Applicability of ATSRAC to Engine Installations

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Overview

- Engine Certification
- Engine Installation Certification
- Existing Maintenance Practices
- Safety Experience

Engine Certification

- Overall Engine Certification
  - Key Certification Requirements Relative to Fire
- Overview of FADECs and engine wiring
- FADEC Certification
- Externals/Accessories Certification

Overall Engine Certification

- Rigorous, severe testing required to demonstrate design and construction of engine & its systems during normal and extreme conditions
  - Endurance
  - Over-temperature
  - Stability/Operability
  - Bird and foreign object ingestions
  - Rain/hail
  - Induction system icing
  - Containment (blade-out)

Key Engine Certification Requirements

§ **33.75 Safety analysis -** It must be shown by analysis that any probable malfunction or any probable single or multiple failure, or any probable improper operation of the engine will not cause the engine to --

(a) Catch fire;

(b) Burst (release hazardous fragments through the engine case);

(c) Generate loads greater than those ultimate loads specified in § 33.23(a); or

(d) Lose the capability of being shut down.

Key Engine Certification Requirements

- §33.17 Fire Prevention
  - All lines, fittings, & other components containing or conveying flammable fluids must be *fire resistant*
  - Components must be shielded or located to guard against ignition of leaking flammable fluid
  - Flammable fluid tanks & supports must be *fireproof* or enclosed by fireproof shield
  - Unwanted accumulation of flammable fluid and vapor must be prevented by draining & venting

Fire resistant – withstand 2000 deg flame for 5 minutes
Fireproof – withstand 2000 deg flame for 15 minutes

Other Relevant Engine Certification Requirements

- §33.19 Durability – Minimize development of unsafe condition between overhaul periods
- §33.21 Engine cooling – Engine design must provide necessary cooling under conditions airplane expected to operate
- §33.25 Accessory attachments –
  - Proper operations with accessory drives & mounting attachments loaded
  - Proper sealing
  - Allow for examination, adjustment or removal of each accessory required for engine operation
- §33.63 Vibration – operation can not induce excessive stress in any engine part or airplane due to vibration

Other Relevant Engine Certification Requirements

- §33.71 Lubrication System –
  - Shutoff valve at outlet unless external portion of system (including supports) is fireproof
  - No leakage at max temperature and over-pressured
  - Leaked or spilled oil may not accumulate between the oil tank and the remainder of the engine
  - Drains must allow safe drainage of the system
- §33.74 Continued Rotation – following any shutdown in flight for any reason, any continued rotation must not result in unsafe condition (i.e., fire, burst, excessive loads)

Other Relevant Engine Certification Requirements

- §33.76 Bird ingestion –
  - 20 minute run-on demonstrations with thrust and operability (small/medium birds)
  - large-bird ingestion safe shutdown demonstration (no fire, burst, etc)
- §33.94 Blade containment & rotor imbalance tests –
  - Demonstrate no fire or excessive loads following release of full fan blade at maximum RPM

Overview of FADECS and Engine Wiring

- FADEC – **F**ull **A**uthority **D**igital **E**ngine **C**ontrol
- The FADEC is an engine mounted component that provides starting, steady state and transient control of the gas turbine engine, engine shutdown, control for some aircraft functions (ex. – thrust reverser) and digital and analog communications to and from the cockpit.
- The signal types typical in the engine wiring are:
  - Low current (ex. thermocouples, resistance temperature devices, computer discretes and data busses) – less than 50mA
  - Medium level (ex. torque motor and solenoid) – 50mA to 0.5A
  - High level (ex. FADEC power, inlet probe heater and ignition exciter) – less than 10A
- The FADEC software provides extensive fault detection, annunciation and accommodation capabilities that ensure that faults are automatically accommodated and communicated to the flight and maintenance crews

