SUBPART F - EQUIPMENT

Section 2. Instruments: Installation

Page No.

SECTION 25.1316 SYSTEM LIGHTNING PROTECTION.....SUB. F-2-2

SECTION 25.1337 POWERPLANT INSTRUMENTS. .....SUB. F-2-9

SUBPART F - EQUIPMENT

Section 2. Instruments: Installation

Section 25.1316 System lightning protection.

a. **Rule Text.**

(a) For functions whose failure would contribute to or cause a condition that would prevent the continued safe flight and landing of the airplane, each electrical and electronic system that performs these functions must be designed and installed to ensure that the operation and operational capabilities of the systems to perform these functions are not adversely affected when the airplane is exposed to lightning.

(b) For functions whose failure would contribute to or cause a condition that would reduce the capability of the airplane or the ability of the flightcrew to cope with adverse operating conditions, each electrical and electronic system that performs these functions must be designed and installed to ensure that these functions can be recovered in a timely manner after the airplane is exposed to lightning.

(c) Compliance with the lightning protection criteria prescribed in paragraphs (a) and (b) of this section must be shown for exposure to a severe lightning environment. The applicant must design for and verify that aircraft electrical/electronic systems are protected against the effects of lightning by:

(1) Determining the lightning strike zones for the airplane;

(2) Establishing the external lightning environment for the zones;

(3) Establishing the internal environment;

(4) Identifying all the electrical and electronic systems that are subject to the requirements of this section, and their locations on or within the airplane;

(5) Establishing the susceptibility of the systems to the internal and external lightning environment;

(6) Designing protection; and

(7) Verifying that the protection is adequate.

b. **Intent of Rule.** The purpose of the rule is to require lightning protection for electrical and electronic systems that perform critical and essential functions when installed in an airplane.

c. **Background.** This regulation was proposed in Notice of Proposed Rulemaking 89-15 (54 FR 23164, May 30, 1989). The following excerpt from the preamble to the Notice, provides insight into the intent of this rule:

> The terms "critical" and "essential" originated when attempts were made to classify failure conditions in accordance with § 25.1309. This regulation requires that systems be designed so that the occurrence of any failure condition that would prevent the continued safe flight and landing of the airplane is extremely improbable. The function affected by such a failure condition is deemed "critical." Additionally, § 25.1309 requires that systems be designed so that the occurrence of any other failure condition that would reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions is improbable. The function affected by such a failure condition is deemed "essential." The combination of systems or system redundancy required to meet these reliability requirements is determined by conducting a preliminary hazard analysis or criticality assessment. Examples of systems that perform critical functions are full authority electronic engine controls, electronic primary flight controls, primary flight displays, and electronic stability augmentation. Examples of systems that perform essential functions are communications systems, navigation systems, and flight management systems.

This rule was adopted as Amendment 25-80 (59 FR 22112, April 28, 1994). The following text comes from the preamble to the Amendment and provides additional insight into the intent of the rule:

> One commenter considers the lightning protection requirements to be unclear when applied to individual subsystems prior to installation in the airplane, and recommends that the relationship between the airframe manufacturer and the subsystem supplier be clarified. The commenter contends that the proposed rule appears to suggest that all systems that perform critical functions would be required to withstand the full direct strike currents, without taking into account any reduction in these currents due to the shielding provided by the airframe.
>
> As discussed in the Notice, the purpose of the proposed regulation is to require lightning protection for electrical and electronic systems that perform critical and essential functions when installed in an airplane. Protection may be provided by the airplane structure, shielding of the wiring, and enclosures of the individual subsystems. The airframe manufacturer generally specifies the level of protection needed for subsystems. In the past, when the airframe manufacturer did not specify the level of protection needed, Radio Technical Commission for Aeronautics (RTCA) Document DO-160, Section 22, "Lightning Induced Transient Susceptibility," was used to provide guidance. While Section 22 of DO-160 is incomplete, it is currently being revised to include the effects of multiple burst and multiple stroke test waveforms so as to be in agreement with FAA Advisory Circular 20-136, "Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning," dated March 5, 1990, and Society of Automotive Engineers (SAE) Committee Report AE4L-87-3, Revision B, dated January 1989. Until the DO-160 revision has been completed, the tests and analyses described in the advisory circular should be used to qualify subsystems. The test waveforms presented in appendix III of the advisory circular represent a severe natural lightning environment, including the multiple stroke and multiple burst criteria, that is external to the airplane and that may be used for certification purposes in assessing the induced effects of lightning. The equipment should be protected to the appropriate test level, as specified in Appendix IV of the advisory circular, for the proposed airplane installations so that the subsystems are able to continue to perform their intended functions after the tests are conducted.

One commenter suggests that the words "contribute to or . . ." be removed from the definitions for critical and essential functions given in proposed §§ 25.1315(c)(1) and (c)(2), because this terminology is undefined and can be subject to broad interpretation.

The FAA does not concur. This terminology is consistent with that used in existing regulations and is generally understood by the aviation industry. It is used in this rule to convey that although a failure by itself may not be catastrophic or major, it may be a contributing factor when combinations of failures are considered. For example, a latent or undetected failure could contribute to a hazardous failure condition when combined with one or more specific failures or events. Also, systems that perform only nonessential functions could contribute to a failure condition involving an essential or critical function.

