APPENDICES

APPENDIX 1. Glossary of Acronyms and Abbreviations

AC	Advisory Circular
ACO	Aircraft Certification Office
AIR	Aerospace Information Report (SAE)
APU	Auxiliary Power Unit
ARP	Aerospace Recommended Practice (SAE)
AS	Aerospace Standard (SAE)
BTC	Before Top Center
BTU	British Thermal Unit
CAR	Civil Aviation Regulations (predecessor of FAR)
C.G.	Center of Gravity
CRes	Corrosion Resistant
De	Engine front face inlet equivalent diameter
DER	Designated Engineering Representative
Ds	Nacelle inlet lip stagnation point equivalent diameter
Dt	Nacelle inlet throat equivalent diameter
ECO	Engine Certification Office
EEC	Engine Electronic Control
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FADEC	Full Authority Digital Engine Control

ft.	Feet (measurement)
g	Gravitational constant
HERF	High Energy Radiated Fields
hr.	Hour (time)
HSI	Hot Surface Ignition
in.	Inch (measurement)
in. Hg	Inches of Mercury
JAA	Joint Aviation Authorities
JAR	Joint Aviation Regulations
JAR-E	Joint Aviation Regulations-Engines (European)
JP	Jet Propellant (turbine) fuel
lbs.	Pounds (force or mass)
LCF	Low Cycle Fatigue
max.	Maximum
min.	Minimum
o’hg. mom.	Overhang moment
°C	Degrees Celsius
OEI	One-Engine-Inoperative
°F	Degrees Fahrenheit
P.s.i./psi	Pounds per Square Inch
r.p.m./rpm	Revolutions Per Minute
S.L.	Sea Level
SAE	Society of Automotive Engineers

SHP	Shaft Horse Power
TC	Type Certificate
TCDS	Type Certificate Data Sheet
TIA	Type Inspection Authorization

APPENDIX 2. Cross Reference for FAR Part 25 and CAR 4b

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4b.425 4b.425(a) 4b.425(b) 4b.425(c)	Fuel Tank Filler Connection	25.973	Fuel tank filler connection
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4b.427 4b.427(a) 4b.427(b) 4b.427(c)	Fuel Tank Outlet	25.977 25. 25.	Fuel tank outlet

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APPENDIX 3. Fuel System Certification Checklist

SAFETY OF AIRCRAFT FUEL SYSTEMS

FUEL SYSTEM SAFETY CHECKLIST for Aircraft Certification Engineers, which was developed in the FAA's Small Airplane Directorate. This is not a rule, but a compliance checklist. It may be used for safety meetings; Type Certificate (TC), Amended TC, and Supplemental Type Certificate (STC) compliance inspections; and initial or special type board meetings.

NOTE: Applicable FAA minimum safety rules may not require all items on checklist, but applicants may comply anyway, since most items are historically related to accidents, fires, and airworthiness directives, carefully monitored by insurance carriers and rate fixers.

A "**Yes**" check indicates a safe design, but may not be enforceable by the rules specified in the certification basis of the aircraft. A "**No**" may require a special condition or search for an applicable rule or a sales pitch/discussion or placards/AFM notes.

a. FUEL CONTAMINATION

Yes **No**

(1) Can all entrained water (no water traps) be easily drained from sumps or-low points in the fuel system through flush mounted quick drain valves at all expected ground attitudes, and does Airplane Flight Manual (AFM) require draining on preflight inspection? (See AC No. 20-125)

(2) Does the fuel filter have a bypass provision with a sediment trap and drain?

(3) When filters block and go to bypass mode, is collected dirt in filter prevented from entering engine inlet?

(4) Air cannot enter the fuel system other than running a tank dry (i.e., via filter inspection when filter located above tank, and AFM does not require fuel pump-on) or from other maintenance action, such as opening a suction system and losing prime.

(5) Are provisions made for adequate indication before bypass?

(6) Do strainers and filters have capacity for adequate fuel flow and protect engine fuel control inlets according to engine limitations for contamination?

(7) Is the fuel filter properly mounted, saftied, and accessible, and is the element easily inspected without special tools.

(8) Especially for jet fuels, are precautions in place with complete instructions for anti-icing (fuel heater and/or additives) and microorganism (fungus) contamination of critical components (valves, bladder cells, fuel controls, filters, pumps, etc.)? (See AC 20-29)

(9) Have fuel system hot weather tests been conducted for vapor lock per AC 23.961-1, especially for suction fuel systems?

(10) Do AFM instructions relate to verification that autogas specification ASTM D439 can be identified at the fixed base operator pumps, and that no alcohol can be added to the autogas? Do placards specify octane ratings and no alcohol additives?

(11) Does tank design use compatible sealers and sloshing compounds that cannot flake off and contaminate the system? Are antislosh foams and materials (explosafe, etc.) compatible with the approved fuels? Floats on fuel quantity sensors?

(12) Are refueling instructions in the AFM and/or Maintenance Manual adequate with fuel stored, handled, and dispensed per AC 150/5230-4?

(13) Does the AFM describe color codes for the approved fuels to prevent using wrong fuels?

(14) Are the tank fillers “Murphy-Proofed” to prevent use of wrong fuels (GAMA s sponsored)?