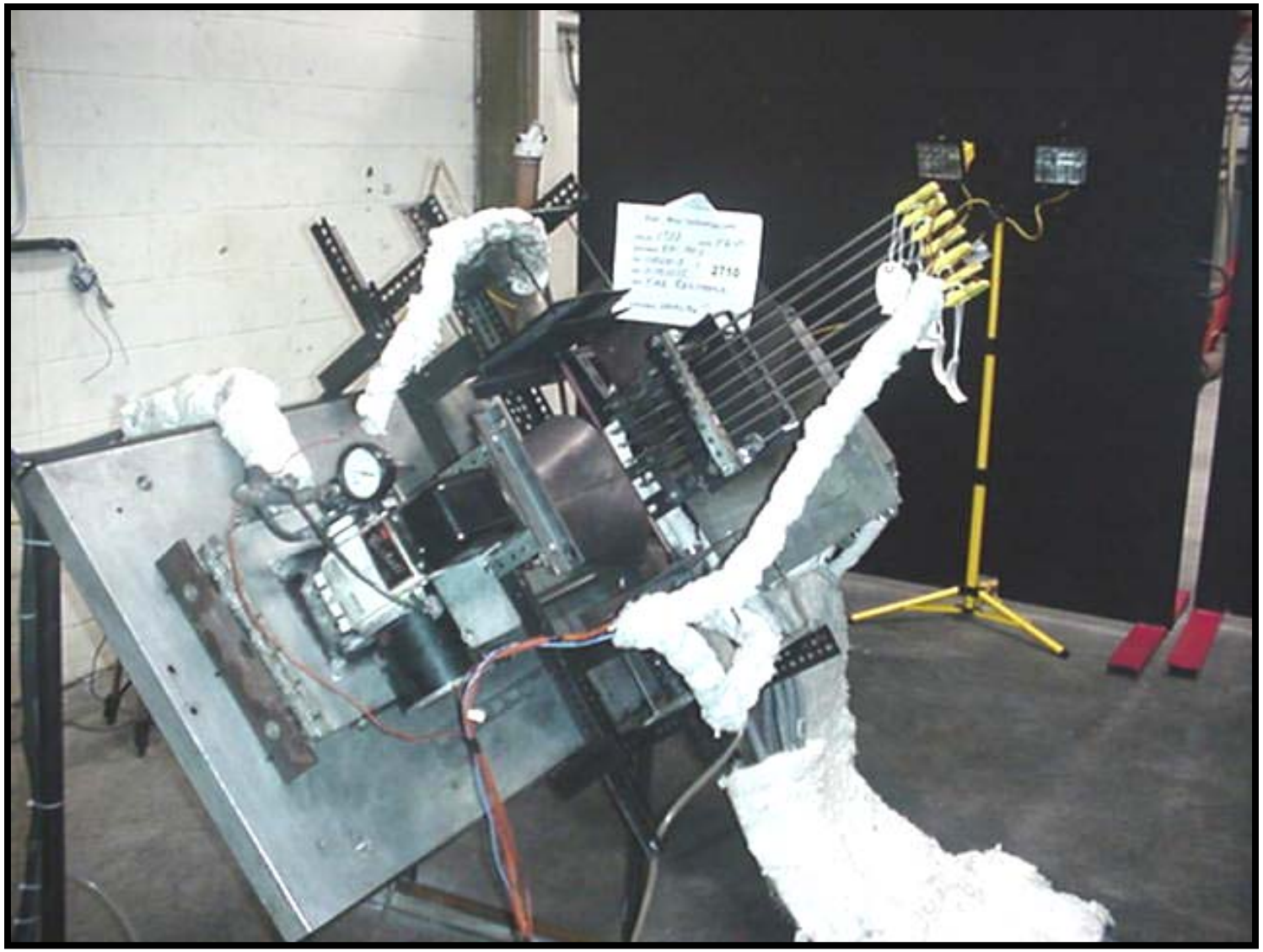
FADEC Certification

- The FADEC is substantiated to the standard FAA environmental considerations (e.g., “36-point checklist”)
- Environmental certification testing typically includes:
  - Thermal Cycling and Temperature/Altitude
  - Overheat and Fire Resistance
  - Vibration and Impact
  - Electromagnetic Compatibility and Lightning
  - Explosion Proofness, Fluid Susceptibility, Water, Humidity, Icing, and Sand & Dust
  - Engine level endurance tests
- The FADEC software is RTCA DO-178B Level A certified

Externals/Accessories Certification

- All Externals/Accessories are substantiated to the standard FAA 36-item environmental considerations
- Certification testing typically includes:
  - Thermal Cycling
  - Fire Resistance or Proof
  - Vibration and Impact
  - Electromagnetic Compatibility and Lightning – system level test
  - Engine level endurance tests

Typical FADEC Fire Test Setup



Fire Testing of Engine Externals

Engine Installation Certification

- Philosophy – Isolation, Separation & Redundancy
- Nacelle operating environment
- Key engine installation requirements