Several commenters request clarification as to exactly what is meant by the statement that critical functions are "not affected" by the lightning encounter.

The FAA concurs that clarification of "not affected" is needed; therefore, the final rule has been revised to read, "not adversely affected," in an attempt to convey this intent. Although the words "not affected" were used in the proposed rule, the FAA did not intend that the requirement be rigidly applied. The intent of the regulation is to require lightning protection for systems that perform critical functions to the extent that the critical functions are not adversely affected by the lightning event. Determination of when functions are adversely affected would be made by the cognizant FAA Aircraft Certification Office based on rational engineering judgment on a case-by-case evaluation of the specified function and the "effect" presented. Literally applying a standard of "no effect" would not be reasonable. In determining compliance with special conditions in past certification programs, the FAA has accepted upsets of a minor nature that do not result in significant fluctuations of control surface position or engine thrust. Any effect perceived by the flight crew would need to be evaluated to ensure that it would not lead to a hazardous condition. For example, some full authority digital engine control (FADEC) systems are designed with two fully redundant channels, either of which can control the engine independently. In addition, the logic within the FADEC will monitor each channel and, by design, switch channels if an anomaly appears on the selected channel. This does not necessarily mean that the channel is no longer functional or has degraded, because if the backup channel were not functional, the selected channel would continue in control. Therefore, it would not be considered an adverse effect if a channel transfer in such a system occurred in accordance with its accepted design when the airplane is exposed to the lightning test waveforms. However, additional tests may be required to demonstrate that neither channel would be adversely affected when tested individually. For example, a mode change within a given channel that could result in the loss of a primary thrust setting parameter, resulting in the possibility of a change in thrust level, would not be acceptable. The effects of lightning must not damage internal monitors that indicate normal operation of critical systems.

Other examples of adversely affected critical functions are hazardously misleading primary flight information, uncommanded flap motion and, of course, loss of primary flight controls in a fly-by-wire airplane.

Determination of adverse effects will be handled on a case-by-case basis subject to the explanation given above. Perturbations or deviations that exceed tolerances agreed upon in the test plan must be reported to the FAA for evaluation.

The same commenters also suggest that adequate lightning protection is provided if the airplane is still capable of continued safe flight and landing after the lightning encounter.

The FAA does not agree that the concept of continued safe flight and landing is sufficient. The FAA has concluded that a higher level of safety is required for systems that perform critical functions when exposed to adverse environmental conditions. This concept would be violated, for example, if engine failure from an expected environmental condition, such as a lightning strike, were allowed because any environmental condition that may adversely affect an engine design must be assumed to affect all the engines on the airplane. For this reason, engines, as installed, must be able to tolerate these conditions without damage or serious loss of thrust. This same line of reasoning applies to other systems that perform critical functions. Lightning strikes to airplanes are unpredictable as to their strength, duration, and number. Therefore, continued safe flight and landing of the airplane after multiple lightning strikes could not be assured unless systems that perform critical functions have a high degree of tolerance to the expected lightning strike environment. This basic environmental requirement also applies to other environmental conditions, such as icing, hail, heavy rain, bird flocks, etc.

One commenter proposes new wording for § 25.1315(a) that would allow crew action to restore critical systems that have been disrupted by lightning induced transients.

The FAA does not concur. Critical function disruption must be automatically restored after the lightning encounter. Under certain flight conditions, such as during takeoff or landing in instrument meteorological conditions when the crew workload is high, the crew may not be able to restore the critical function in time to prevent a catastrophic event from occurring. The FAA allows crew action to restore systems that perform essential functions; however, systems that perform critical functions must recover automatically.

Two commenters consider the definition of the environment given in the proposed appendix to be unrealistic and propose several changes to the idealized test waveforms.

The FAA does not concur that this definition is unrealistic. The FAA has worked closely with SAE Committee AE4L in developing the idealized test waveforms that are presented in Revision B of Report AE4L-87-3. The FAA has adopted these waveforms as acceptable representations of a severe natural lightning environment for certification purposes and has included them in AC 20-136. The proposed changes submitted by the commenters have been forwarded to the AE4L Committee for consideration. The FAA will consider appropriate changes to the definition of the waveforms in the AC if the Committee recommends them.

Two commenters object to statements in the background and discussion of the NPRM that new generation systems and airframes are more vulnerable to the indirect effects of lightning than previous designs.

The FAA agrees that new generation systems are not necessarily more vulnerable to the indirect effects of lightning if proper design, shielding, and grounding techniques are used. However, the use of sensitive electronics that respond to low level voltage commands makes these systems potentially more vulnerable if they are not properly designed and shielded. Reduced electromagnetic shielding provided by nonmetallic airframe materials also raises the potential for system interference from lightning. The intent of these new lightning protection requirements is to maintain the level of safety that is inherent in the older airplane designs.

One commenter expresses concern that application of the proposed rule to existing airplanes could present problems for supplemental type certification (STC) applicants when new systems are installed. Many airlines, for example, do not have the capability to demonstrate compliance.

