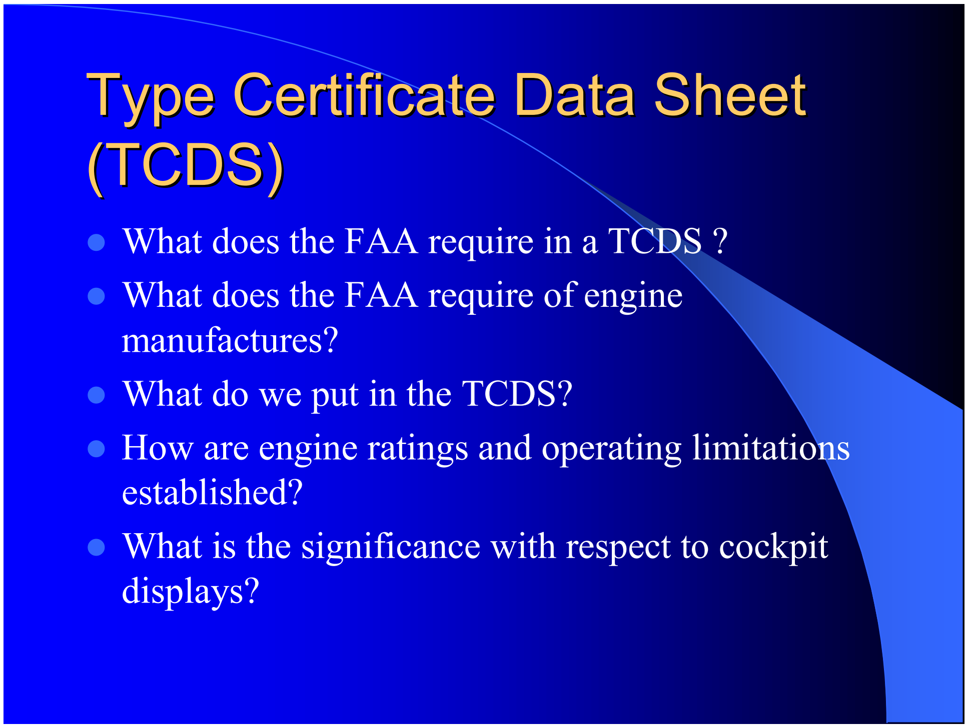
PITT - PSM+ICR is now the second leading cause of Category 4 and higher propulsion-related accidents. It is anticipated that the continued operation of the engine beyond a TCDS limit will at worst result in a contained engine shutdown; this is acceptable state for a twin-engine aircraft. The current practice for stating engine TCDS limits causes the aircraft to show engine limit exceedence as a red warning, leading to PSM+ICR accidents. One possible solution is to indicate in the TCDS if the parameter is associated with hazardous effect. Suggested wording includes:

- "Exceedence of parameter X does not require immediate action to prevent hazardous engine effect"
- "Take action at first reasonable opportunity"
- "Maintenance after flight"

Presentation 3 – Enumerates possible flight crew actions for an engine exceedence

Presentation 1





What does the FAA require in a TCDS?

- **The TCDS is required to include engine ratings and operating limitations**
  - " (a) **Engine ratings and operating limitations** are established by the Administrator and included in the engine certificate data sheet specified in §21.41 of this chapter" (**§33.7**)
- **The TCDS is also intended to document information necessary for safe operation**
  - "publicly document the engine ratings and limitations data and other **information necessary for safe operation** of the engine (AC 33-2B)

What does the FAA require of engine manufactures?

- An acceptable means of compliance is to demonstrate engine ratings and operating limitations by test.
- "a. Tests. Specific block tests are conducted to establish the various rated powers and thrusts, and the maximum and minimum operating limitations." (AC 33-2B)
- "(2) The ratings' limiting maximum operating parameters should be qualified by operation as indicated in the 150-hour FAA endurance test. Other limitations may be qualified by testing in which the limiting values may be the average attained for appropriate durations." (AC 33-2B)
- "(3) Special or additional tests may be necessary, at times to qualify some limitations for either complex engines, … or where limits for components may be tested separately on rig tests…" (AC 33-2B)

What does the FAA require of engine manufactures? (con't)

- Other engine requirements are demonstrated by approved processes, sub-component tests, design or combinations of all three. Some examples are:
  - Rotating component life – approved process and sub-component test
  - Fire Prevention – design and sub-component test
  - Controls – approved process, sub-component test, and design

What do you write in the TCDS

- §33.7 Engine ratings and operating limitations.

  (a) **Engine ratings and operating limitations are established by the Administrator and included** in the engine certificate data sheet specified in §21.41 of this chapter, including ratings and limitations based on the operating conditions and information specified in this section, as applicable, and any other **information found necessary for safe operation** of the engine"

How are engine ratings and operating limitations demonstrated?

- A widely used means is test
  - "a. Tests. Specific block tests are conducted to establish the various rated powers and thrusts, and the maximum and minimum operating limitations." (AC 33-2B)
- This can leave out parameter values based on the safety analysis and sub-component tests.
- Values selected for the FAA block test are usually based on what the manufacture knows will pass, and not the full capability of the design.

Conclusion - What is the significance with respect to cockpit displays?

- With the emphasis on conducting block tests to establish various rated powers and thrusts, and the maximum and minimum operating limitations:
  - It is taken by default that these are the safe operating limits for the engine.
- Many of the features that establish freedom from 33.75 hazards are established by the controlled process, sub-component test, and design activities.

Presentation 2

FAA Engine & Propeller Directorate
Engine Limits Meeting
October 4, 2004.

Engine Limits & Airplane Flight Deck Powerplant Displays

John Doherty
Boeing Propulsion Controls
October 4, 2004

Objective:

- Establish the link between engine regulations and airplane flight deck design.
- Cite evolutionary developments in airplane flight deck & engine design.
- Show that there are inconsistencies regarding engine limits on flight deck displays.
- Cite examples of in-service events where attention to engine limits resulted in less safe airplane operation.
- Offer opportunities for potential improvement.

Boundaries:

- This pitch restricts the subject matter to Boeing commercial transports, 14 CFR 25 regulations, turbofan engines, 14 CFR 33 regulations. The examples cited are from Boeing airplanes.
- The presenter has bolded, underlined and italicized text for emphasis in places.

Boeing Flight Deck Powerplant Display Design:

- Boeing flight deck displays are designed to comply with the applicable Airplane regulations:
  - The Airplane regulations refer back to the Engine regulations, i.e. certified engine limits per the Engine TCDS.
  - The following pages list regulatory references connecting Airplane certification back to the Engine certification established limits.
- Exceedance of a certified engine limit is displayed in **red**.
- Per 25.1322 **red** is used for warnings. Warnings are defined as "for conditions that require immediate flight crew awareness and immediate flight crew response".
- Boeing operates under the assumption that the engine limits are safety related (i.e. imminent engine failure or hazard)
- If any of these limits are not related to safety, then they should not be displayed as such on the flight deck.

Regulatory References

Part 25 AIRWORTHINESS STANDARDS: TRANSPORT CATEGORY AIRPLANES

§ 25.1305 (c) (3) A tachometer (to indicate the speed of the rotors **with established limiting speeds**) for each engine.

JAR 1305 (a) (9) "Any other **instrumentation or warning means as listed in the Engine Type Certificate Data Sheet** which is necessary to ensure safe operation of the aeroplane". [This currently is not included in the harmonized version

§ 25.1309 (c) Warning information must be provided to alert the crew to unsafe system operating conditions, and to enable them to take appropriate corrective action. Systems, controls, and associated monitoring and warning means must be designed to minimize crew errors which could create additional hazards.

Subpart G--Operating Limitations and Information

§ 25.1521 Powerplant limitations.

(a) General. **The powerplant limitations prescribed in this section must be established so that they do not exceed the corresponding limits for which the engines or propellers are type certificated** and do not exceed the values on which compliance with any other requirement of this part is based.

(3) **Any other parameter for which a limitation has been established as part of the engine type certificate** except that a limitation need not be established for a parameter that cannot be exceeded during normal operation due to the design of the installation or to another established limitation.

New draft rule: FAR/JAR 25.1322 Flight Crew Alerting

(b) Alerts must conform to the following prioritization hierarchy based upon urgency of flight crew awareness and urgency of flight crew response.

1) Warning: For conditions that require immediate flight crew awareness and immediate flight crew response. If warnings are time critical to maintain the immediate safe operation of the airplane, they must be prioritized higher than other warnings.

2) Caution: For conditions that require immediate flight crew awareness and subsequent flight crew response.

3) Advisory: For conditions that require flight crew awareness and may require subsequent flight crew response.

(d) Alerts must conform to the following color convention for visual alert indications:

1) Red for Warning alert indications.

2) Amber/yellow for Caution alert indications.

3) Any color except red or green for Advisory alert indications.

(e) The colors red and amber/yellow are normally reserved for alerting functions. The use of these colors for functions other than crew alerting must be limited and must not adversely affect crew alerting.

§ 25.1549 Powerplant and auxiliary power unit instruments.

(a) Each maximum and, if applicable, minimum safe operating limit must be marked with a red radial or a red line;

(c) Each takeoff and precautionary range must be marked with a yellow arc or a yellow line; and

(d) Each engine, auxiliary power unit, or propeller speed range that is restricted because of excessive vibration stresses must be marked with red arcs or red lines.

§ 25.1583 Operating limitations.