(15) Does AFM caution to check before further flight the fuel filter when warning light is on for by pass/fuel contamination?

(16) Will ethanol (gasohol) additions, up to 10% react with non-metallics in fuel system including fuel tank sealer sloshing compounds?

b. <u>VENT SYSTEMS</u>

Yes No

(1) Are aircraft fuel tanks vented to assure expected fuelflow and to prevent unwanted fuel transfer, siphoning, or flow stoppage if a single vent tube is plugged with snow, ice or insects?

(2) Do fuel vents connect the expansion spaces of inter connected tanks even when full?

(3) Are spaces adjacent to fuel cells vented and drained? If auxiliary tank is allowed in cabin area, is a sealed, vented, and drained fumeproof compartment provided?

(4) Do vents and drains discharge clear of aircraft and away from exhaust plumes or stacks and lightning exposure?

(5) Are vents and tank airspace interconnects such that no unequal fuel flow (or-pressure) occurs? Are vents sized for rapid altitude changes and pressure refueling?

(6) If fuel tank drain from vent system when aircraft is parked on a 1 %slope, fumes cannot enter cabin area or endanger the aircraft.

(7) If a vent system becomes blocked from ice, dirt, insects, etc., is a safe alternate vent source available?

(8) For fully serviced wing tanks, with air spaces at outboard end due-to dihedral, if fuel select can be set to both, are the air spaces interconnected such that the crossover vent will not act as a feed line causing unwanted fuel transfer? [See § 23.975(a)(4).]

(9) Are vent outlets positioned in airstream to prevent differential pressure or suction leading to uneven fuel flow, siphoning, vapor lock, fuel tank collapse, or engine stoppage?

(10) Has the vent system been evaluated for all approved operating conditions (acrobatics, pressure refueling, fuel jettison, etc.)?

(11) When vent lines connect engine components (carburetors, fuel injectors, etc.) to a fuel tank expansion space, a fractured vent will not pour fuel into the engine compartment fire zone on a crash landing and/or rollover.

c. HUMAN FACTORS

Yes **No**

(1) Fuel will not be inadvertently shut off from incorrect rotation (opposite from on-off position of common water faucet).

(2) Is shutoff valve for each engine easily accessible from both seats, and is visibility good while in flight?

(3) Do fuel controls operate with ease, and are detents reliable and adequate with acceptable marking?

(4) If the fuel valve can be inadvertently switched to “OFF,” thus stopping the engine, has a safety guard or positive action stop been considered?

(5) Are all fuel filters, strainers, and quick drains accessible and located to enhance required maintenance actions? Are drains located to enable crewmembers to visually confirm closure after drainage?

(6) Are all fuel system management instructions and operational limitations listed in the proper section of the FAA approved AFM? Do they comply with § 23.955(f)(2)? Are instructions and diagrams simple and clear?

(7) Must fuel be managed for structural, aerodynamic or control limitations (wing bending, stall recovery, etc.); i.e., zero fuel weight in one wing?

(8) Is fuel crossfeed design and management defined in flight manual to prevent adverse c.g. shifts with fuel burnoff and to comply with § 23.955(f)(2)?

(9) If a ground refueling sequence is required for c.g. control, are instructions adequate? Is refueling with wrong fuel “Murphy-Proofed” (like autos)?

(10) Is pilot’s mixture control or power control designed to prevent inadvertent movement to cut off?

(11) Does the fuel valve require a separate and distinct action to place in “OFF” position? Are tank selection positions such that it is impossible to pass through the “OFF” position? [ref Amdt. 23-29, § 23.995(g)(1)]

(12) Are fuel valve handles and connections “Murphy-Proofed” to prevent a hazardous assembly and installation?

(13) Are fuel valves mounted properly, outside the engine compartment, and designed to resist change from vibration or abuse?

(14) Are markings and placards permanent, clear, and complete as determined by 18b of TIA?

(15) Does the fuel selector have a "both" position. The "set to forget" position is statistically safer.

(16) Is the motion of the handle in the right sense, i.e., right for right tank, etc.

(17) Are control handles of an approved shape?

(18) If a single fuel gage can read from a different tank than selected: Are instructions "Murphy-Proofed"?

d. HARDWARE AND COMPONENTS

Yes **No**

(1) Does filler cap have reliable lock and seals, and is the risk minimized for incorrect closure?

(2) When filler cap is located in negative pressure area, no fuel can siphon nor water enter. If cap is vented, does it have a reliable service history for its check valve?

(3) Is the fuel filler cap designed for lightning strikes? (See AC 20-53A)

(4) Are fuel filler areas properly marked with fuel type and octane rating, and does all spilled fuel drain clear of aircraft?

(5) To prevent dangerous static charges, are refueling ground points identified?

(6) Are all lines and fittings TSO or aircraft quality and installed to be chafe-proof with adequate clearances, especially within control system full travel limits and engines at full torque excursions.

(7) Are fuel lines routed per AC 43.13-lA and such that possible leaks will not drip on ignition sources (wire bundles, exhaust components, etc.)?

(8) Is quality of workmanship for installed components per AC 43.13-lA, and are normal or high temperature TSO-C53a hoses used as appropriate (fire resistant or fireproof depending on certification basis)?