The FAA considers lightning to be an environmental condition that must be taken into consideration to assure confidence of safe operation when a new system is installed in an airplane. Equipment manufacturers have historically used the test procedures in RTCA Document DO-160 to qualify their equipment to environmental conditions. The capability of the equipment to meet the tests described in this document establishes a minimum level of protection for system components. Additional protection may be provided by the airframe materials, shielding of wire bundles, proper equipment grounding, etc. In addition to bench tests, a determination should be made that systems that perform critical and essential functions, as installed in a given airplane, are provided with adequate protection, including margins, and that installation level testing and/or verified analysis is adequate. The cognizant FAA Aircraft Certification Office makes this determination, based on guidance contained in AC 20-136 ["Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning"], and sound engineering judgment. In addition, the FAA has issued special conditions for new systems in existing airplanes under the provisions of § 21.101(b)(2). The extent of review required for a system installed in existing airplanes will depend on the type of system, installation considerations such as type of airplane, airframe materials (metallic or composite), service experience in "similar" airplanes, and other factors. These evaluations should be reviewed with the cognizant FAA Aircraft Certification Office so that the FAA and the applicant can agree on a certification plan.

One commenter states that the proposed requirement for lightning protection of essential systems is not justified and should not be adopted.

The FAA disagrees with this comment. Lightning encounters, even though infrequent, do occur. Therefore, a degree of protection is required commensurate with the criticality of the function that the system performs. Protection requirements are much less stringent for systems that perform essential functions than for those that perform critical functions. System components may be damaged as long as the function can be recovered after the lightning encounter. The justification for imposing requirements for systems that perform essential functions is that loss of function would unacceptably decrease the inherent level of safety of the airplane.

d. **Policy/Compliance Methods**. While current FAA policy is reflected in the preamble to Amendment 25-80, as discussed above , the following excerpt from an internal FAA memorandum provides additional guidance..

SUBJECT: Identification Criterion; Expansion of Zone 1A Due to "Flight Safety Hazard' Considerations

DATE: July 29, 1990

The Lightning Protection Advisory Circulars, AC 20-53A and AC 20-136, and the "Lightning Protection Requirements'" Issue Papers for [*certain airplane models*] highlight the need to consider extending Lightning Strike Zone 1A "if the probability of a flight safety hazard due to a Zone 1A strike to an unprotected surface is high." Further, the Issue Papers require that the lightning strike zone identification used by the applicant specifically address "direct lightning attachment to the full authority digital engine control (FADEC) or to any other control system component where direct attachment may occur through non-conductive (such as composite) cowling or other aerodynamic fairing.'" During the course of [*certain airplane*] programs, the need for clarification of these requirements became apparent. The following FAA policy is intended to provide that clarification.

For transport category aircraft the lightning zone identification used by the applicant should be shown to comply with the intent of the expanded Zone 1A consideration by:

1. Specifically identifying <u>any</u> aircraft external surface which:

   a. Has not been shown to provide adequate protection from the direct effects of a Zone 1A strike as defined in Section 11 of AC 20-53A; and

   b. Is located aft of a leading edge extremity (i.e., is located in a traditional Zone 2A, swept stroke zone, as defined in the lightning protection AC's).

2. Addressing the exposure of each surface to a Zone 1A strike when demonstrating compliance with the lightning certification requirements by:

   a. Establishing that the surface will not be exposed to Zone 1A strike, or

   b. Demonstrating that, if the surface is exposed to a Zone IA strike, the lightning direct and indirect affects will not contribute to or cause a failure condition, which would prevent continued safe flight and landing, and any resultant failure condition, which could significantly impact the safety of the airplane or the ability of the crew to cope with adverse operating conditions, is recoverable immediately following the strike (i.e., any critical function is not affected and any essential function can be immediately recovered).

This assessment process, when applied to the powerplant installations of a transport category aircraft, should recognize the following:

1. Lightning models and service experience show that fan cowls on typical wing mounted engines are exposed to lightning first return strokes.

2. Loss of engine structural integrity (e.g., uncontrolled fire or overspeed), a multiple engine loss of thrust control, high power reverse thrust in-flight, and single engine loss of thrust control during certain critical phases of flight are examples of powerplant malfunctions which could contribute to or cause a failure condition which would prevent continued safe flight and landing.

3. Loss of thrust control on a single engine or any other adverse change in an engine's operating capabilities or characteristics, loss of any powerplant instrument required by § 25.1305, and loss of a fault detection, accommodation or annunciation feature are examples of powerplant failures which could significantly impact the safety of the airplane or the ability of the crew to cope with adverse operating conditions.

(Note: 'loss of thrust control' as used herein is defined as any loss of control over the magnitude or direction of thrust to the extent that it could adversely impact aircraft safety. The principal hazardous conditions to be considered are:

- uncommanded change in the direction of thrust,
- inability to attain and retain rated forward or reverse thrust, and
- unpredictable or unstable powerplant operation that significantly increases crew workload, or otherwise adversely impacts aircraft safety.)

As an example, an engine installation certain airplane models have a FADEC located directly under a composite fan cowl on the wing-mounted engines. Since malfunction of this FADEC could cause an engine overspeed, it must be shown to be unaffected when the fan cowl is exposed to a Zone IA lightning strike.

e. **References**.