(b) owerplant limitations. The following information must be furnished:

(1) Limitations required by §25.1521 [above] and §25.1522. [1522 is APU]

(2) Explanation of the limitations, when appropriate.

(3) **Information necessary for marking the instruments required by §§25.1549 through 25.1553.**

Boeing Procedures & Documentation

Operations Manual:

Boeing procedures call for the flight crew to respond when engine limits are approached, reached or exceeded. Examples from a Boeing Ops Manual:

- Engine Start (Supplementary Normal) - "EGT must stay within limits"
- Aborted Engine Start (Non-Normal) – "Start parameters exceeded or EGT rising rapidly approaching limit during manual start"
- Engine Limit/Surge/Stall (Non-Normal) – "Engine indications are abnormal or are approaching or exceeding limits…" "Retard [thrust lever] until indications remain within appropriate limits or the thrust lever is closed' "If…. EGT continues to increase…. CUTOFF"
- Engine Limit Protection (Non-Normal) – "Engine Control is operating in alternate mode and commanded N1 exceeds maximum N1" "Thrust Lever… Retard… Retard until N1 remains within appropriate limits."
- Engine Oil Temperature (Non-Normal) – "If oil temperature stays above red line limit, or in amber band for [X] minutes…" shut down engine.

Airplane Flight Manual:

All of the following are listed under "CERTIFICATE LIMITATIONS" in the front of a Boeing AFM:

ENGINE THRUST

[TO, MCT, GA] "These power settings are operational limits."

ENGINE RPM

"The maximum operational limits are:" [followed by list of rotor speed and EGT redline values]

ENGINE OIL SYSTEM

- Maximum oil temperature, continuous operation, is [#] C.
- Minimum oil pressure is [#] psi at Idle RPM/ [#] psi at Maximum Continuous RPM.
- Oil temperature must be greater than [#] degrees C for engine start and [#] C before advancing throttles to takeoff power."

Evolution

Flight Deck Displays

Flight deck powerplant displays are now **screen-based** and **computer-generated.** Electromechanical gauges with fixed limits are no longer used.

Flight Crews

As stated in the AIA Powerplant Indications Task Team ground-rules, the assumptions for modern flight decks differ from those of 20 years ago:

- Assume a two-crew flight deck, no flight engineer.
- Assume the flight crew does not have flight engineer background or training.
- Assume the flight crew has no in-service experience with engine malfunctions.
- Assume the flight crew does not continuously monitor powerplant displays.

Electronic Engine Controls

Current generation Propulsion control systems typically include:

- Thrust rating calculation & closed-loop control ("set & forget")
- Automatic limiting to engine rotor speed redlines
- Independent back-up rotor overspeed protection.
- EGT redline protection during ground autostart
- Automatic protection of burner pressure limit

PSM+ICR

The "AIA / AECMA Project Report on Propulsion System Malfunction Plus Inappropriate Crew Response

(PSM + ICR)" (re: Volume 1, 1 November 1998) showed the importance of flying the airplane first and responding to propulsion malfunctions second. This is highlighted in the Turbofan Engine Malfunction Recognition Training which stemmed from the PSM+ICR activity:

- All transport category aircraft are designed and certified to be controllable with the most critical engine failed. Unlike early turboprops, turbofan powered airplanes do not require immediate pilot action to the engine in the event of a single engine malfunction or failure.
- Once the flight path is stabilized, the engine malfunction may be safely identified, and the appropriate checklists executed.
- Taking the time to stabilize the flight path may sometimes lead to further engine damage, but despite that, the airplane still has the capability of safe flight. Engines are tested during initial certification, to demonstrate ruggedness following bird and ice ingestion. Even after a major failure, such as loss of an entire fan blade, which is an extremely rare event, the engine shuts down safely and the airplane is still airworthy.
- Service history of fleet aircraft verifies that there are generally no engine failures requiring an instant engine shutdown in order to maintain airplane safety and that continuing a takeoff after engine failure at V1 is safer than rejecting the takeoff.

In-Service Events

Below are examples of in-service events where flight crew responded to an engine parameter exceedance in the absence of any other apparent engine malfunctions, to the detriment of overall airplane safety.

- PSM+ICR Item Report Volume 2 Item 83/EWB/4/S – "Aircraft was departing RWY 12…. During the takeoff acceleration, the crew gradually reduced thrust on #2 engine because of high EGT. The amber warning light having come on at approx 80 kts and the red warning on at 120 kts. Stopping action [high speed RTO] was initiated at about 163 kts and the airplane eventually accelerated to 166 kts. Near the end of the runway, the airplane departed the left side of the runway, breaking off all landing gear in soft ground. All four engines contacted the ground. The resulting upward forces damaging the engine struts. There was no fire and only minor fuel leak through a pulled center fuel tank fastener. Failure of the engine was determined to be separation of the first stage turbine blade retainer…"
- From a Boeing internal database of in-service problem reports: "The flight crew aborted the takeoff at approximately 148 knots airspeed, after observing illumination of the red engine overtemperature warning lights for both engines. One main landing gear tire blew out during the aborted takeoff. A subsequent borescope inspection of both engines disclosed no discrepancies. The Flight Management computer and the Autothrottle computer were both replaced. Tests of the removed computers disclosed no faults. The operator returned the airplane to revenue service after performing engine operational tests and a maintenance test flight. Pertinent flight recorder data was forwarded to Boeing. This data is currently being converted to Engineering data for review within Boeing.

Inconsistencies Regarding Engine Limits

EGT Red Takeoff Limit

- Takeoff is a critical flight phase.
- Boeing trains flight crews not to adjust the thrust levers after thrust set during takeoff.
- An EGT exceedance of the Takeoff limit during this time will cause the EGT display to turn red, which generally implies "immediate corrective action".
- Boeing Flight Crew Training explicitly instructs the crews not to respond to this event above 80 kts, thereby preventing unnecessary high-speed RTOs.
- There are cases where EGT increases during takeoff roll and liftoff, sometimes turning the display red for deteriorated engines, without an engine failure.
- This represents an inconsistency in the application of red vs. procedure, a potential for confusion among flight crews and perhaps an unnecessary increase in the exposure to high-speed RTOs (or even RTOs just after lift-off).

EGT Amber MCT Limit

- Boeing displays the MCT EGT Limit as an amber indication.
- If EGT exceeds the MCT limit outside of takeoff/go-around or for more than 5 (or 10) minutes during takeoff/go-around the display will go amber.
- There is a difference between the 5 vs. 10 minute implementation for FAA vs. UK CAA operators.
- There is a perception by some pilots that this MCT EGT limit is a "cautionary limit" due to the amber color, where in fact, the MCT EGT limit is a "continuous limit" per the ETCDS.

Oil Pressure & Temperature Limits

- Oil pressure & temperature have limits, implemented as redline limits on the flight deck.
- Oil temperature, and in some cases pressure, have "continuous limits", implemented as amber limits on the flight deck.
- Corresponding to the red Oil T & P displays, there are amber Caution or Advisory EICAS messages (condition not appropriate for warning level alert).
- This represents an inconsistency between the application of red parameter displays and amber messages. This is another example of confusion between "Cautionary limits" per the flight deck vs. "Continuous Limits" per the ETCS.
- Boeing questions the importance of any Oil system display, amber or red, during takeoff.

Opportunities for Potential Improvement

Screen-based, computer-driven flight deck displays have

- Flexibility regarding display format & content
- Capability for additional intelligence in the logic driving the powerplant displays

This offers the potential for better designing safety-based powerplant displays.

Align Engine Limits with Display Capabilities:

Existing system capability allows the addition of more intelligence to limits displays. Examples of where this capability is already in use:

- Pop-Ups – Primary engine display limited to parameters for normal operation. Secondary engine parameters "pop-up" if crew attention is required (e.g. parameter exceeds limit)
- Timers – EICAS messages typically include "persistence timers": the flight crew is not alerted until a condition exists for TBD seconds. This feature can be used to screen out nuisance indications.
- Transient vs. Steady-State Limits – Rotor Speeds and EGT indications typically include two redline levels, a "steady-state" redline and a higher "transient redline". The display does not turn red if the steady-state redline is exceeded for less then TBD seconds (examples 5 seconds, 20 seconds) while the transient redline is not exceeded.
- Variable Limits – Engine parameter limits can be a function of other parameters such as core rotor speed. Oil pressure is an example where the feature is used.
- Histograms – Using EGT as an example, there display has a maintenance which tracks the time duration of exceedances in different threshold bands. The threshold bands are set to align with the Engine Maintenance Manual "EGT Histogram".

CONCLUSION

- Boeing sees opportunity for improvement in the display of engine limits which could contribute to overall airplane safety.
- Any improvements to the airplane display design must be within the context of the certified engine limits.