(9) Are flexible hoses used to account for expected differential motion or deflections, and is operational and shelf life described in appropriate maintenance data?

(10) Are fuel lines routed away from or protected from turbine wheel or high energy rotating parts $\pm$ 5^{o} cone angles in event of uncontained burst? (ref. Amdt. 23-29)

(11) Are fuel valves, pressure switches, connections, and seals highly reliable and located so that possible leakage will not be a fire hazard? (Review for compliance with § 23.863.)

(12) Are aircraft quality materials, components and hardware used through out the installation?

Have they been qualified for the expected environment (MIL-STD-810) or equivalent)? Fuel types?

(13) Are fuel lines shrouded and drained in cabin areas or compartments with ignition sources? Especially for lines at high pressure?

(14) Are fuel lines in engine compartment separated adequately from heat sources, such as exhaust to prevent excessive vapor formation or fire hazard?

(15) Can electrolytic corrosion from use of dissimilar metals become a problem? (aluminum on steel)

(16) Have components located in burnable fuel-vapor mixtures been explosion proof qualified per AIR 7304, MIL-STD-810 or MIL-E-5272C?

(17) Do drain valves have provisions to prevent accidental opening where fuel could be lost in flight?

(18) Provisions are in place to prevent fuel pumps from burning up when run dry.

e. INSTRUMENTATION

Yes **No**

(1) Is unusable fuel based on worst case sustained maneuver or expected flight condition per AC 23.959-1, and is fuel quantity gauge calibrated to reliably read 0 in expected cruise attitudes at the established unusable fuel?

(2) Has fuel quantity gauge system been calibrated with proper fuel dielectric, if capacitive, and does maintenance manual require periodic inspections/calibrations to cover fuel-critical operations at partial fuel loads?

(3) If a low fuel quantity indicator or warning is installed, does AFM describe, flight time to 0 useable fuel condition with (4).

(4) Is a calibrated dip stick provided, as a pre-flight measurement backup for electrical fuel-quantity systems when fuel critical flights are initiated with partial fuel load (FAR 135 operators who often reduce fuel for pay load tradeoff).

(5) Has AC 23.1305.1 been followed in certifying fuel flowmeter installations?

(6) Are powerplant instruments independent and isolated from each other?

(7) Are powerplant instruments reliable to perform their intended functions?

(8) Are fuel lines routed in cabin area shrouded and drained? If not, is an adequate line restrictor installed?

(9) Can fuel quantity indicator system rely on a float assembly that will not become saturated to change float level?

f. <u>CRASHWORTHINESS</u>

<u>Yes</u> <u>No</u>

(1) Is a crashworthiness evaluation report of fuel system planned which shows that precautions have been taken to minimize hazards due to a survivable crash environment?

(2) If aircraft upsets in pitch or rollover, is fuel system designed to prevent fuel spill from vents or lines which could cause a fire hazard?

(3) Is system crashworthy with adequate slack in lines to permit large engine shifts in survivable accidents (to 16 g's) without severing lines or connections?

(4) Are self-sealing valves or frangible fittings used where breakaways near ignition sources are likely in survivable crash?

(5) In the event of a wheels-up landing, can fuel tanks, shutoff valve ,drain valves, etc., fracture, and are adjacent ignition sources, such as electrical components explosion proof or hermetically sealed? Are flexible and stretchable hoses used? (AC 25.994-XX)

(6) Are fuel system components and engine mounts strong enough to be nonhazardous in a survivable crash of (8-16 g's) even though current rules call for 3-4.5 g's down load?

(7) For hot air balloons, are high-pressure propane fittings and lines protected against impact loads from crew or passengers in hard landings?

(8) Are gascolators and other components carrying fuel flow supported by structure rather than cantilevered off AN/MS fittings?

(9) Are fuel tanks located behind spars or structure to provide for crash and ignition protection?

g. DESIGN DATA

Yes No

(1) Are materials and process specifications compatible, and are detail and installation drawings complete?

(2) Are approved fuels and additives compatible with each other and with non-metallic materials used in fuel system components?

(3) Are top vendor drawings, acceptance specs and instructions complete and adequate?

(4) Do parts fit without being forced or subjected to a permanent set creating an installation stress?

(5) If fuel quantity is increased (main or aux tanks), has oil quantity been checked per AC 23.1011-1?

(6) Are continued airworthiness instructions and inspections adequately covered by service instructions, manuals, AFM or placards?

(7) Is torque for fuel line fittings, etc. adequate on drawings and in field instructions to prevent overtorque cracks and/or fuel seepage?

(8) If fuel jettison system is installed, are established precautions in place and tested per FAR 23.1001?

(9) Is vent line size large enough to maintain positive pressure on the fuel in the event of minor leakage on the upper wing surface (negative pressure on leaking filler caps, etc.)?

h. FIRE HAZARDS

Yes No

(1) Is there at least a 50^{o} F margin between fuel auto ignition temperature and the max temperature possible of submerged pumps, quantity sensors, etc., per AC 25.981-IA? Is overtemp protection provided?

(2) Are energy levels of internally mounted electrical accessories in event of shorts, etc. intrinsically safe to prevent fire/explosion hazards (no sparks)?