(1) Notice of Proposed Rulemaking 89-15 (54 FR 23164, May 30, 1989).

(2) Amendment 25-80 (59 FR 22112, April 28, 1994).

(3) Advisory Circular 20-53A, “Protection of Aircraft Fuel Systems Against Fuel Vapor Ignition Due to Lightning,” April 12, 1985.

(4) Advisory Circular 20-136, “Protection of Aircraft Electrical/Electronic Systems Against the Indirect Effects of Lightning,” March 5, 1990.

Section 25.1337 Powerplant instruments.

a. **Rule Text.**

(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

(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.

(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.

(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.

(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 paragraph (f)(1) of this section, the gauge balance lines must be independently connected to the carburetor inlet pressure to avoid erroneous readings.

(Doc. No. 5066, 29 FR 18291, Dec. 24, 1964, as amended by Amdt. 25-40, 42 FR 15044, March 17, 1977)

b. **Intent of Rule.** The intent of this rule is self-evident.

c. **Background.**

(1) The regulatory history shows that this requirement originated from section 4b.613 of the Civil Air Regulations (CAR), December 31, 1953. Amendment 25-AD (29 FR 18289, December 24, 1964) added Part 25 [New] to the Federal Aviation Regulations and replaced Part 4b of the CAR. It was part of the Agency recodification program announced in Draft Release 61-25, published in the Federal Register on November 15, 1961 (26 FR 10698). It was recodified from CAR 4b.613 without any substantive changes.

(2) The regulation was further modified by Amendment 25-40 (42 FR 15034, March 17, 1977), which followed two Notices of Proposed Rulemaking:

- Notice 75-10 (40 FR 10802, March 7, 1975) and
- Notice 75-19 (40 FR 21866, May 19, 1975).

The amendments based on Notice 75-10 were deferred to the series of amendments titled "Miscellaneous Amendments" (41 FR 55454, December 20, 1976) so that they could be considered in conjunction with the final disposition of certain proposals in Notice 75-19. The following excerpts are from the preamble to that Amendment:

One commenter agrees with the intent of the proposal for § 23.1337(a), concerning powerplant instruments and instrument lines that utilize flammable fluids, but suggests a number of changes to make the provision more specific. The FAA does not agree. Flexibility in the requirement is necessary to avoid creating unnecessary design restrictions.

The commenter also suggests that a fire extinguisher be specified for compliance with the proposed rule. The FAA does not agree. The intent of the proposal is to prevent the occurrence of a fire hazard.

Another commenter concurs with the proposal if, with respect to APU's, it is limited to those approved for use in flight. The FAA does not believe the proposal should be so limited, since the failure or malfunction of an APU approved for use only on the ground could jeopardize safe operation on the ground and in flight. The proposal is adopted without substantive change.

d. <u>Policy/Compliance Methods</u>.

(1) Historically, FAA guidance has been provided on fuel quantity indicator and unusable fuel requirements, i.e., compliance with § 25.1337 (b), as follows:

> The purpose of this guidance is to provide policy relative to determination of the unusable fuel quantity for showing compliance with § 25.1337. This section requires that each fuel indicator be calibrated to read "zero" during level flight when the quantity in the tank is equal to the unusable fuel supply determined under § 25.959. The statement in this regulation of "during level flight" has resulted in confusion as to how the unusable fuel quantity should be determined. As stated in § 25.959, the unusable fuel must be established under the most adverse fuel feed configuration for all intended operations and flight maneuvers involving fuel feed from that tank. The intended usage range should be established by the applicant based on flight characteristics of the particular airplane type. For example, an auxiliary tank that is normally depleted during cruise may use the normal cruise attitudes based on analysis of allowable airplane center of gravity configurations to establish the unusable fuel for the tank. For a main fuel tank that may be used during takeoff, climb, approach, and landing, the worst attitude within these flight regimes must be used. The applicant may choose to limit the allowable airplane nose up/down and roll attitudes, by providing an Airplane Flight Manual (AFM) limitation for low fuel operations, to reduce the unusable fuel quantities. However, these limitations must be found to be operationally acceptable for the flight conditions that are likely to exist during a low fuel state (including go-around flight attitudes).
>
> Once the intended usage range has been established, the applicant must define attitude versus unusable fuel quantity relationships for each tank. These analytically determined relationships must be validated during flight and or ground test. The § 25.959 unusable fuel should be determined by flight testing at the point where the maximum unusable fuel would exist within the intended usage range of the tank. An example of a typical unusable fuel curve for an auxiliary and main tank is provided below. The fuel indicator system should be calibrated to read zero at this value.
>
> Fuel tank indication errors for level flight and for coordinated maneuvers should be consistent with the guidance provided in policy memorandum "Standards for Transport Airplane Fuel Quantity System Accuracy, dated May 30, 1984. This memorandum references MIL Specification MIL-C-26988C, "Military Specification for Gauge, Liquid Quantity, Capacitance Type, Transistorized," which states that complete gauge system error at room temperature shall not exceed two percent of the indication plus one percent of full scale indication. In addition to this guideline, each system should be reviewed to show that no unsafe condition could result due to high indication errors. Large errors, particularly errors that result in false high readings and the inability to accurately predict remaining reserves or detect a fuel leak within the fuel system are not allowed.