Presentation 3

Exceedence of LIMIT X ________.

does not require immediate flight crew action to prevent hazardous engine effect
indicates a need for pilot action as stated in the engine operations manual

indicates a need to monitor

indicates a need to reduce TLA if flight conditions permit
indicates a need to reduce TLA immediately

indicates a need to perform an engine shutdown if flight conditions permit
indicates a need to perform an engine shutdown immediately

indicates continued normal operations provided [insert condition] remains within limits

indicates a need for post flight maintenance as indicated in the engine maintenance manual

1 Abstract

When the §25.1305 and §33.7 lists of prescriptive engine parameter indication requirements were introduced (in 1964 and 1974, respectively) an immediate flight crew action for some engine parameter exceedances was an appropriate standard since the flight crew was the primary means for monitoring and maintaining engine limits. Today, in contrast, automatic (i.e., autonomous) control systems monitor or operate the engine within limits and the flight crew is no longer the primary means for monitoring or maintaining engine limits. In addition, the flight crew no longer includes a dedicated flight engineer to monitor engine condition; instead, the flight crew is provided with status information and alerts on engine operation via computer based display systems such as EICAS/ECAM/CAS. To realize the full benefit of today's systems in providing information to the flight crew rather than numbers, the regulatory framework for engine indications needs to support a system of objective safety assessment based flight crew displays. Currently, regulations such as 14 CFR 25.1549 and other FAA policies with respect to engine Type Certificate Data Sheets (TCDS) make assumptions about the safety impact of an engine TCDS limit. Specifically, per §25.1549, engine operating limits are required to be shown in the color red because, it is believed, of assumptions made at the time of §25.1549 incorporation that engine operating limits are "do not exceed" limits or "immediate action required" if exceeded. This paper will establish that, for today's engine installations, an immediate crew action is not required for most operating limit exceedances; as a result, crew alerts (e.g. alert messages on EICAS/ECAM/CAS) provided for operating limit exceedances are typically not warning level, and, therefore, typically not in the color red. As a result, a color inconsistency is created in the flight deck with engine limit indications shown in the color red per §25.1549 and associated crew alerts typically provided in amber per §25.1322. This paper recommends that §25.1549 be revised or removed so that engine displays can be developed that use colors consistently with crew alerts provided for engine limit exceedances. While removing the color coding constraint of §25.1549 alone could allow for engine limits to be displayed in the same color as their corresponding alerts, a display format would have to be demonstrated and evaluated, by qualified Human Factors and Flight Crew Operations experts, to determine if amber "operating limits" along with amber "caution ranges" provide equivalent meaningfulness and effectiveness to the flight crew vs. today's indications per 25.1549. Given the long established standard, both within the aviation industry and other industries for "red lines" being synonymous with operating limits, further study (which is not elaborated on in this paper) would be needed to determine whether departing from this established convention would make engine parameter displays more clear or less clear. It should also be noted that §25.1322 allows for colors other than amber/yellow for advisory alert indications and some exceedances are accompanied by advisory alerts (e.g. engine oil temperature limit exceedances on some applications); therefore, it is possible that this additional color other than red or amber/yellow could be introduced into the color conventions for limit indications on a particular engine/airframe application. In the meantime, by removing the color coding constraint of §25.1549, and clarifying the role of the engine TCDS in establishing the requirements for engine indications and alerts, the possibility is opened up for evaluation of "new" engine display concepts for effectiveness vs. the traditional displays for engine limit indications per §25.1549.

2 Background

Studies of aircraft accidents with propulsion system involvement have identified several areas, including human performance and certification standards, requiring industry and regulatory efforts to address improvements that will reduce the aircraft accident rate. One issue central to achieving these improvements is the need for integrated system level solutions rather than addressing isolated issues[1]. One aspect of providing integrated system solutions is to improve certification standards and ensure the standards are current, applicable, and reflect best practice. An Aerospace Industries Association (AIA) working group, Powerplant Indications Task Team (PITT), will be making recommendations on the regulatory requirements for propulsion system displays. The majority of these requirements are in 14 CFR 25.1305, but other sections of Part 25, as well as §33.7 and FAA advisory material, influence the aircraft level system design.

One of the PITT activities included a review of in-service experience with aircraft powerplant indications. Along with other groups[2], the PITT concluded the data indicate a need to revise the certification requirements for propulsion display systems. The PITT recommendations permit display of engine parameter indications based on a system safety assessment. The systems envisioned under the new certification requirements address human factor issues in powerplant indications, provide consistent flight deck engine indications and alerts, and eliminate aircraft certification requirement conflicts/inconsistencies.

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[1] *Federal Aviation Administration Human Factors Team Report: The Interfaces Between Flightcrews and Modern Flight Deck Systems, June 18, 1996, Executive Summary, page 4, first paragraph.*

[2] *See AIA/AECMA Project Report on Propulsion System Malfunction Plus Inappropriate Crew Response (PSM+ICR).*

Regardless of the proposed regulatory changes, the PITT has identified an issue beyond the powerplant indication regulations that will constrain the ability of industry to implement the envisioned improvements. The specifics at issue are the data entries on the engine type certification data sheet (TCDS) and their interpretation. Currently, all engine parameter "maximum permissible" values on the TCDS are treated as limits in accordance with 14 CFR 25.1521(c)(3). Compliance with §25.1549 requires such limits to be indicated in red, which is also the color used for warning alert indications per §25.1322, and in accordance with §25.1322(e)(1)(i), red is used for warning conditions that "require immediate flightcrew awareness and immediate flightcrew response" . Taken together, the effect of the current certification standards requires the engine displays for exceedance of engine parameter limits to be the same color as the indication for warnings. There is concern among the PITT that, by using the color convention associated with warnings, the engine limit exceedance displays imply that "immediate action" is required, even though it may not be. This is regardless of the actual safety risk that the engine parameter exceedance represents, is inconsistent with the immediacy of awareness and/or action required for a warning, and disregards the safety risk in high workload situations of distracting the flight crew from maintaining flight path control. Additionally, when crew alerts are provided at the appropriate alerting level for engine limit exceedances, they are most typically provided at levels other than warning; therefore, the crew alert is a color other than red. As a result, a color inconsistency is created within the flight deck for engine indications and crew alerts provided for the same engine limit exceedance condition.

3 Discussion

The results of the AIA/AECMA PSM+ICR investigation showed the importance of flying the airplane first and responding to propulsion malfunctions second. This is highlighted in the Turbofan Engine Malfunction Recognition Training, which stemmed from the PSM+ICR activity:

> **Taking the time to stabilize the flight path may sometimes lead to further engine damage, but despite that, the airplane still has the capability of safe flight. Engines are tested during initial certification, to demonstrate ruggedness following bird and ice ingestion. Even after a major failure, such as loss of an entire fan blade, which is an extremely rare event, the engine shuts down safely and the airplane is still airworthy.**
>
> **Service history of fleet aircraft verifies that there are generally no engine failures requiring an instant engine shutdown in order to maintain airplane safety and that continuing a takeoff after engine failure at V1 is safer than rejecting the takeoff.**
>
> *— From Turbofan Engine Malfunction Recognition and Response Final Report, text for video training*

In the event of an engine parameter exceedance in most circumstances, turbofan engines do not require immediate action from the pilot. The primary action expected of the flight crew in response to an engine malfunction is to continue flying the aircraft. Once the flight path is stabilized, the engine malfunction may be safely identified (**detect, interpret**), the appropriate checklists identified (**strategy/procedure**), and the correct procedure(s) completed (**execute**)[3].

> **Training in turbofan airplanes needs to continually emphasize the necessity of taking the time to integrate all data relevant to a PSM in order to interpret the situation correctly and enhance the likelihood that appropriate action will be taken. There is anecdotal evidence to suggest that some operators may consciously or unconsciously establish training environments that tend to promote too-rapid a response to PSM's. There is also potential for negative transfer of training and experience from turboprop to turbofan airplanes (e.g., in certain turboprop airplane engine malfunctions, immediate action is required in order not to lose control of the airplane). Negative transfer issues such as this should be considered in detail in the development of training programs.**
>
> *— PSM+ICR Section 8.4.2.2*

[3] *The parenthetical references are to Figure 8.4 in the PSM+ICR report. While the sequence as written implies a significant amount of time is available to the flight crew to perform the tasks, this is obviously not the case for engine failures in certain flight phases such as a rejected takeoff at the V1 decision speed. Time critical tasks such as this are supported two ways: flight crew training and required memory items in the checklist. The training and memory act to reinforce the required actions and develop flight crew procedure and response times accordingly.*

Implementation by the flight crew of the correct response to any engine parameter exceedance is a several part process (see PSM+ICR report Figure 8.4). The first two steps in this process are "detect" followed by "interpret." The time window within which the crew needs to respond to an engine malfunction, to protect continued safe operation, may be a few seconds (in a few exceptional cases), a few minutes (a few cases), or in the majority of cases, an indefinite time - no unsafe situation will result, no matter how long the crew takes.[4]

With respect to engine parameter limit exceedances, no immediate flight crew action (monitor, reduce power, and/or commanded shutdown) is generally required in response to an engine exceedance. This conclusion is supported in the following two ways:

- Firstly, service history for aircraft accident/incident data shows that in general the majority of engine exceedances do not require an immediate flight crew action to maintain continued operation. Of particular interest is the fact that control system related rotor speed exceedence has not been a causal factor in any uncontained engine rotor failure.
- Secondly, industry experts have supported this conclusion and incorporated the conclusion into FAA supported engine malfunction training material. For example:

  Again, the first priority is to fly the airplane, not the engine. After you have positive control of the aircraft's flight path, then identify and secure the affected engine when time permits…

  Diagnosis of exactly what caused the engine problem is neither necessary nor safe, if it diverts resources from flying the airplane…

  The malfunctions discussed so far have had compelling cues, such as loud bangs, vibration, and warning or advisory messages. In each case, the challenge is to fly the airplane without being distracted by very compelling or alarming engine symptoms.