(3) Does fuel system have provisions to prevent ignition of fuel vapor in event of lightning strikes, including swept strokes per AC 20.53A? Note that 0.080 aluminum skin thickness is no longer believed to be adequate to protect against direct strike penetration in zone 1 areas fuel storage, such as tip tanks.

(4) Are all flammable fluid system components located in the engine compartment firezone at least fire-resistant (2000^{o} F for 5 minutes)?

(5) Are probable leak sources located such that no hazard exists because adequate drains exist, or fuel cannot run or drip on ignition sources; i.e., tip lights, turbo chargers, turbine engine cases, electrical connectors, exhaust areas, etc.? (FAR 23.863)

(6) Are filler areas and electrical components adequately bonded or grounded, including lines in tanks?

(7) Is protection provided for static charges and arcing?

Note: If distance between probes and skins is less than 3/8”, insulators are needed.

(8) If overfill of tanks is possible during fuel transfer, are safeguards and instructions in place to prevent fuel loss through vents?

(9) For single reciprocating engine airplanes with more than one tank, can full fuel pressure and power be regained in 10 seconds or less after switching to a full tank after engine stoppage due to fuel depletion? (Ref. 23.955(e))

Note: The rule says “full tank,” however, demonstration should include tanks with a small amount of “useable” fuel, unless this is determined to not be critical.

(10) Is the flow rate, pressure, and line size adequate to meet engine installation manual requirements for all approved maneuvers and flight conditions?

i. FUEL TANKS

Yes **No**

(1) Do cells and tanks have adequate sump and expansion spaces per the applicable rules?

(2) Are the tanks completely drainable at worst case ground attitudes with sump quick drains, which can be positively/visually checked for post drainage closure?

(3) If a fuel pump is needed to assist the engine main pump in any approved flight condition, is another backup pump supplied to automatically prevent an engine stoppage? (required for turbines and all helicopter engines)

(4) Is a caution supplied if a pump malfunctions?

(5) Have fuel tanks been structurally analyzed and tested per the rules for both static pressures and per vibratory surveys representing worst case fatigue steady and oscillatory loads expected in flight?

(6) Are bladders and wet tank sealants compatible with the approved fuels? Gasoline fuels containing alcohol additives?

(7) Bladders will not normally collapse or tear due to rapid altitude changes, hard landing, blocked vents, etc. nor deflect from inadequate support or negative pressures that can lead to erroneous fuel quantity sensing or loss of fuel.

(8) Are bladders and their supports structurally applicable to prevent collapse or fracture? TSO or better?

(9) Are the fuel tanks separated from engine(s) with a firewall and installed per applicable rule (FAR XX.967)?

(10) Are fuel outlet ports above the sump and equipped with proper strainers?

(11) Are fuel outlet ports above the sump?

(12) For pressure refueling, have pilot valves and hydraulic surge forces been analyzed and tested for worst case conditions? Are vents sized to prevent dangerous pressure buildup?

(13) Are bladders and tanks accessible for inspection of cracks, tears, fungus, and repairs?

(14) Have slosh and vibration tests been successful on tanks of over 10 gal. capacity (14”x l4” x l4”), or unsupported flat areas of over 15”x l5” per FAR XX.965 or MIL-T-6396?

(15) Has analysis been submitted to determine whether slosh testing for bladder tanks is appropriate?

(16) Are tank baffles structurally reliable and functional when used to reduce unusable fuel?

(17) If turbine powered, is all fuel automatically supplied to the engine without pilot inputs?

<u>Note</u>: Beware of STC'd turboprop conversions where existing fuel system no longer complies with 23.955(f)(2).

j. <u>FUEL FLOW</u>

<u>Yes</u> **<u>No</u>**

(1) Has fuel flow, under critical flight conditions [i.e., inverted flight, if applicable, negative g's, flow interruption (bends) near heat sources (exhaust stacks), altitude, hot day, sustained maneuvers, maximum rate of climb, etc.] been tested to comply with FAR XX.955?

(2) For multi engines, does each engine have an independent fuel system per FAR XX.953 and a good pilot-controlled crossfeed system that has been functionally tested (F&R)?

(3) For aircraft with carburetor bowls, has differential pressure between tank and carburetor bowl been considered per AC 23.955-1?

(4) Does fuel flowmeter have a bypass in event of rotor blockage per AC 23.1305-1?

(5) If overfill of tanks is possible during fuel transfer, are safeguards and instructions in place to prevent fuel loss through vents?

(6) For single reciprocating engine airplanes with more than one tank, can full fuel pressure and power be regained in 10 seconds or less after switching to a full tank after engine stoppage due to fuel depletion? (Ref. 23.955(e))

<u>Note:</u> The rule says "full tank;" however, demonstration should include tanks with a small amount of useable fuel, unless this is determined to not be critical.

(7) Is the flow rate and line size adequate to meet engine installation manual requirements for all approved maneuvers and flight conditions?

(8) Can fuel flow be interrupted by fuel pump cavitation at any approved operating ambient?

(9) Have functional articulated test rigs validated the fuel system motions and accelerations by duplicating aircraft installations, including supports?