(2) The following excerpt from an internal FAA memorandum dated January 20, 1984, provides guidance on fuel gauge accuracy requirements.

> Section 25.1337(b) requires that each fuel quantity indicator be calibrated to read "zero" during level flight at the unusable fuel quantity. The FAA has never considered this regulation to require absolute accuracy of the fuel quantity gauge at "zero." Basically, instead of literal compliance, the system should perform its intended function, provide an equivalent level of safety, and not exhibit unsafe features or characteristics. A reasonable degree of accuracy, as presented below, is generally adequate.

The TSO requirement for fuel quantity instruments (TSO-C55) refers to SAE Aeronautical Standard AS-4058, "Fuel and Oil Quantity Instruments," dated July 15, 1958. This standard specifies that the error at any point in the scale shall not exceed 3% of full scale indications.

However, it is the current practice of some ACO's to use as guidance the information in Military Specification MIL-G-8798, "General Specification for Integrally Light, Non vacuum Tube, Capacitance Type Fuel Quantity Gauge System." This document specifies that complete gauge system error at room temperature shall not exceed 2.0% of the indication plus 1.0% of the full scale indication (paragraph 4.5.8). MIL-G-8798 has been superseded by MIL-G-26988C, but the accuracy requirements for Class I systems (non-attitude corrected for older designed airplanes) remain the same (paragraph 4.6.8). These specifications are compatible with the TSO requirements and generally provide satisfactory criteria for evaluating fuel quantity gauge accuracy. Other ACO's have adopted certain constant accuracy tolerances, based on a manufacturer's recommended criteria, that are within the "'Mil. Spec." requirements.

Based on our investigation, this office recommends that the fuel quantity gauge accuracy requirements that are set forth in Military Specification MIL-G-26988C for the complete gauge system at room temperature (2.0% of indication plus 1.0% full scale) be used as guidelines for fuel systems on transport category airplanes using capacitance type fuel tank probes.

(3) The following excerpt is from an internal FAA memorandum that describes the minimum acceptable standards for the accuracy of transport airplane fuel quantity indication:

During recent certification programs and reviews of production flight test reports, questions have been raised concerning transport airplane Fuel Quantity Indication System accuracy requirements. Section 25.1337(b)(1) requires that "Each Fuel Quantity Indicator must be calibrated to read "ZERO" during level flight when the quantity of fuel is equal to the unusable fuel supply . . . Section 25.1337(b) further requires that the fuel quantity indicator(s) must indicate the usable fuel in each tank during flight. A literal interpretation of these regulations would be that the Fuel Quantity Indication System must be absolutely accurate during any flight condition.

Military Specification MIL-G-8798, ”General Specification for Integrally Lighted Non-Vacuum Tube, Capacitance Type Fuel Quantity Gauge System,” specifies that complete gauge system scale error at room temperature shall not exceed 2.0 percent of the indication plus 1.0 percent of the full scale indication (ref. paragraph 4.5.8.). Currently, the usage of this type of information for certification would create a literal noncompliance with Section 25.1337(b).

Based upon a realistic assessment of the inherent accuracy capabilities of capacitance probe indication systems, including airplane attitude sensitivity, and the relatively large powerplant fuel consumption rates which render extremely accurate displays academic, some accuracy tolerance is necessary and appropriate to preclude imposing an unreasonable economic burden and foster certification standardization.

We advised in an earlier letter that a fuel quantity indication system that bottoms out and fails to read down to the unusable fuel quantity does not comply with § 25.1337(b). Based on our understanding that the indication system bottoms out with 49 pounds of fuel remaining on each side (or a total of 98 pounds), we advised that the airplane

manufacturer would have to replace the fuel quantity indication system with a system that did not bottom out or increase the unusable fuel to include the 98 pounds.

We now understand from the applicant that their fuel quantity indication system does not bottom out with 98 pounds of fuel remaining. Rather, the indication system is a digital type that provides readings in 50 pound increments (per side). Since the indication system does read zero at the original unusable fuel quantity and continues to provide readings with increasing quantity (albeit in increments of 50 pounds per side), the indication system would be in compliance without considering the 49 pound per side between the first two increments as unusable fuel.

Although production tolerance is not an issue in this instance, the referenced letter was not intended to preclude a normal production tolerance on the reading at the unusable fuel quantity that is consistent with the total quantity and consumption rate of the airplane involved.

(4) The following excerpt from an FAA Issue Paper provides guidance on fuel gauge accuracy.

STATEMENT OF ISSUE: During FAA certification flight testing it was discovered that hazardously misleading fuel quantities are displayed to the crew during climb and descent. These errors are well beyond the limits prescribed in any of the referenced industry standards, which have historically served as FAA policy on this subject.