  — From text for Turbofan Engine Malfunction Recognition and Response video

Conversely, examples exist of in-service events where the flight crew response to an engine parameter exceedance in the absence of any other apparent engine malfunctions was detrimental to overall airplane safety[5]. For instance, a study by General Electric[6] of rejected takeoffs above V1 examined the incidence of engine symptoms in the high-speed portion of the takeoff roll (above 100 knots). The study then derived the conditional probability of an error, specifically a Reject Takeoff (RTO) above V1, given various types of indicated engine symptoms. For engine failures where there were indications but no noted inherent tactile or audible sensations, the indications involving a red or amber light turning on (Fire Warning, and Engine Fail in the DC10 fleet) had a higher conditional probability of precipitating a crew error (RTO above V1) that was 3 to 4 times more than the indications where no red or amber light turned on (e.g. when an EGT pointer is in the amber band, but without any associated light, alert or color change).

The higher conditional probabilities for indications with discrete annunciations (fire warning or engine fail verses high EGT) supports the concepts that both the timing and presentation of information to the flight-crew is a factor in selection of the correct response for an engine failure. In response to these types of issues more recent flight deck designs suppress indications/alerts dependent on flight phase[7]. One intent of the recommendations herein is to allow system safety tradeoffs such as takeoff phase inhibits to be formally recognized in the certification rules.

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[4] However once the aircraft flight path is stabilized prompt crew action with respect to the engine frequently lessens or prevents further engine damage.

[5] See the PSM+ICR report for examples.

[6] This study was conducted on the GE/CFMI High Bypass Turbofan fleet between 1975-1996. This material was original presented to the AIA /AECMA PSM+ICR group during their Atlanta meeting.

[7] For the period of study 1975-1996, the great majority of the fleet did not have the takeoff phase alerting inhibit features standard on more recently designed aircraft

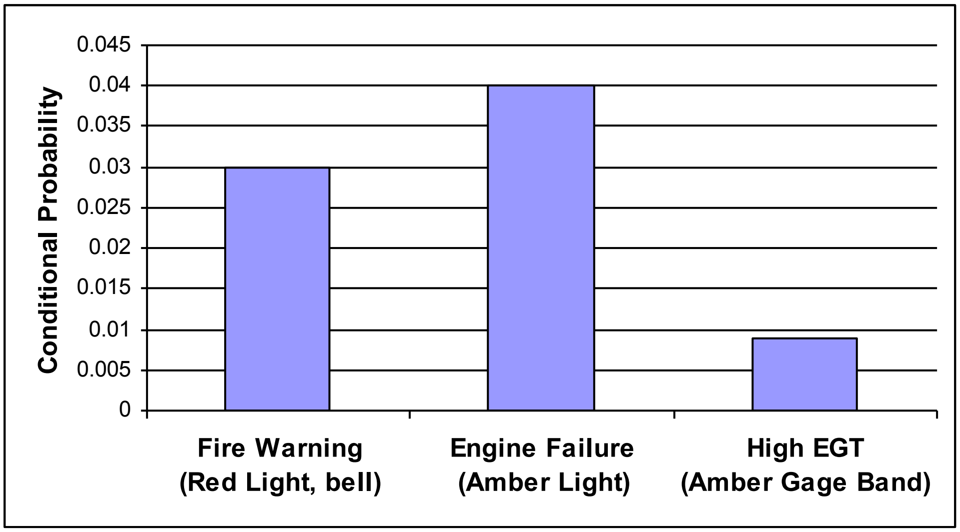

Figure 1. Probability of RTO above V1, given a symptom.

Prior groups when reviewing service experience of accidents/incidents, developing structured analyses such as airplane-level generic FHAs, or consulting engine technical specialists, has concluded that a rapid response to engine parameter changes or exceedances may be counterproductive to safe flight. These critical reviews of in-service experience indicate the need for refining the powerplant displays concepts. Specific points for consideration include the following:

- The most common instances of engine unsafe operation are not associated with a limit exceedance that could be recognized and acted upon by the crew. (Examples: disk burst, multiple engine rollback in inclement weather, fuel exhaustion [from FAA SAT presentation October 1997]).
- Rapid crew response to limit exceedance has been associated in some cases with excessive crew workload and inappropriate crew responses (shutting down wrong engine, rejecting takeoff after V1).
- Given that the crew error (RTO above V1) in the examples above was as likely or more likely to occur with an amber light vs. a red light, it is apparent that there is need to examine appropriate inhibits/suppression of engine display indications as much or more than the color of the indication itself.

For many parameters itemized in §33.7, limit exceedance is likely to cause reduced performance or failure propagation to shutdown (i.e., reduced capability to operate) rather than incipient unsafe behaviors. The effect of the exceedance would be typically linked with the amount of the exceedance (magnitude) and the length of time for which it persisted (duration), as well as the parameter involved.

> **Training in turbofan airplanes needs to continually emphasize the necessity of taking the time to integrate all data relevant to a PSM in order to interpret the situation correctly and enhance the likelihood that appropriate action will be taken.**
>
> *— PSM+ICR Report §8.4.2.2 Interpret*

The engine certification process (analysis, component test, and engine test) demonstrates margin between the certified engine limits and the point where unsafe operation is anticipated. Many of the parameter levels achieved during 14 CFR 33 Subpart F Block tests, in particular the §33.87 endurance test, are the result of conditions required to run the test or are values established by the manufacturer to achieve a particular capability such as time on-wing (e.g., EGT, oil temperature). Thus, the engine TCDS limits are not necessary representative of the short-term operational capability of the engine. As evidenced by the certification of turboshaft engines under the requirements for 30 Second/2 Minute OEI power this short-term capability can be as much as 20% above the baseline engine.

Historical experience shows that margin exists between TCDS limits and unsafe engine operation. One area where this is evident is the instructions for post-exceedance maintenance. Typically, these instructions will group in three tiers with the maintenance action based on the magnitude-duration of the engine parameter exceedance. The first tier is return to service with no action, the second tier is inspect and return to service if results are within limits, and the third tier is repair/overhaul. Not only have engine manufacturers determined it is possible to return an engine to service after an exceedance of a TCDS limit, in some cases the engine may be returned to service without further maintenance.

Considering the above it can be established that most engine parameters have a magnitude/duration envelope above the engine TCDS limit where operation can occur without progression to an unsafe condition. This envelope can be categorized as shown in **Table 1**. These categories take into account design practice, engine certification test, and historical data and combine this information with a potential flight crew alerting level. Thus, the alerting level of the engine limit exceedance is defined by the immediacy of crew awareness/action required for mitigation of an unsafe condition and not the engine exceedance alone.

The outcomes in Table 1 are generally applicable to all gas turbine engines, though specific engine design features may cause some of the regions to be impractically small. If the engine exceedance does not directly cause an unsafe condition (Category 4), it may have an effect on the capability of the engine (Categories 1 through 3). Typically, the capability effect limits are reflected in items such as engine temperature limits, low oil pressure limits, oil/fuel temperature limits, and low fuel pressure limits.

Table 1 Categories of engine limit exceedances and related indications and alerts

Category	Description	Outcome	Potential Alert Level[1]
1	No effect	The exceedance is logged against the engine, but the operator has no post-flight required action beyond investigation (with potential action to correct the cause for the exceedance) and logging of the event.	Alert Level[2]: None
2	Potential capability effect	Post-flight maintenance action required. This exceedance may have damaged the engine. Post flight a maintenance action (e.g hot section borescope inspection for an EGT exceedance) is required prior to continuing operation.	Alert Level [2,3] :None or Advisory or Caution
3	Capability effect	The engine may or may not continue to operate. Post-flight maintenance activities and potential engine overhaul required. This exceedance may have damaged the engine; replacement, or repair, or overhaul, of damaged components is required to ensure continued engine reliability.	Alert Level[3]: Advisory or Caution
4	Unsafe operation	Operation of the engine in this region is unsafe and can result in a §33.75 hazard, such that immediate crew action is required to prevent the 33.75 hazard.	Alert: Warning

Notes:

[1] For any of the categories of this table, the level of alert would be defined by the immediacy of crew awareness/action required to mitigate an unsafe condition.

[2] Whether a non-alert message, e.g. maintenance or dispatch message (without engine exceedance indication), or an exceedanceindication and alert is appropriate depends on whether the change in potential capability effect has the possibility to impact the current flight. If so, an exceedance indication and alert may be appropriate. If not, then no alert indication for the exceedance is required.

[3] Alert level depends on the immediacy of the crew action required, e.g. an advisory alert for high oil temperature may be appropriate if engine operation is not affected for many minutes. The alert level may also need to escalate after a period of time if the condition persists, or worsens.

Engines and aircraft may have design features that alter (i.e. make more severe or less severe) the category of failure effects shown in Table 1. For example, oil system failures can result in different engine failure modes for, turbofan, geared turbofan, and turboprop engines. Aircraft specific installations (e.g. thrust reversers, wing mounted verses tail mounted engines) can change the criticality of engine level failures (even for the same type of engine technology) due to the differences in the yaw force under one-engine-inoperative conditions. In this case, the system (indication, alerting level, flight crew procedure, etc.) should be based on the safety assessment for the engine parameter indication, the safety impact of the failure at the aircraft level, the immediacy of crew awareness and action required per §25.1322 and the airframe manufacturer's alerting function philosophy.

The additional concern about engine reliability after an engine exceedance event is addressed on two levels: proper post-event maintenance and existing service history. For the correct post-event maintenance to be performed the engine maintainer will need information on the magnitude and duration of the exceedance event.

Post flight maintenance includes the following:

- Identify and correct the underlay cause of the exceedance
- Based on the exceedance parameter and the magnitude/duration of the exceedance:

  Inspect the engine in accordance with the maintenance instructions

  Determine the condition of affected engine components

    Return to service without further maintenance

    Remove components from the affected system

    - Remove the engine for overhaul

These concepts for the proposed post-event maintenance is already supported by the existing service data since today's engine maintenance manuals already contain the envisioned maintenance tasks.