(10) Have TIA flight tests verified the fuel system for those parameters that can't be simulated, i.e., climb to altitude?

k. <u>Design Safety Assessment</u>

<u>Yes</u> <u>No</u>

(1) Has applicant been given guidelines for safety evaluations such as the Appendix 1 Guide from AC 25.1309-lA, "System Design Analysis," and Appendix 2, "The FAA Failsafe Design Concept"?

1. <u>COMPLIANCE CHECKLIST</u>

<u>Yes</u> <u>No</u>

(1) To follow up the above safety items, has compliance with the appropriate fuel system certification basis rules (CAR or FAR) been determined, including documentation and approval of all "equivalent safety" items and special conditions?

It is recommended that the applicant submit a compliance certification plan or checklist to verify that all rules and special conditions have been met with drawings, specs, analysis and test reports, inspections, etc. This burden should be placed on the applicant and approved by the ACO prior to TIA and final type board meeting.

APPENDIX 4. Index of Guidance Material and References

Document	Title	Related FAR
Advisory Circular (AC) 20-18A-	Qualification Testing of Turbojet	25.934
AC 20-24B-	Qualification of Fuels, Lubricants, and Additives	
AC 20-26	“Turbine and Compressor Rotors Type Certification Substantiation	33.27
AC 20-29B	Use of Aircraft Fuel Anti-icing Additives dated	25.951
AC 20-73	Aircraft Ice Protection	33.68
AC 20-116-	Marking Aircraft Fuel Filler Openings with Color Coded Decals	25.1557
AC 20-119-	Fuel Drain Valves	
AC 20-124 -	Water Ingestion Testing for Turbine Powered Airplanes.	
AC 20-125	Water in Aviation Fuels, dated 12/10/85.	
AC 20-128	Design Considerations for Minimizing Hazards Caused by Uncontained Turbine Engine and Auxiliary Power Unit Rotor Failure	
AC 20-135	Powerplant Installation and Propulsion System Component Fire	33.68
AC 21-lB	“Production Certificates,” 5/10/76	33.7
AC 23-10	Auxiliary Fuel System Installations Standards, and Criteria	
AC 25-8	Auxiliary Fuel System Installations	
AC 25-13	Reduced and Derated Takeoff Thrust (Power) Procedures, dated May 4, 1988.	25.1521
AC 25-571	Damage Tolerance and Fatigue Evaluation of Structure	
FAA Engineering Report No. 3A	“Standard Fire Test Apparatus and Powerplant Procedure (for Flexible Hose	33.17
FAA Order NE CD 8110.lA	“Evaluation and Approval Responsibilities for Manufacturer’s Material and/or Process Specifications Specified in the Type Design,” 5/28/86	21.33

APPENDIX 5. Powerplant Installation Special Topics

As mentioned within the main body of this Advisory Circular, there are certain issues, that are interdisciplinary and extend throughout Part 25, Subpart E sections. The intent of this Appendix is to provide additional guidance on the most significant of them. These include:

(1) HIRF, Lightning, EMI, Hot Short, and Electrostatic Charge Protection:

Bonding the powerplant installation components can help protect them during exposures to electromagnetic fields, lightning strikes, electrical power shorts, or generators of electrostatic charge. However, selecting the bonding methods and characteristics that best protect all components is a design decision that must take into account:

- the specific type design features and requirements,
- anticipated exposures to the sources of electrical differentials,
- necessary instructions for continued airworthiness, etc.

In some cases, higher bonding resistances/impedances may be advantageous to reduce or redirect currents while, in other cases, lower bonding resistances/impedances are needed to keep the voltage down or distribute currents. Also, the types of bonding that are effective for low frequency or low power threats may not be effective for high frequency or high power threats and visa versa.

Typical bonding resistances are on the order of 1 ohm. However, effective electrostatic “bleed-off” can occur through a bonding resistance of 1 mega-ohm, while low voltage electronics may require bonding better than 100 milli-ohms to protect them from the effects of a lightning strike.

Consequently, given the proposed bonding scheme, the effects of foreseeable electrical differentials between adjacent components should be assessed and found to not create an unsafe condition. This can be done by

- similarity to previous designs;
- through a dedicated assessment for § 25.901(b)(4);
- as part of related compliance assessments, such as those performed to demonstrate compliance with § 25.581, § 25.901(c), § 25.954, § 25.1316, etc.; or
- any combination thereof.

(2) Electronic Engine Controls Air Data Fault Tolerance

Electronic Engine Control (EEC) equipped engines generally use selected air data (e.g., TAT, Altitude, Mach, etc.) to schedule fuel, stability augmentation systems, engine and accessory cooling, etc. These systems also often use this data to calculate ratings and actual thrust levels. In many installations, these EEC-selected air data values are what are used for cockpit displays and operations. Therefore, any substantial error in or loss of this data can effect the selection, indication, and control of thrust, as well as powerplant operating characteristic and material integrity. To assure safe reliable operation, the design must suitably accommodate anticipated air data failures and malfunctions.