BACKGROUND: During FAA certification flight testing the fuel quantity gauges were found to read as much as 20% high during descent, about 10% low during climb and 3 - 4 % low during cruise with fuel below 30 tonnes. While on the ground the fuel quantity values also increased by one tonne after the fuel pumps were switched "on". Fuel quantity readings along with fuel used calculations are used by the flight crew to determine fuel load remaining values that are in turn used to calculate fuel remaining at the planned or alternate destination. Large fuel quantity errors, particularly high readings that occur during the descent portion of the flight, result in the inability of the flight crew to accurately calculate and validate the remaining fuel load. In addition, the inability of the flight management computer to cross check the fuel remaining from the totalizer versus that shown on the fuel gauges will not allow detection of potential fuel leakage. The flight crew is dependent on manual calculations using the initial fuel load from the fuel gauges minus the total fuel used by the engines to detect leaks or unplanned fuel consumption. The fuel gauge errors noted during the flight test program may contribute to an unsafe operating condition.

FAA POSITION: The fuel quantity gauging system must be shown to be accurate to within 2% of the indicated fuel quantity plus 1% of full scale during sustained flight conditions anywhere in the normal flight envelope .

CONCLUSION: The applicant has presented to the FAA the modifications necessary to correct the noted fuel system gauging inaccuracies and have identified the specific modification numbers that define the changes. The modifications to correct the fuel gauging inaccuracies are considered necessary to be contained in the basic type design. As such the modification numbers must be included in the basic type design data. Verification of the incorporation of the modifications and test results verifying that the fuel gauging system meets FAA accuracy requirements should be transmitted to the FAA when available.

(5) The following excerpt is from an FAA memorandum that provides guidance for the approval of Flight Management Systems (FMS) that are capable of displaying Part 25 Airplane Flight Manual (AFM) performance information on cockpit display units [e.g., multi-function display (MFD) units]. This guidance supplements and clarifies that contained in Advisory Circular (AC) 25-15, "Approval of Flight Management Systems in Transport Category Airplanes," dated November 20, 1989.

A case was recently brought to our attention wherein a modification center was requested to install a flight management system (FMS) with the capability to present AFM performance information to the flightcrew, with no airworthiness review. An outside party had compiled a database of AFM performance information and supplied it to the FMS manufacturer. The FMS manufacturer added the AFM performance database to the system as programmable read only memory (PROM). The affected FMS design (i.e., manufacturer's model designation) has been approved for installation in several transport category airplane types, including airplane type design approvals that provided for the display of AFM performance information.

Flight management systems with the ability to present AFM performance information on cockpit display units should not be installed without suitable airworthiness review to assure compliance with the pertinent requirements of Part 25. This applies to FMS's being incorporated as part of a type design, or by modification to a type design by either the manufacturer or a second party. These stipulations are supported by the guidance provided in the following excerpts from Advisory Circular (AC) 25-15 *["Approval of Flight Management Systems in Transport Category Airplanes," dated November 20, 1989]*, as referenced below:

a. Paragraph 5.f. of AC 25-15 addresses the display of AFM performance information under the subject of "performance management" functions. That paragraph provides guidance relative to system accuracy, resolution of data, substantiation of displayed data, and the integrity of FMS generated performance data, depending on whether it is to be used as primary or advisory information. Paragraph 5.f.(9) states that when the FMS generated data is used as the "primary" reference for airplane performance information, "[I]t is incumbent upon the applicant to provide documentation to the FAA to show that the computer memory contains authentic performance data <u>for each airplane/engine combination</u> for which the approval is sought." Paragraph 5f(10)(ii) states that takeoff and landing approach performance information, even when presented as "advisory information," must meet the same integrity criteria as data presented as "primary information."

b. Paragraph 5.l.(1) of AC 25-15 addresses software changes and discerns between "major" and "minor" changes. That material classifies any change to software that affects FMS performance management functions as a major change. Any FMS change related to the display of AFM performance information is therefore considered a "major" change and should receive FAA review.

c. Paragraph 5.l.(1) of AC 25-15 also notes that, "Software changes incorporated in equipment already installed in an aircraft may require additional evaluation...." In the case of FMS's that display AFM performance information, this statement should be interpreted as also applying to database changes.

d. Paragraph 5.n. of AC 25-15 addresses the type and extent of testing necessary to verify that the installed FMS performs its intended function, and does not adversely affect any other airplane systems and sensors. Under the heading of "ground tests," that paragraph alludes to the extensive amount of testing needed to verify the large

matrix of airplane performance data generated by the FMS. In the case of AFM performance information, the verification of the data presented by the FMS is also crucial from the standpoint of assuring accurate information is presented to the flight crew when determining airplane weights associated with performance limited conditions (e.g., takeoff field length limited).

Any change to an FMS performance management function, including hardware, software, or database changes, should be reflected as a change in the manufacturer's identifying part number(s). A change in part number(s) will ensure that this change, and its impact on other functions, is reviewed under an airworthiness approval and that interchangeability is not compromised. Additionally, whether the FMS is to be used as a "primary" or "advisory" reference for AFM data, flightcrews will be tempted to use it as the sole source of performance information. Consequently, these systems should receive the same level of review, and type of approval, as the paper AFM. This review and approval process applies to any revisions and supplementary additions made to the performance database contained in the FMS.

(6) The following is from an FAA Issue Paper concerning the proposed installation of direct-reading digital fuel quantity displays on airplanes:

Statement of Issue: An airplane manufacturer has proposed the installation of direct-reading digital fuel quantity displays on that are to be located on the lower left corner of the pilot's center instrument panel.