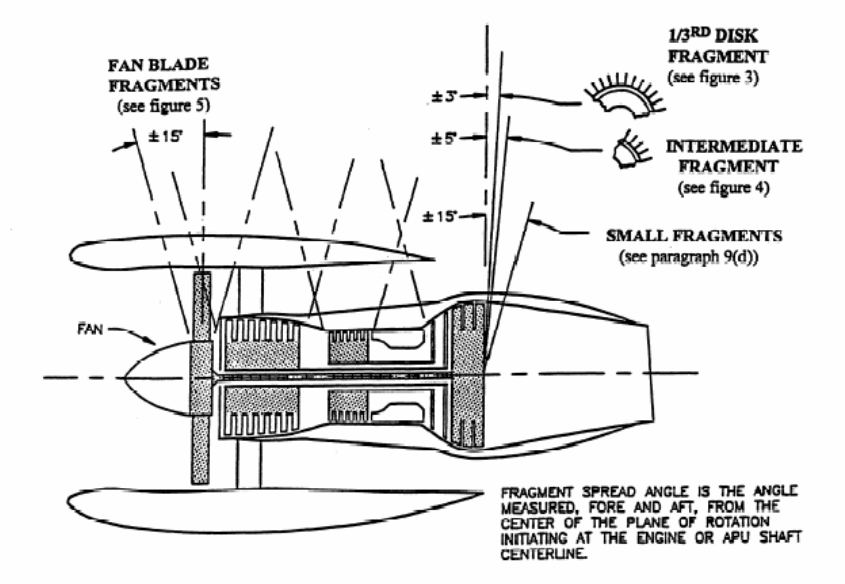
Philosophy

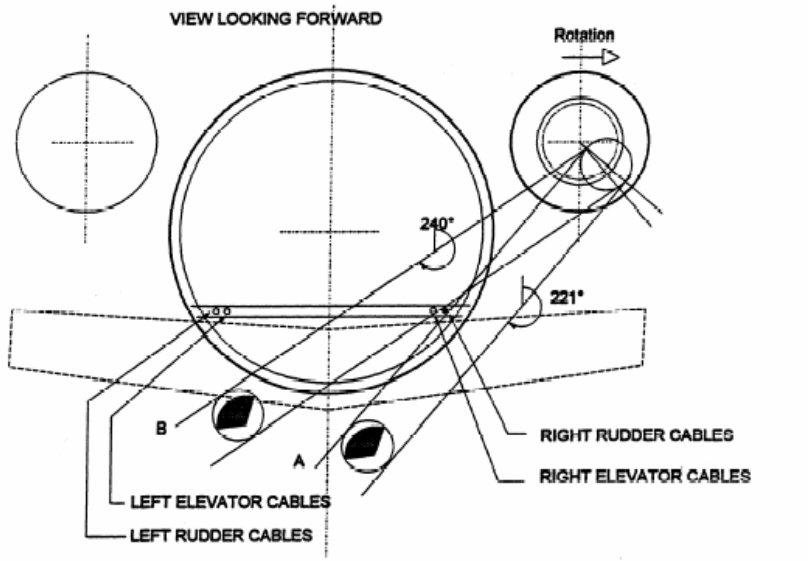
- “Belt & suspenders” approach, or “plan for the best – account for the worst”
  - Engines designed/certified to be robust – e.g., do not allow engine to burst or catch fire
  - But, design installation to mitigate effects of engine malfunctions, including burst or fires
- Engine installation drivers:
  - Isolation
  - Separation
  - Redundancy
- These are evident in the robust set of airplane certification requirements for engine installation
  - Many relevant requirements are outlined in this briefing

Philosophy of Isolation, Separation and Redundancy for Engine Installation

- Examples in practice –
  - Airplanes safe to fly with engine-out (and its associated services)
  - FADECs have redundant channels, each fully capable of controlling engine
    - FADEC fault accommodation & enunciation logic
  - Continued engine operation (until crew shuts down) if separated from throttle input or airplane power sources
  - Engines physically separated
  - Redundant fuel cut-off
  - Redundant fire detection & suppression in each nacelle
  - Engine fire detection system accommodation & enunciation logic
  - Fireproof engine fire walls
  - Fire resistant nacelle & strut sidewalls

Uncontained Engine Hazards - §25.903(d)(1)





Effect on design of critical aircraft systems:

- *Separation and redundancy*
- *Isolation away from the engine*

Electrical Isolation from Airplane

- Engine controls designed to continue safe engine operation if aircraft input (e.g., throttle position, air data, etc) or aircraft power busses lost
  - Detailed fault accommodation logic
- Airplane wiring:
  - Power feeder cables from engine protected by generator control system & load shedding
  - Low voltage wiring from engine protected by circuit breakers