On any given airplane, what constitutes "suitable accommodation" under Part 25 of the regulations will depend on the intended operation, the type design details, and the rate at which causal failures are anticipated to occur. Part 33 of the regulations attempts to isolate the engine from any significant adverse effects of aircraft air data failures by requiring that:

> *". . . any failure of aircraft- supplied power or data will not result in an unacceptable change in power or thrust, or prevent continued safe operation of the engine."*

However, we are still left to define what an "unacceptable change in power or thrust" is, and what will "prevent continued safe operation of the engine." Therefore, establishing a single inclusive set of acceptance criteria for the engine level effects of air data is still problematic. Nevertheless, we can make some general observations that can serve as guidance.

First of all, there are certain failure conditions which we consider will always "prevent continued safe operation of the engine." These include:

- Loss of engine structural integrity (e.g., case rupture/burn through, uncontained rotor or blade failure, uncontained fire, engine mount failure, etc.);
- Asymmetric thrust conditions which lead to loss of airplane controllability (e.g., uncommanded reverser deployment or propeller reverse pitch);
- Engine fire;
- Exceeding certified ratings or limits;
- Loss of thrust capability to less than 50% of takeoff rating for any notable duration;
- Loss of any safeguards required by the regulations (e.g., provisions for safe shut down, engine overspeed, fire protection capability, etc.);
- Undetected thrust loss greater than the average to minimum engine correction (typically 2-3%); and

- Loss of any powerplant instruments required by the regulations (e.g., instruments required by § 25.1305).

Furthermore, some scenarios of concern regarding “unacceptable changes in power or thrust” can be highlighted. These include:

- Loss of thrust capability to less than 25%/33% of takeoff rating for any notable duration on 4/3 engine airplanes respectively;
- Multiple engine symmetric thrust loss (see figure 1); and
- Uncommanded changes in the magnitude or direction of thrust which lead to increased pilot workload and/or error (e.g., uncommanded thrust change during critical phases of flight such as during takeoff rotation or landing flare; unpredictable or distracting thrust oscillations; etc.).

When determining potential failure conditions, care must be taken to assure that all direct and indirect effects are taken into account. Some related failures and effects that have been overlooked in the past include:

- the effect of case or oil cooling failures on internal engine components (e.g., stator hooks or bearings overheating, bearing fire, etc.);
- the effects of vane and bleed scheduling on stability margins, overspeed, or vane flutter;
- the effects of fuel cooled oil cooler scheduling on fuel icing/overtemp;
- limit exceedance due to increased accel/steady state fuel flow (e.g., increase in accel schedule, delay in “roll-off” due to increased target rating, etc.);
- common mode failures (e.g., failures affecting both “target” and “actual” thrust indications on multiple engines, failures that effect engine-to-engine isolation, environmental threats common to all engines, etc.);
- the effects of failures on the probability of subsequent failures (e.g., the effect of a wire short-to-shield failure on the continued lightning qualification of attached circuits, the effect of losing one load path on the likelihood of the redundant path failing, the effect of a fuel pump bushing failure on the explosion proof-ness of the pump, etc.; and
- the effects of common mode software/hardware design errors.

NOTE: EEC’s typically use local engine sensors to validate the air data supplied from the aircraft within a tolerance that assures continued safe operation following aircraft air data failures. However, if an applicant for a transport airplane type certificate proposes an architecture that relies strictly on aircraft air data, Part 25 would require that:

- Engine operation on hazardously misleading air data is extremely improbable and shall not result from a single failure or malfunction; and
- Either-
    - the loss of airplane air data is extremely improbable and shall not result from a single failure or malfunction; or
    - engine operation in the most adverse operating mode, resulting from loss of airplane air data, can be certified under Parts 25 and 33.

FIGURE 1 - HAZARDS FROM SYMMETRIC THRUST LOSS

SYMMETRIC THRUST LOSS (based on typical margins)	FLIGHT PHASE	DETECTED	POTENTIAL HAZARDS[1]
0- ≈2%	ANY	YES OR NO	NO SIGNIFICANT HAZARDS (covered by typical avg.-to-min. engine performance margins)
≈2 - ≈ 55%(TWINS) ≈2 - ≈ 38%(TRI'S) ≈2 - ≈ 30%(QUADS)	POWER SET TO V1	YES[2]	T/O ABORT/ OVER-RUN[3] (MINOR TO HAZARDOUS DEPENDING ON SCENARIO)
		NO	UNABLE TO CLEAR OBSTACLE IN EITHER ALL ENGINE OR ENGINE-OUT FLIGHT PATH (MINOR TO CATASTROPHIC DEPENDING ON SCENARIO)[4]
	> V1	YES	AIR TURN BACK/ UNABLE TO CLEAR OBSTACLE IN ENGINE-OUT FLIGHT PATH (MINOR TO CATASTROPHIC DEPENDING ON SCENARIO)
		NO	UNABLE TO CLEAR OBSTACLE IN EITHER ALL ENGINE OR ENGINE-OUT FLIGHT PATH (MINOR TO CATASTROPHIC DEPENDING ON SCENARIO)
> ≈55%(TWINS) > ≈38%(TRI'S) > ≈30%(QUAD'S)	POWER SET TO V1	YES	T/O ABORT/ OVER-RUN (MINOR TO HAZARDOUS DEPENDING ON SCENARIO)
		NO	OVER-RUN (HAZARDOUS TO CATASTROPHIC DEPENDING ON SCENARIO)
	>V1	YES OR NO	UNABLE TO MAINTAIN ALTITUDE OR CLIMB (ASSUMED TO BE CATASTROPHIC)

(See Footnotes on following page.)