The fuel quantity indicators must be shown to provide adequate sensory cues to warn the flight crew of unsafe operating conditions, including, but not necessarily limited to, lateral fuel imbalance, fuel system configuration anomalies, and low fuel quantities.

Discussion: Direct-reading digital displays are used for presenting quantitative data when a continuous trend indication is not required. Digital displays provide the most accurate method of monitoring numerical settings with a minimum of reading error. They allow the designer to minimize the required panel space and scale length is limited only by the number of display digits.

Direct-reading digital displays are not desirable for indications that may be utilized for qualitative, check reading, or tracking functions. Values can change easily without being detected and, during transitions, rate-of-change and direction of travel are not readily monitored. Digital displays also present design difficulties in the presentation of usable and effective limitations and operating range information.

Some of the disadvantages of direct-reading digital displays can be overcome by the use of displays which contain a moving-pointer (analog) and digital counter combination or ancillary displays, caution lights, etc., activated by threshold sensors or logic systems to direct the flight crew's attention to a display.

FAA Position: Direct-reading digital instrument displays of powerplant instruments must be shown to comply with the referenced regulations under all expected operating conditions. The required instrument systems must provide adequate sensory cues to the flight crew to alert them to possible unsafe operating conditions.

(7) The following excerpt from an internal FAA memorandum dated March 11, 1977, contains guidance concerning the limit markings and the use of digital powerplant instruments.

This is to inform you of the present guidelines on the marking of required powerplant instruments where digital type instruments are to be used instead of pointer/vertical scale type instruments.

1. If there are no limits on either the cockpit powerplant instruments or in the AFM, such as a fuel quantity instrument, then the digital instrument can be installed without concern for limit markings or placards, unless other considerations, such as rate information, dictate otherwise.

2. If there are no limits on the cockpit powerplant instrument, but there are limits in the AFM, such as engine stall limits, then the digital instrument can be installed without concern for limit markings; but other considerations, such as rate information, must be evaluated.

3. If there are limits on both the cockpit powerplant instruments and in the AFM, such as a rotor speed limit, then the digital instrument can be installed as a supplement to a pointer/vertical scale instrument, but, in general, cannot replace it.

We do not consider that the use of placards and/or lights with digital instruments will provide or display the necessary put to the crew to detect a trend toward exceeding the powerplant limits that are provided by pointer/vertical scale instrument. In addition, the digital instruments do not provide the intent per paragraph 3 of Advisory Circular 20-38 *[“Measurement of Cabin Interior Emergency Illumination in Transport Airplanes”]* that the markings are intended to indicate to the pilot, at a glance, that powerplant operation is being accomplished in a safe or unsafe region. Round dial pointer-scale instruments can be read quickly by observing the angular position of the pointer, and comparison between instruments in a row can quickly disclose that one is "out of line." Well-designed linear pointer-scale instruments can provide similar fast readability. Digital instruments, however, require deliberate reading and mental interpretation. This must be done individually for each instrument.

(8) Further guidance on transport category aircraft propulsion system parameter displays can be found in the following excerpt from Advisory Circular AC 25-11, “Transport Category Airplane Electronic Display Systems,” dated July 16, 1987:

(ix) <u>Propulsion System Parameter Displays</u>.

(A) The required powerplant instrument displays shall be arranged and isolated from each other so that the failure or malfunction of any system or component that affects the display or accuracy of any propulsion system parameter for one engine will not cause the permanent loss of display or adversely affect the accuracy of any parameter for the remaining engines.

(B) No single fault, failure, or malfunction, or probable combinations of failures shall result in the permanent loss of display, or in misleading display, of more than one propulsion unit parameter for a single engine.

(C) Combinations of failures that would result in the permanent loss of required powerplant instrument displays for more than one engine must be improbable.

(D) Combinations of failures that would result in the hazardously misleading display of any parameter for more than one engine must be extremely improbable.

(E) No single fault, failure, or malfunction, or combinations of failures not shown to be extremely improbable, shall result in the loss of all propulsion system displays.

(F) Required powerplant instruments that are not displayed continuously must be automatically displayed when any inhibited parameter exceeds an operating limit or threshold, including fuel tank low fuel advisory or maximum imbalance limit, unless concurrent failure conditions are identified where crew attention to other system displays takes priority over the powerplant instruments for continued safe operation of airplane. In each case, it must be established that failure to concurrently display the powerplant instruments does not jeopardize the safe operation of the airplane.

(G) Propulsion 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 the loss of normal electrical power.

(H) Individual fuel tank quantity information must be displayed whenever the fuel system is not in the normal configuration for flight.

(x) Crew Alerting Displays. Crew alerting of selected parameters may be an essential function. Loss of crew alerting for essential functions must be improbable. Display of hazardously misleading crew alerting messages must be improbable.

(xi) Flightcrew Procedures. The display of hazardously misleading flightcrew procedures caused by display system failure, malfunction, or misdesign must be improbable.

(xii) Weather Radar. Display of weather radar in the cockpit is a nonessential function; however, presentation of hazardously misleading information must be improbable.

NOTE: Operational rules may require the installation and functioning of weather radar.