In addition to the historical experience, the engine certification process also requires margin between the certified limits and unsafe operation. For example, the TCDS values for maximum rotor speed and turbine temperature are the average maximum achieved during the 150-hour test. While the distribution of rotor speeds (primarily N2) and turbine temperatures are small, a number of cycles will run just above the TCDS limit. Engine rotor speed limits also include margin by requiring damage tolerance in design and automatic overspeed protection devices to protect against disk burst. By officially recognizing the concept that the TCDS limits already contain margin, it should then be possible to design a safety-based system of engine indications, alerts, and flightcrew procedures based on a combined safety/human factors analysis. Thus the flight crew response both in timeliness and procedure would be based on the safety effect of the limit exceedance rather than a dictate in the engine TCDS. Furthermore, this change would harmonize the engine indication markings with the aircraft alerting functions and ensure appropriate crew awareness and response.

4 Conclusions

The consensus of the PITT is that the engine indicating and alerting system should be based on safety analysis and historical experience. It is anticipated that such an analysis will be able to make a distinction between those engine limits relating closely to safe operation and those limits relating to a capability effect, i.e., long-term engine operation and reliability. Engine limits requiring an immediate flight crew action when exceeded would have an associated red indication and warning alert if appropriate. Other limits, where it is permissible to allow the flight crew some time to respond to the engine exceedance, would have a caution or advisory alert, along with, potentially, an engine display in a color other than red. Adoption of this practice means the majority of engine limits, which today relate to engine capability, could be displayed in a color other than red. As previously stated, while these engine limit indications would have a color consistent with the color of corresponding alerts provided for engine limit exceedance, they would be new and different compared to the engine instruments and indications that have been in place for generations. This departure from a long established standard would need to be validated from a human factors point of view. It should also be noted that §25.1322 allows for colors other than amber/yellow for advisory alert indications (per §25.1322 (e)(1)(iii) "Any color except red or green for advisory alert indications") and some exceedances are accompanied by advisory alerts (e.g. engine oil temperature limit exceedances on some applications); therefore, it is possible that this additional color other than red or amber/yellow could be introduced into the color conventions for limit indications on a particular engine/airframe application. Given that, per §25.1322 and some airframe/engine applications, advisory alert indications can be provided in white or cyan/blue color, human factors evaluations of new engine display schemes would have to consider the introduction of these colors into the engine limit indication conventions.

Depending on the engine design, adoption of these recommendations means that in response to a propulsion system malfunction, the engine indicating and alerting functions would support short periods of operation with an engine exceedance. Once operation outside of the normal operating range takes place, maintenance activity to address the cause of the propulsion system malfunction and ensure continuing engine capability will be required.

The potential safety benefit in the adoption of this practice, regardless of whether the indications and alerts for exceedances are warning, caution or advisory (or red, amber, or other), would be the implementation of appropriate alerting and annunciation features inhibiting during critical phases of flight. Specifically, if flight crew action is not required during takeoff for an engine limit exceedance, then alerting features and other annunciations such as color changes can be inhibited until after the critical portion of takeoff is complete (just like they are for warnings alert features such as the fire bell and master warning light for an engine fire). The adoption of these recommendations mean that our system designs would permit flight crews to operate for short times with an exceedance indication[8]. Which in fact is the same thing that already takes place when we emphasize that the flight-crews need to maintain the aircraft flight path first. Once operation outside of the normal operating range takes place, maintenance activity to address the cause of the propulsion system malfunction and ensure continuing engine capability will be required.

The individuals, groups studying PSM+ICR, and members of PITT have at various times reached one or more of the following conclusions:

- The regulatory presumption that operation above engine TCDS limits (redlines) is hazardous sets a policy dictating immediate flight crew response to parameter indications, rather than allowing the safety assessments to establish the correct response.
- All engine TCDS parameters have a magnitude/duration envelope above the TCDS values where engine operation does not lead to an unsafe condition. Engine specific design features influence the size of this envelope.
- Rapid crew response to engine parameter exceedances is neither necessary nor desirable, except as required to control the airplane flight path/ground path.
- Review of service experience shows there is a wide range for the speed of crew response to engine parameter exceedances, but there appears to be no adverse safety effect caused by this variation.
- Crew intervention during an engine malfunction based on engine parameters does not generally prevent hazardous engine effects due to disk burst or over-speed. However, it may preserve engine capability for continued operation and minimize engine or economic damage.
- Crew intervention does not prevent disk burst because the crew does not see any parameter directly related to disk burst, nor is there the means to provide one
- Crew intervention does not prevent internal engine fire because the crew is not given a parameter related to internal engine fire (i.e. currently technology cannot predict the start of a fire event, it can only detect and extinguish).
- Crew intervention does not prevent rapid overspeed because overspeed such as to hazard engine integrity would occur so rapidly that crew monitoring and intervention would not be practicable.
- The regulatory requirements for engine parameter exceedances should not be automatically associated with red indications, unless based on the system safety analysis immediate crew action is required. Non-red engine exceedance indications along with caution or advisory alerts and corresponding color engine indications are more appropriate. Note that the required crew action, and therefore the indication, may change based on the duration and/or magnitude of an exceedance.

[8] *Depending on the engine design, the engine operating instructions may need to address continuous operation with caution indication. In some cases, after a predetermined magnitude or duration, the caution indication will need to be automatically upgrade to a warning indication*

- Providing appropriately integrated engine limit/exceedance indications and alerts, even at a caution or advisory level (i.e. with alerts that utilize colors other than red), will not change the pilot action, only the implied immediacy required to accomplish that action (potentially – assuming pilots correlate the color used on an engine display to colors used to connote alerting level). While additional study would be needed to verify a human factors improvement, a consistent powerplant indicating and alerting system may improve flightcrew response.

5 Recommendations

This section discusses the PITT's recommendations to the FAA for changes to allow improvements in the integration of the engine limits with the powerplant displays. This includes suggestions for a clarification of FAA policy on engine limits, improvements in the formatting of information on engine limits in the TCDS, and improvements in the manufacturers' operations manuals. It is anticipated the effect of following these recommendations will result in most powerplant parameter exceedances being displayed using amber engine indications with corresponding caution alerts if appropriate. As previously stated, while these engine limit indications would be more consistent with the corresponding alerts provided for engine limit exceedance, they would be new and different than the engine instruments and indications that have been in place for generations. This departure from a long established standard would need to be validated from a human factors point of view. Only a limited number of engine related parameter exceedances would retain a red engine indication with a possible warning alert if appropriate to the need for immediate flightcrew action/awareness.

5.1 Recommendation 1–FAA Policy on TCDS Limitations

Engine operating limits as required by §33.7 are generally contained in the engine's TCDS. The engine's operating instructions may recommend a flight crew procedure/response when a particular operating limit is exceeded. It is recommended that the engine manufacturers provide a hazard assessment associated with a particular parameter's limit exceedance. The duration and magnitude of an exceedance may impact this assessment. This hazard assessment should be communicated to the installer and the engine maintenance manual should include appropriate post-exceedence maintenance tasks. It is anticipated that the airplane manufacture will use this information to evaluate the engine indicating needs along with the design of the aircraft's alerting/indicating system to ensure that the resulting displays are consistent with the alerting philosophy, displays, and operating instructions of the airplane. At the aircraft level the resulting alerting design should be consistent with the corresponding warning, caution, and advisory alert requirements in rule §25.1322. The intention of this recommendation is to drive the separation of the limits required by §33.7 into categories based the engine's safety assessment and for the aircraft's engine indicating/alerting systems to be consistent with §25.1322.

5.2 Recommendation 2 –Policy for Linking Engine Safety Assessment the Engine TCDS and the Aircraft Entries Safety Assessment

In order to allow installation of the engine consistent with §25.1322, the FAA should develop policy material on the interpretation of limits linking the safety assessment of the limit exceedance with the required aircraft indication, with required flightcrew action/awareness and consistency with §25.1322.

The intent of this recommendation is for engine manufacturers to introduce additional data into the safety assessment process to allow evaluation of operation above the proposed engine TCDS limits. It is anticipated that most engine parameter exceedances could be displayed in a color other than red with an associated caution or advisory alert since the engine exceedance itself does not require immediate action. Only a few powerplant related indications, such as fire warning and engine exceedances where immediate flight crew action is required would be indicated in red with an associated warning alert. The overall intent is to ensure consistency between the display of engine parameter indications and the aircraft warning, caution, advisory alerting system. Please see Recommendation 4 below regarding validation of new displays – this should be accomplished before new policy is established.

5.3 Recommendation 3–Standardize Engine Operating Procedures for Engine TCDS Limits

The FAA should develop policy material to standardize engine operating procedures for engine TCDS limits so that these procedures are consistent with the §25.1322 requirements for immediacy of flightcrew required awareness/action, while ensuring that manufactures address any unique requirements inherent to a specific design. This policy material should state that manufacturers' operating instructions need to clearly define the immediacy of flightcrew action/awareness and make distinct those engine operating procedures required to maintain safe engine operation and those procedures required to maintain engine capability (e.g., low oil pressure shutdown procedures).