[11] Detection below approximately 15% thrust loss requires annunciation. Above 15% thrust loss, detection may occur due to operational effects. However the Air Florida Accident indicates that this cannot be relied upon too heavily.

[1]The worst case scenario is where the thrust loss is such that it occurs throughout the takeoff roll but is only detected near V1 and the aircraft is too far down the runway to avoid a high speed over-run.

[1]The two scenarios which produce the greatest risk are: 1)operating for an extended period of time with a small symmetric thrust loss (<15%) followed by an engine failure; and 2) a single takeoff exposure to a large reduction in the all engines operating flight path.

(3) <u>Engine -Airplane Regulatory Interface</u>:

The following guidance comes from an FAA inter-Directorate memorandum, dated November 13, 1996. It describes application of Part 25 airplane certification requirements to engine build units (EBU) that have received a Part 33 Engine Type Certificate:

The transport airplane manufacturers continue to contract with the engine manufactures to provide complete EBU's that include increasing amounts of the attachment structure and components surrounding the engine. In some cases, this has caused confusion as to what parts of the EBU are certified under Part 33 and what parts must be certified under Part 25.

The engine must be approved under the provisions of Part 33 in order to be eligible for consideration for installation on a transport category airplane. However, the Part 33 approval does not, by itself, constitute FAA approval of the engine installation on a transport airplane. The engine installation must be evaluated to ensure compliance with all the applicable Part 25 regulations, and to ensure that the level of safety intended by all the Part 25 provisions is maintained.

In many cases, the engine performs functions beyond the production of forward thrust or power and the installation must be evaluated under the Part 25 regulations governing those functions. For example, in practically all modern wing mounted engine installations, the engine provides the effective wing mass balance that is critical for aeroelastic stability. The integrity and rigidity of the engine mounting must be evaluated under Part 25 rules for damage tolerance and aeroelastic stability.

It is difficult to strictly partition the EBU parts to which Part 33 or Part 25 airworthiness standards apply, since both airworthiness regulations may apply to certain parts in many cases. However, as a general rule of thumb, all structure and components down to but not including the engine case are airframe components and must be certified to all the applicable Part 25 requirements regardless of who builds and installs them. This includes the nacelle strut, nacelle, cowls, engine mounts and attachments to the engine case, thrust reversers, tail pipe assemblies and other engine accessories. Notwithstanding this general rule, the engine attachment points on the engine case must be evaluated for their fail-safe and damage tolerance capability so that the provisions of § 25.571 and § 25.629 are met. Furthermore, certain specific failure modes of internal engine structure supporting the rotating machinery must be evaluated as described in § 25.629(d)(5).

In situations where the engine manufacturer provides additional structure and components beyond the engine case, the engine manufacturer is "effectively" performing in the capacity of a vendor or subcontractor to the airframe manufacturer, for such parts historically are not included as part of the engine type design. However, the airplane type certificate holder is ultimately responsible for all of these items. In some cases the engine manufacturers have included all the additional structure and components under a single top drawing and submitted the whole package for approval under the provisions of Part 33. There is nothing fundamentally wrong with this approach as long as all the additional items can meet the applicable Part 33 requirements. However, this does not exempt the airframe manufacturer from demonstrating compliance to the applicable Part 25 requirements for all the additional hardware included as part of the approved engine type design.

Private contractual agreements between the airframe and engine manufacturers have no bearing on applicability of the regulations, and cannot be used as a basis to effectively establish exemptions to the applicable Part 25 requirements.

(4) <u>Engine Powerloss / Cause Of Accidents</u>

The following extract comes from Section 3, paragraphs (a) through (d); and Section 4, paragraphs (a) through (d); of Advisory Circular (AC) 20-105A, "Reciprocating Engine Power-Loss Accident Prevention and Trend Monitoring," dated November 20, 1980. It provides guidance on prevention of accidents caused by engine power-loss:

BACKGROUND. A review of Federal Aviation Administration's General Aviation Accidents Factual Reports for the years 1977, 1978, and 1979, that list engine failure as a cause, showed a total of 2,608 accidents. Those accidents resulted in 473 fatalities and 1,396 injured persons. For several years, "power loss" has been the greatest single type of general aviation accident and during this review period accounted for 19.9 percent of all accidents. Analysis shows that accidents have resulted from:

a. Personnel Errors.
- Operations which exceeded the limitations of the powerplant.
- Failure of maintenance personnel to utilize acceptable maintenance procedures.

b. Failure of Engine, Engine Part, or System Component.
- Engines were operated beyond the overhaul time recommended by the manufacturer.
- There was noncompliance with airworthiness requirements regarding inspection, overhaul, repair, preservation, and/or replacement of parts.
- Design changes and alterations were completed without Engineering evaluation and approval.
- Parts failed due to operation outside operating limitations; i.e., overtemperature, overboost, low oil pressure, etc.