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b. **Compliance Considerations**.

(1) Human Factors. Humans are very adaptable, but unfortunately for the display evaluation process, they adapt at varying rates with varying degrees of effectiveness and mental processing compensation. Thus, what some pilots might find acceptable and approvable, others would reject as being unusable and unsafe. Airplane displays must be effective when used by pilots who cover the entire spectrum of variability. Relying on a requirement of "train to proficiency" may be unenforceable, economically impractical, or unachievable by some pilots without excessive mental workload as compensation.

(i) The test program should include sufficient flight and simulation time, using a representative population of pilots, to substantiate:

(A) Reasonable training times and learning curves;

(B) Usability in an operational environment;

(C) Acceptable interpretation of error rates equivalent to or less than conventional displays;

(D) Proper integration with other equipment that uses electronic display functions;

(E) Acceptability of all failure modes not shown to be extremely improbable; and

(F) Compatibility with other displays and controls.

The manufacturers should provide human factors support for their decisions regarding new or unique features in a display. Evaluation pilots should verify that the data supports a conclusion that any new or unique features have no human factors traps or pitfalls, such as display perceptual or interpretive problems, for a representative pilot population.

(ii) It is desirable to have display evaluations conducted by more than one pilot, even for the certification of displays that do not incorporate significant new features. At least one member of the team should have previous experience with the display principles contained in this document. For display designs that incorporate unproven features, evaluation by a greater number of pilots should be considered. To help the FAA certification team gain assurance of a sufficiently broad exposure base, the electronic display manufacturer or installer should develop a test program with the certificating office that gathers data from FAA test pilots, company test pilots, and customer pilots who will use the display. A reasonable amount of time for the pilot to adapt to a display feature can be allowed, but long adaptation times must receive careful consideration. Any attitude display format presented for FAA approval should be sufficiently natural in its design so that no training is required for basic manual airplane control.

(iii) For those electronic display systems that have been previously approved (including display formats) and are to be installed in airplanes in which these systems have not been previously approved, a routine FAA certification should be conducted. This program should emphasize the systems' integration in the airplane and may require further detailed systems failure analysis (where "system" means the display, driving electronics, sensors and sources of information).

(iv) Simulation is an invaluable tool for display evaluation. Acceptable simulation ranges from a rudimentary bench test set up, where the display elements are viewed statically, to full flight training simulation with motion, external visual scene, and entire airplane systems representation. For minor or simple changes to previously approved displays, one of these levels of simulation may be deemed adequate for display evaluation. For evaluation of display elements that relate directly to airplane control (i.e., air data, attitude, thrust set parameters, etc.), simulation should not be relied upon entirely. The dynamics of airplane motion, coupled with the many added distractions and sensory demands made upon the pilot that are attendant to actual airplane flight, have a profound effect on the pilot's perception and usability of displays. Display designers, as well as FAA test pilots, should be aware that display formats previously approved in simulation may well (and frequently do) turn out to be unacceptable in actual flight.

(2) Hardware Installation.

(i) It is assumed that all display equipment has met the requirements set forth in SAE Document AS 8034 or guidance provided in TSO C113. Therefore, the purpose of the following guidance is to ensure compatibility of the flight-qualified equipment with the airplane environment. It is recognized that the validation of acceptable equipment installations considers the individual and combined effects of the following: temperature, altitude, electromagnetic interference, radiomagnetic interference, vibration, and other environmental influences. The installation requirements of Part 25 of the FAR are applicable to critical, essential, and nonessential systems, and should be determined on a case-by-case basis by the aircraft certification office based on-the specific circumstances.

(A) Analysis and testing shall be conducted to ensure proper operation of the display at the maximum unpressurized altitude for which the equipment is likely to be exposed.

(B) Electromagnetic interference analysis and testing shall be conducted to show:

1 That the installed system is not susceptible to interference from other airplane systems, considering both interference of signal and power systems; and

2 That the installed equipment does not affect other airplane systems.

(C) If improper operation of the display system can result from failures of the cooling function, then the cooling function must be addressed by analysis and test/demonstration.

(ii) Pilot-initiated preflight tests may be used to reduce failure exposure times associated with the safety analysis required under § 25.1309(d). However, expecting an equipment preflight test to be conducted prior to each flight may not be conservative. If the flightcrew is required to test a system prior to each flight, it should be assumed, for the safety analysis, that the flightcrew will actually accomplish this test once per day, providing the preflight test is conveniently and acceptably implemented. An autotest feature designed to preclude the need for pilot initiated preflight tests may receive credit in the safety analysis.

e. **References**.

(1) Civil Air Regulations 4b, December 31, 1953.

(2) Amendment 25-40 (42 FR 15034, March 17, 1977).

(3) Advisory Circular 20-38A, “Measurement of Cabin Interior Emergency Illumination in Transport Airplanes,” February 8. 1966.

(4) Advisory Circular 25-11, “Transport Category airplane Electronic Display Systems,” July 16, 1987.

(5) Advisory Circular 25-15, "Approval of Flight Management Systems in Transport Category Airplanes," November 20, 1989.

(6) Advisory Circular 29-2B, “Certification of Transport Category Rotorcraft,” July 30, 1997.