The intent of this recommendation is for the FAA to develop policy material that will standardize manufacturer's engine operating procedures for engine exceedance limits so these procedures are consistent with the safety assessment, and aircraft installation requirements for §25.1322 alerting. Inherent in this recommendation is the need for the engine manufacturers to provide engine-operating instructions that separate out actions required to maintain safe operation from actions that maintain the long-term capability of the engine. Typically, for an engine limit exceedance this will require the engine operation manual to state "PERFORM [ACTION] WHEN FLIGHT CONDITIONS PERMIT" as the first action for conditions that maintain the long-term capability of the engine (i.e. no hazardous effect for short term operation) and "PERFORM ACTION" for those conditions where immediate flightcrew action/awareness is required.

By implementing, some or all of the above recommendations, the FAA will enable evaluation of the safety effect for the engine limits by the installer at the aircraft level. This in turn will allow for engine indications and alerting functions appropriate for the indication, and consistent with the overall aircraft indicating and alerting design philosophy.

5.4 Recommendation 4 Implementation and Validation

With the recognition that for most engine limit exceedances immediate crew action is not required, the following are recommended in going forward for engine limits/engine limit exceedance indications:

1. That any crew alerts provided via the crew alerting function (e.g. ECAM, EICAS) are at the appropriate alert level per §25.1322, typically caution or advisory, regardless of the color of the engine display per §25.1549.
2. That an assessment be made as to whether crew awareness or action is needed during critical phases of flight, and that appropriate alerting/engine display inhibits are incorporated (including, as appropriate, the inhibit of the presentation of the engine display and/or color change associated with limit exceedance).
3. That development, study and evaluation of new engine limit displays that are consistent with §25.1322 – by qualified Human Factors and Flight Crew Operations experts - are done to validate that they are a) as or more effective than today's displays, and b) do not introduce undesirable negative transfer effects when considering today's fleet as standardized per §25.1549. The primary consideration is to evaluate whether proposed new schemes for engine instruments are using color appropriately and effectively, regardless of the use of color for alerting by 25.1322. Consideration should be given to engine limit displays that correspond to advisory alert indications that are provided in a color other than yellow/amber.
4. Upon validation of engine display schemes that are consistent with §25.1322, then regulatory activity should be undertaken to update or delete §25.1549, taking into the consideration the value of standardized engine displays across the fleet.

5.5 Additional Comments

The addendums of this paper provides a discussion of powerplant exceedance indications, linkage of the engine TCDS and Part 25 installation requirements, the rationale for safe engine operation beyond the engine TCDS limit.

Addendum 1

PITT's Dilemma and the Need for System Level Solutions

During the 1990s, aerospace industry reports on accidents and incidents with propulsion system involvement (CAAM, PSM+ICR, SAT, etc.) made recommendations on areas requiring improved design practices and regulations. One of the recommendations concerned powerplant displays:

> **It is proposed that ARAC be tasked with reviewing the requirements of FAR/JAR 23 and 25, paras 1305, 1321, 1337 and 1585, in order to produce an updated standard for powerplant instrumentation based on the information available**
>
> *— PSM+ICR Report §9.3 Powerplant Instrumentation*

Factors behind the recommendations made in the original PSM+ICR report include the following:

- Accidents in which the crew was not aware of, did not understand, or did not use, the information presented to them
- Certification of fewer airplanes with flight engineers dedicated to monitoring instrumentation
- Improvements in avionics and electronic controls that enable more technical choices in how information should be displayed

The purpose of the AIA PITT is to address this recommendation by developing an industry proposal for revised regulations on powerplant instrumentation.

The regulatory proposal by PITT will allow for a system safety assessment for each powerplant parameter requiring display, and will link the system safety assessment to required flight crew awareness and action. The PITT dilemma stems from the interaction of the current regulatory requirements and their historical interpretation that mandates certain aspects of the powerplant display. At issue is the display of powerplant limits and exceedances in the color red per the color of the associated limit as required by §25.1549, regardless of the system safety assessment and regardless whether the condition requires immediate flightcrew action/awareness as is typical for warnings under the alerting requirements of §25.1322. For example, on some applications in order to show compliance with both requirements the exceedance of the high oil temperature limit results in an caution or advisory alert in amber, while the color of the limit marking and color change of the oil temperature gage associated with the high oil temperature is red per §25.1549. In short, the compliance with §25.1549 for the parameter limit marking and §25.1322 for the flight crew alert results in a color coding inconsistency within the flight deck. Without further clarification of FAA policy in this area, the human factor improvements anticipated by the PITT under the proposed safety based §25.1305 Powerplant instruments regulation may not be realizable from a regulatory perspective. Compounding this dilemma is that the standards that drive the color coding for engine limit markings have been in place for decades, have become a common convention for generations of pilots, and are also common to "limit indications" used in other application such as common automobile RPM gauges. As such, any changes to this convention would have to be evaluated to confirm that they are, clear and understandable to flight crews, and do not introduce unintended human factors issues resulting from negative transfer.

Issue of Concern to PITT

While engines are certified by the FAA under 14 CFR Part 33, and again as installed under 14 CFR Part 25 the powerplant indication systems are certified under §25 as part of the aircraft. Two areas of linkage between the aircraft limits and the engine limits are established in §25.1521. First, §25.1521(a), requires powerplant limits be established so the corresponding engine limits are not exceeded. This mandates two things, the aircraft has to display powerplant limits and these powerplant limits cannot be greater than the corresponding §33 engine limits. Next, §25.1521(c)(3), defines the source of the powerplant limits, in that, any engine parameter for which a limit is established during engine certification cannot be exceeded during normal operation. The effect then of the regulation is to make any certified engine limit a "not-to-exceed" limit at the aircraft level. Also, in §25.1549, prescriptive requirements state the maximum, and if applicable minimum, safe operating ranges are marked in red. Red is also the color used for warning alert indications per §25.1322, where the warning alert indications as defined in §25.1322 require immediate flight crew action:

> **[The TCDS] constitute the official status of the engine(s) and serve as a guide for identification, use, and installation.**
>
> *— AC 33-2B Chap.2 Para.7 (a)*

As indicated in AC 33-2B, the engine TCDS is to serve as the official document to guide installation and use of the engine. The content of the engine TCDS is defined in §33.7. The engine TCDS is to include "engine ratings and operating limitations," which are defined by a specific list of parameters and indications. The FAA clarifies that the intent of the regulation is to capture "information necessary for safe operation of the engine" (AC33-2B, Chap.2, Paragraph 18). Finally, the regulations require the FAA to establish engine operating limits , and publish the limits[9] in the engine TCDS §21.43.

To establish the content for the engine TCDS the engine manufacturer applies a variety of technical approaches to demonstrate compliance with the requirements of Part 33. An acceptable means of compliance is to demonstrate engine ratings and operating limitations by test:

> **a. Tests. Specific block tests are conducted to establish the various rated powers and thrusts, and the maximum and minimum operating limitations.**
>
> **(2) The ratings' limiting maximum operating parameters should be qualified by operation as indicated in the 150-hour FAA endurance test. Other limitations may be qualified by testing in which the limiting values may be the average attained for appropriate durations."**
>
> **(3) Special or additional tests may be necessary, at times to qualify some limitations for either complex engines, … or where limits for components may be tested separately on rig tests…**
>
> *— AC 33-2B*

Beyond the engine primary parameters (e.g., thrust, N1, N2, exhaust gas temperature [EGT]) operating limits, other engine requirements are demonstrated by approved processes, subcomponent tests, design, material compatibility, or combinations thereof.. Some examples are:

- Rotating component life—approved process and sub-component test, §33.14.
- Fire Prevention—design and subcomponent test, §33.17.
- Controls—software approved process, subcomponent test, and design, §33.28(e).

When engines are installed in aircraft, engine limits from the engine TCDS are translated into aircraft limits. These limits are marked red in accordance with §25.1549, and are considered "not-to-exceed" indications for limitations established as part of the engines certification per §25.1521(c)(3), whether or not their impact on safe operation requires them to be "not to exceed" . The primary source of the engine limits is the engine TCDS values, thus the engine TCDS values become the powerplant limits and their exceedance requires a red indication per §25.1549. Since some of the engine TCDS values are required by regulation, even if the specified limits are not related to safe engine operation, the aircraft is required to have a red indication per §25.1549. Thus, aircraft limitations are potentially required where no consideration has been given to a safety based analysis to determine the need for the limitation based on the engine or aircraft effect. Furthermore, many of the engine limits required under §33.7 are listed based on the capability demonstration within the block Tests, as required under §33 Subpart F, and not the design and construction requirements of §33 Subpart B and Subpart E, where the effects of engine failure are established (reference §33.75).

The cumulative effect of the regulations is to provide engine exceedance indications to the flight crew in the same color (red) as used for warnings that require immediate flight crew action for limitations required by the regulations. This applies even if observance of the limitation has no effect on the continued engine operation or where immediate flight crew action could be delayed for several minutes. While it is assumed that establishing/maintaining the aircraft flight path is a higher priority and that response may be delayed, the requirements of the regulation should be clearer with respect to making allowance for the existing practice of time/phase of flight inhibits.

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[9]While the FAA establishes the limits, the values of the limits are chosen by the manufacturer.

Addendum 2

I. Engine Margin—Safe Operation Based Historical Data, Design and Test

It is anticipated that most engine exceedance indications, when based on historical experience and system safety analysis, only require a caution or advisory level of alerting. Under PSM conditions, and when considered operationally necessary, flight crews would explicitly be permitted to operate for short time periods within a caution range above the engine TCDS limit. Under normal conditions, the engine limits will continue to be protected by the autonomous engine control system and thus not accessible for everyday use.