c. Fuel Starvation and Exhaustion.
- Fuel starvation [fuel on board the aircraft but not supplied to the engine(s)] and fuel exhaustion (no fuel available on board the aircraft) resulted in 47 percent of the engine power-loss accidents. This usually results from improper preflight planning or improper fuel management procedures.
- Contamination continues to be a notable factor in fuel starvation accidents. During this review period of the 1,230 engine power-loss accidents related to fuel system, fuel contamination was a cause in 381 or 31 percent of those accidents. Advisory Circular 20-34C, Aircraft Fuel Control, contains valuable information that alerts the aviation community to the possibility of inadvertent mixing or contamination of turbine and piston fuel and provides recommended servicing procedures.

d. Fuel System Design.
- Accidents have resulted because pilots and maintenance personnel failed to become familiar with the different fuel systems and operating procedures.
- Design changes, accomplished without proper evaluation, the lack of standardization of controls configuration among aircraft, plus the peculiarities in aircraft fuel system designs, have contributed to power-loss accidents.

RECOMMENDATIONS. The following are recommended operating practices that could help reduce engine power-loss accidents:

a. General. Engines

- Know the limitations of the aircraft and aircraft powerplant. Avoid operating in excess of those limitations. Be sure all engine(-s) are within acceptable operating parameters prior to takeoff. Keep proficient in all engine and systems operating, procedures, including emergency procedures. The aircraft flight manual or the rotorcraft flight manual contain the normal and emergency procedures, and proper power assurance check procedures. Use the checklist during normal and emergency operations.

- Follow the manufacturer's operating instructions. Have a qualified person investigate all abnormal engine operating conditions (oil and fuel consumption, low power, vibration, engine instrument readings, etc).

- Positively utilize a powerplant and propeller maintenance program that gives full consideration to the Federal Aviation Regulations and manufacturer's recommendations.

- Keep abreast of technical information related to the aircraft, oil, parts, airworthiness directives, manufacturer's technical publications, etc.

- Know proper procedures when engine inlet or carburetor icing conditions are encountered.

- Follow engine manufacturer's inspection procedures following propeller strike or sudden engine stoppage.

- Operate engine controls smoothly, as abrupt movements can result in engine malfunction and power loss.

- Avoid overspeed, overboost, and overheat.

- Do not fly an aircraft with known engine discrepancies.

b. Fuel Management

- In relation to airplane performance, the fuel quantity on board the aircraft is only "time in your tanks." Management of that time should rank high on the list of a pilot's priorities. Be fully familiar with the aircraft fuel system and fuel management procedures.

- Make adequate preflight preparations to ensure that sufficient clean fuel is on board the aircraft for the time to destination, plus an adequate reserve, predicated an airplane performance.

- Know and understand the positions of the aircraft fuel selector valves. Markings should be legible, and valves should be easy and smooth to operate and with positive identification.

- Be familiar with the sequence for selecting fuel tanks of the aircraft. The use of fuel from tank(s) other than as recommended (especially during takeoff and landing) can result in eventual fuel starvation. Many aircraft return unused fuel from the carburetor to a tank. If the tank is full, the fuel goes overboard through the vent and is lost, thus reducing range.

- A pilot should know the total USABLE fuel on board the aircraft before flying. The UNUSABLE fuel should not be considered when planning a flight.

- Make a visual inspection to assure that the fuel tanks are full. If you are in the habit of flying with partial fuel loads, use positive means to know the quantity of fuel on board the aircraft before flight. Complete trust in only the gage has often resulted in fuel depletion short of destination and accidents.

- Make a thorough fuel drain check of all sumps before flight. Consult the owner's manual for proper procedures.

- During preflight inspection, determine that all tank vent openings are clear of obstructions.

- Check fuel flow from each tank to engine(s) prior to taxi. Remember to allow sufficient time for this check as the carburetor and lines hold fuel that would have to be used before you would know if there was no fuel flow from a tank.

- Determine that hand primeters are closed and locked in the detent after use.

- Be fully familiar with fuel boost pump operating procedures.

- Before switching tanks, check the fuel quantity in the tank to be selected and after moving the selector check the fuel selector position to be sure proper tank is selected.

- After switching tanks, monitor the fuel pressure until you are sure there is fuel flow from the tank.

c. Maintenance.

- Maintenance should include inspection of fuel cells and tanks for discrepancies such as collapse, contamination, vent obstruction, internal damage, security, leaks, gauge accuracy, and general condition.

- Periodically make a visual check of the fuel filter for condition and/or contamination.

- Check operation and security of fuel selector and system control handles and/or knobs.

- During maintenance, a detailed inspection should be made of fuel quantity indicating system wiring, components, and calibration.

- Design changes and alterations to aircraft engines should be done with approved data.

- Replacement of engine parts should be completed following manufacturer's instructions.

- Maintenance should be accomplished in accordance with the manufacturer's recommendations.

- Have a qualified maintenance person dress out propeller blade nicks, dents, scratches, etc., as necessary, to prevent fatigue cracks that could cause propeller blade failure resulting in power-loss. The dressing of propeller blades should be done following the propeller manufacturer's recommended procedures. Excessive dressing could alter the airfoil shape of the propeller blades to the point where propeller efficiency is lost, causing insufficient propeller thrust. In the case of twin engine aircraft, that loss of thrust could prevent the aircraft from maintaining flight with one engine inoperative.