It is the intention of the FAA that the engine TCDS is to act as the guide for engine installation and to document information required for safe operation of the engine; however, there is a tendency to believe the corollary of this intention, i.e., operation outside of the TCDS limits is unsafe, is also true. While certain instances depending on the unique characteristics of engine designs where the engine TCDS limits do mark a boundary between safe and unsafe engine operation, for most turbofan engines this limit is an outcome of the certification process.

II. Engine Exceedances—Historical Data on Hazardous Effects

One of the considerations in allowing operation with an exceedance for short time periods is the possibility for the underlying engine malfunction to have a hazardous effect. Three studies (SAT, CAAM1, CAAM2) have been completed using aircraft accident/incident data to assess the role of the engine malfunctions in aircraft level events. The top ten propulsion system hazards from the most recent study (CAAM2) are shown in Table 2. Taken alone such historical data indicate engine exceedances are not a hazard to the aircraft.

Table 2. Top 10 propulsion system safety hazards (fatal accident and hull loss [CAAM 4&5 events only 1992-2000]) (From *Second Technical Report on Propulsion System and APU-Related Aircraft Safety Hazards [CAAM2])*. Note: a single event may be classified into more than one category in

Malfunction	Number of events
PSM+ICR	21 5 turbofan 5 turbojet 11turboprop
Multi-engine power loss – fuel related	13
Multi-engine power loss – non-fuel	10
Reverser/beta – in-flight deploy	5
Uncontained – all	5
Engine separation	4
Propeller crew error	3
Crew error	3
Reverser/Beta – failure to deploy	3
Propeller separation/debris	3

It has been suggested by some that operating with engine parameters outside of the engine TCDS limits is unsafe[10], or that it will result in a failure propagating upwards to a hazardous effect[11]. The two most frequently cited concerns are:

- Release hazardous fragments (overspeed and uncontained disk burst).
- Catch fire (in particular internal to the engine).

Examination of these two risks in detail shows that pilot intervention to reduce or eliminate an exceedance that can lead to these failures is an unrealistic concept.

III. Margin from Design Intent

The following points support the fact that safe engine operation beyond the engine TCDS is possible for several of the required engine TCDS limits:

- Existing maintenance manual instructions allow for continued operation after exceedances of certain magnitude and duration. These instructions can be classified into three categories:

  No inspection required, return the engine to service

  Inspection required return to service or remove based on inspection results

  Remove engine[12]
- Margin requirements for certification of rotors, which are then protected by speed control modes of the engine control, and independent analog overspeed devices
- Operation of the engine above the engine TCDS limits during certification tests. In particular, the block test required by §33.87 establishes thrust/torque/speed/EGT limit from the averages achieved during the test. Additional capability is demonstrated by the 5 minute, at 75°F overtemperature tests required by §33.88.

The general concept has been recognized by industry and the FAA in jointly prepared materials, such as the Turbofan Engine Malfunction Recognition and Response Final Report. The next section discusses several additional concepts underpinning the conclusion that for many engine TCDS parameters operation at or above the engine TCDS limit is not inherently unsafe.

IV. Rotor Speed

For parameters such as rotor speed, design practice is to limit the rotor speeds so safe operating limits are not violated during normal, as well as damaged, engine operating conditions. Typically, this limiting is implemented in software, taking the form of maximum speed limiting control laws[13]. Should the FADEC or hydromechanical unit fail in a manner that would cause the engine to be driven to higher than redline rotor speed conditions, all control systems (or the engine design itself) are required to incorporate an independent system that will sense the condition and take appropriate action to protect the engine against disk burst. This action may be to limit rotor speeds at a condition that is higher than the engine TCDS redline limits or to shut

[10] *This can lead to a circular argument that the reason for the low risk rate relative to engine exceedances is that we inhibit operation above the engine TCDS limit. It can be argued though that the overall risk rate is not low though because engine exceedances that have no aircraft hazard can couple with inappropriate crew response (PSM+ICR). This is the leading safety risk in table 2 and has a CAAM Level 4 and 5 Hazard ratios of 0.0005 and 0.0003 respectively. Meaning that between 3 to 5 accidents per 1,000 propulsion system malfunctions could be addressed through improved human factors.*

[11] *The FAA generic issue paper on digital only displays reflects this concern with respect to rotor speed exceedances in footnote 3.*

[12] *For many parameter exceedances, the progress in severity for the exceedance inspection task mirrors a reduction in engine capability and is not indicative of an immediate unsafe condition. . Cases where exceedances are detrimental to safe operation should be clearly identified in the engine installation and engine operating manuals.*

[13] *An engine running continuously against the maximum rotor speed limiter is a normal condition for the engine, in that the engine will not suddenly fail at this speed. The condition maybe unsafe for the aircraft due to loss of thrust caused by operation on a limiter, but even this is a very small risk as the aircraft would have to be in a situation where a one-engine thrust reduction is unsafe.*

the engine down[14]. In addition to design, the following points also support this concept:

- Engine manufacturers' existing operations and maintenance instructions contain magnitude duration limits along with any required maintenance procedures.
- Execution of the §33.88 overtemperature test will typically require N2 speeds in excess of the engine TCDS limits; thus, this test also demonstrates integrity of the N2 rotor components, i.e., a nonhazardous condition.
- Execution of the §33.87 endurance test will typically require operation at a triple point . The N1 speeds in excess of the engine TCDS limits caused by this condition also demonstrate integrity of the N1 rotor components, i.e., a nonhazardous condition.
- The design process for certification of turbine engine rotors designs margin into the system by requiring the usage of -3 sigma material properties, minimum margins between 100% speeds and rotor burst, and statistical treatment of material defects.
- Temperature Limits – Engine Gas Temperature

> **High EGT can be an indication of degraded engine performance. Deteriorated engines will be especially likely to have high EGT during takeoff.**
>
> **EGT is also used to monitor engine health and mechanical integrity. Excessive EGT is a key indicator of engine stall, of difficulty in engine starting, of a major bleed air leak, and of any other situation where the turbine is not extracting enough work from the air as it moves aft (such as severe engine damage).**
>
> **There is an operational limit for EGT, since excessive EGT will result in turbine damage. Operational limits for EGT are often classified as time-at-temperature.**
>
> *— Chapter 4 Engine Malfunctions, Airplane Turbofan Engine Operation and Malfunctions - Basic Familiarization for Flight Crews*

Most engines used in Part 25 aircraft do not have a specific system for protection of EGT during operation; however, some autostart systems have EGT protection (limiting, start abort, etc.) during ground start, and may have EGT protection (limiting) during airstart depending on engine/aircraft manufacturer preference. When an engine does not have automatic EGT protection, the flight crew is responsible for EGT protection during abnormal or failure conditions. During normal operation (no failure condition present) modern FADEC engine control systems use thrust rating tables designed to maintain EGT operating temperatures within limits, without crew intervention (though engine deterioration with operating time causes the engine to operate closer to the EGT limit when ambient conditions are near/above the thrust rating break point[18]). In addition to design, the following points also support this concept:

- Magnitude duration limits for EGT exceedances have already been established by the engine manufacturers. Typically, these limits are based on operational experience with existing similar hardware. On new designs these limits will typically be set at an initially conservative level, and then expanded through a program of inspection/test of hardware from service events.
- The overtemperature test in §33.88 demonstrates the capability to withstand a 75°F for 5-min exceedance with no detrimental effect on the engine.

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[14] *Typically, the rate of rotor acceleration during overspeed events is sufficiently high that the flightcrew will be unable to react in time to prevent the engine TCDS limit exceedance. Under this condition, a red indication display has no practical value. One could envision a control high-side fuel flow failure resulting in the engine stabilizing at a power above the engine TCDS limit and below the independent overspeed trip point. An engine in this condition still does not represent a rotor integrity risk as the disk burst speeds will be above independent overspeed trip point.*

[15] *This refers to running with N1, N2, and EGT at or above the TCDS limits, i.e., all three points are at or above limit. Typically, N1 and N2 will be above limit for EGT to be at limit.*

[16] *FAA Advisory Circular AC 33.14-1.*

[17] *At least one system that limits EGT to the engine maximum takeoff rating is certified and in general use.*

[18] *To some degree, exposure to this condition is limited by operators and manufacturers though engine condition monitoring programs, as these program seek to remove engines prior to EGT exceedance service disruptions.*

- While not applicable to turbofan engines, the certification requirements for turboshaft 30-sec and 2-min one engine inoperative (OEI) ratings recognize that the nature of gas turbine engines is such that engines can operate for short periods at power levels well in excess of the takeoff rating..
- Operating experience with ratings for engines having Automatic Takeoff Thrust Control Systems (ATTCS) or Automatic Power Reserve (APR) shows that once sufficient performance margin is ensured, usually gas path temperature (EGT), even minimum performance engines are capable of achieving the bump rating.

Operation with an EGT exceedance will in a relatively short time likely result in engine capability reduction. The capability reduction is most apt to come about through distress/damage to turbine airfoils. If the engine is operated in this manner for sufficient magnitude/duration, the exceedance may propagate to an engine shutdown (due to efficiency loss in the turbine). The loss of the turbine airfoils does not pose a blade containment risk because in such situations the airfoils are breaking up at the edge and tip, generating debris typically much smaller than a blade airfoil, and the debris is carried downstream by the airflow. As well, the situation does not pose a disk burst risk, as the disk is not exposed directly to flowpath air but is surrounded by secondary cooling air[19].

V. Oil and Fuel Limits

Under the requirements of §33.7(c)(6) oil and fuel pressure operating limits are required. Oil pressure is to be sensed/measured at a location specified by the engine manufacturer, while fuel pressure is to be sensed/measured at the fuel inlet. In §33.87(a)(7), the requirements for the gas turbine engine endurance test state that "At least one run must be made with fuel, oil, and hydraulic fluid at the minimum pressure limit and at least one run must be made with fuel, oil, and hydraulic fluid at the maximum pressure limit." In the same manner as the oil/fuel temperature limits, the manufacturer has demonstrated a capability relative to a test and not a safety limit related to an unsafe condition for the engine.

Oil Limits

Exceedances of secondary engine parameters (oil pressure, temperature, fuel flow) are in and of themselves not intrinsically unsafe conditions for the engine, and the engine can operate for a short term under these conditions. When one of these parameters has an exceedance, it may be a false indication or it may indicate some type of engine or oil cooler failure in progress:

- **Oil temperature high**—can indicate oil cooler thermostat failure or low fuel/oil/air-flow (low oil viscosity, excessive bearing wear, premature removal, capability reduction) or oil sump scavenge failure (oil temperature high due to churning of oil within sump, oil may overflow sump, risk of internal engine fire). This parameter may be more critical on some engines due to engine design features, i.e., geared fan, sump location, and/or sensor location. It is critical on turboprop engines where excessive oil temperature can compromise propeller reduction gearbox material properties, leading to loss of the propeller, which can be a catastrophic condition to the aircraft. See additional discussion below for Table 3, and section VII flight Crew Role in Response to Internal Fire.
- **Oil pressure low**—can indicate complete oil exhaustion as a result of a leak, loss of oil supply or oil pump failure (rapid bearing wear, possible bearing failure and uncommanded engine shutdown, premature removal, capability reduction). Parameter may be more critical on some engines due to engine design features, i.e., geared fan.
- **Oil pressure high**—can indicate oil pump regulator failure, oil cooler thermostat failure, or cold ambient starting temperature. Parameter may be more critical on some engines where it is used to gage internal air-oil seal health.

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[19] This is not to say that the disk material properties were unaffected. Depending on the design features and reason for the overtemperature condition the material properties may make the disk unsuitable for continued service. This is more true of starting temperature exceedance and low power exceedances were cooling airflow is nonexistent or low, verses versus running at high power with full airflow.

The FAA turbofan malfunction training package cited above states, for oil system indications:

> **Many of the sensors used are subject to giving false indications, especially on earlier engine models. Multiple abnormal system indications confirm a genuine failure; a single abnormal indication may or may not be a valid indication of failure.**
>
> **There is considerable variation between failure progressions in the oil system, so the symptoms given below may vary from case to case.**
>
> **Oil system problems may appear at any flight phase, and generally progress gradually. They may eventually lead to severe engine damage if the engine is not shut down.**
>
> **Low oil pressure may result from pump failure, from a leak allowing the oil system to run dry, from a bearing or gearbox failure, or from an indication system failure. High oil pressure may be observed during extremely low temperature operations, when oil viscosity is at a maximum.**
>
> **Elevated oil temperatures indicate some unwanted source of heat in the system, such as a bearing failure, sump fire or unintended leakage of high temperature air into the scavenge system. High oil temperature may also result from a malfunction of the engine oil cooler, or of the valves scheduling fluid flow through the cooler.**
>
> *— Chapter 3 Engine Instrumentation in the flight deck, Airplane Turbofan Engine Operation and Malfunctions - Basic Familiarization for Flight Crews*

In §33.87(a)(7), the requirements for the gas turbine engine endurance test state that "the oil inlet temperature must be maintained at the limiting temperature." The maximum oil inlet temperature used in this test then becomes the engine TCDS oil temperature limit. The effect of this relationship means the engine TCDS limit represents a capability value established during one engine test. The value in and of itself is not a safety limit determined through analysis and/or test in the same manner a minimum rotor burst speed limit is a safety limit.

As a capability value, oil temperature exceedance does not indicate an unsafe condition[20], service history has shown a sustained exceedance of this limit to be an indication of malfunction within the engine lubrication system.

Fuel Limits

Exceedance of the fuel temperature and pressure limits can have the following effects on the engine:

- **Low pressure**—cavitation within the fuel pump elements (capability reduction reduced pump life), vapor lock fuel flow reduction/loss, uncommanded engine shutdown
- **High pressure**—hydromechanical unit (HMU) seal deterioration, fuel flow leakage potential, potential risk of internal engine fire after shutdown if pressure is sufficiently high to open pressure regulating valve[21]
- **Low fuel temperature**—risk of water contamination accumulating as ice in the fuel filter, blocking fuel filter or other screens within HMU, uncommanded fuel flow reduction/loss, uncommanded engine shutdown or uncontrollable high thrust.
- **High fuel temperature**—cavitation within the fuel pump elements, vapor lock, fuel flow reduction/loss, intermittent power reduction, fuel coking with risk of loss-of-thrust-control event, or uncommanded engine shutdown

The failure to maintain fuel pressure/temperature limits on an engine is not in and of itself an unsafe condition[22]. These conditions lead to uncommanded engine shutdown. Fuel temperature and pressure limits do not provide an indication of an under cowl fuel leak, which would be more directly relevant to airplane safety.

[20] This statement is not applicable to turboprop engines, and may be design dependent on geared turbofans.

[21] This risk can be mitigated by design; maximum aircraft fuel pump boost pressure should be below that of the HMU pressure-raising valve.

[22] This excludes the common cause events that affect all engines simultaneously.

VI. Flight Crew Role in Overspeed and Uncontained Disk Burst Response

There are two primary causes of engine overspeed: shaft separation leading to an uncontrolled acceleration of the turbine section and control system malfunction (CVG position error or overfueling). In the first case, an overspeed as the result of a main shaft separation or similar event, the overspeed occurs so quickly (less than 1 second) that human response time is insufficient to prevent an uncontained failure. For this reason, engine designs incorporate safeguards, typically automatic overspeed protection devices, to protect against such a failure progressing to a disk burst. An overspeed condition can also occur because of a control system malfunction. In general, these failures are self-limiting to speeds less than those demonstrated during disk overspeed testing due to maximum fuel flow limits, maximum rotor speed control laws, or automatic overspeed control shutdown.

An SAE report on rotor uncontained failures[23] documented the causes of disk and blade containment failures in the commercial transport fleet. The majority of the causes involved a very rapid failure propagation event, such as a loss of structural integrity due to low cycle or high cycle fatigue failure, without prior indication to the crew. For 93% of the documented events there was no indication to the flight crew of an incipient disk burst. For the remaining 7% of failures, the failure mode involved might conceivably have been associated with a parameter excursion as shown in **Table 3**, although there is no record of whether this was actually the case.

Table 3. Uncontained failures with possible parameter exceedance.

Failure Mode	Failures (%)
Oil Fire	4.2
Reduction gearbox (applies to turboprops only)	1.4
Bearing failure	0.7
Control systems	0.7
Loss of lubrication	0.0
Overspeed	0.0
Overtemperature	0.0
Total all events	7.0
Total turbofan only	5.6

In 5.6% of these events (excludes turboprops), the flight crew could have acted given an appropriate indication[24] to prevent an unsafe engine condition (1.4% were undetermined). The remainder, or 93%, occurred so rapidly that the flight crew could have had no opportunity to prevent the failure by responding to a parameter excursion.

[23] *AIR 4770 Report on Aircraft Engine Containment - 1984 through 1989 (unpublished).*

[24] *It is not clear that such indications are feasible. Currently rotor overtemperature conditions cannot be inferred from other indications. An overtemperature of the rotor, such as those that can be caused by internal oil fires, can lead to uncontained blade and/or uncontained rotor failures. In general, this condition can be mitigated through design, but may still be experienced in the case internal oil fires.*

VII. Flight Crew Role in Response to Internal Fire

Oil transfer tubes and oil sumps can be located within areas where metal surface temperatures are greater than the ignition temperature of the oil used within the lubrication system. Therefore, a potential exists for failure within the engine oil system to leak oil into these high temperature areas, and if airflow conditions are suitable[25], for the leak to propagate into an internal engine fire. This fire may be in a location where it could overheat a disk, resulting in an uncontained disk burst, or it may possibly burn through scavenge lines into the nacelle, causing a nacelle fire that could be detected by the normal fire detectors.

> **It is important to know that, given a fire in the nacelle, there is adequate time to make the first priority "fly the airplane" before attending to the fire. It has been shown that, even in incidents of fire indication immediately after takeoff, there is adequate time to continue climb to a safe altitude before attending to the engine. There may be economic damage to the nacelle, but the first priority of the flight crew should be to ensure the airplane continues in safe flight**
>
> *— Chapter 4 Engine Malfunctions, Airplane Turbofan Engine Operation and Malfunctions - Basic Familiarization for Flight Crews*

Other than the extreme cases, such as a nacelle fire or uncontained rotor failure that present with unique failure signatures, there is no means for the pilot to discriminate between the few cases of oil parameter excursions associated with internal fires, and the many cases where the parameter excursions are associated with a more benign failure such as undercowl oil leakage, false indication, or oil system contamination.

[25] *Fire after all is a chemical process so the air and oil have to be present in the correct ratio to initiate and sustain a fire. Too little oil and the mixture is lean, too much oil and the mixture is rich. Under such conditions, no fire can be sustained.*

Addendum 3

References

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