Nacelle Operating Environment

- Extremely demanding high temperature environment
- Environment defined by airframer – communicated to engine company
  - Maximum temperatures vs material capability (e.g., nacelle composite structures) interconnected in defining environment
- Engine development testing measures actual environmental temperature based on nacelle ventilation and heat convection from engine cases
- Component certification testing per FAA standard environmental checklist
  - Includes endurance testing at max temperature (max temp becomes a limit)
- Aircraft certification testing includes flights to verify components are below certified limits

Key Installation Requirements – General Fire Protection

- §25.863 Flammable Fluid Fire Protection –
  - Each area where leakage could occur must be identified & defined
  - Must minimize the probability of ignition o fluids and vapors, and the resultant hazards if ignition does occur in each area where flammable fluids or vapors might escape by leakage of a fluid system
  - Tests and analysis must consider:
    - Possible sources and paths of leakage (and means to detect)
    - Flammability characteristics of fluid (including effects of combustible or absorbing materials)
    - Possible ignition sources:
      - Electrical faults
      - Overheating equipment
      - Malfunctioning protective devices
      - Hot surfaces

§25.863 Flammable Fluid Fire Protection – *(continued)*

- Tests and analysis must consider: *(continued)*
  - Means to control or extinguish fire
    - Stopping fluid flow
    - Shutting down equipment
    - Fireproof containment
    - Use of extinguishing agents
  - Ability of airplane components critical to safety of flight to withstand fire & heat
- If flight crew action required (e.g., equipment shutdown, discharge fire extinguisher) quick-acting alerting must be provided

Key Installation Requirements – General Fire Protection

- §25.865 Fire Protection of Flight Controls, Engine Mounts, and Other Flight Structure – in designated fire zones or in adjacent areas which would be subject to the effects of fire, these must be fireproof or shielded to withstand the effects of fire (retain functionality in event of fire in fire zone)
- §25.867 Fire Protection: Other Components – Surfaces to the rear of the nacelles, within one diameter of the nacelle centerline must be at least fire-resistant
- §25.869 Fire Protection: Systems – Electrical cables, terminals, and equipment in designated fire zones, that are used during emergency procedures, must be at least fire resistant

Key Installation Requirements

- §25.901 Installation – For each powerplant
  - Comply with § § 33.5 installation instructions
  - Components of installation must be constructed, arranged, and installed so as to ensure their continued safe operation between normal inspections or overhauls
  - Installation must be accessible for inspection & maintenance
  - Major components of installation must be electrically bonded to other parts of airplane
  - Key safety systems assessed for continued functionality under vibration associated with engine hardware failure
  - No single failure/malfunction or probable combination may jeopardize safe operation (links to §25.1309)

Key Installation Requirements

- §25.903 Engines –
  - Each engine must have Type Certificate
  - Each engine must be arranged and isolated from each other to allow operation so that the failure or malfunction of any engine, or any system that can affect the engine, will not
    - Prevent continued safe operation of the remaining engines
    - Require immediate action by any crewmember for continued safe operation
    - Note §25.1143 requires separate and simultaneous control of thrust for each engine
  - In addition to burst (earlier slide) §25.903(d)(1) also requires minimization of effects of engine case burn through

Key Installation Requirements

- §25.994 Fuel system components –
  - Design precautions for effects of fuel spilled on hot engine & nacelle components (including engine wiring) during gear-up landing or gear collapse to minimize fire hazard

Explicit Powerplant Fire Protection Requirements

- §25.1181 Designated fire zones; regions included – *effectively includes entire engine/nacelle/strut as a fire zone*
- §25.1182 Nacelle areas behind firewalls and engine pod attaching structures containing flammable fluid lines – must meet array of venting and fire protection requirements, including those concerning designated fire zones
- §25.1183 Flammable fluid carrying components – Fireproof/fire resistant requirements for lines/fittings/components in fire zones
- §25.1185 Flammable fluids – Isolation requirements for tanks & reservoirs containing flammable fluids in and near fire zones

Explicit Powerplant Fire Protection Requirements

- §25.1187 Drainage and ventilation of fire zones –
  - Must be complete drainage of each part of each fire zone to minimize the hazards resulting from failure or malfunctioning of any component containing flammable fluids. Drainage must be:
    - Effective when drainage required
    - Arranged so no discharged fluid will create additional fire hazard
  - Each fire zone must be ventilated to prevent accumulation of flammable vapors
  - Can not introduce entry of new flammable vapors, nor can discharged vapors create an additional fire hazard

Explicit Powerplant Fire Protection Requirements

- §25.1189 Shutoff means –
  - Each engine must have a means to shut off fuel for that engine (and not affect other engines)
  - Must be fireproof or located/protected so that any fire in a fire zone will not affect operation
  - No hazardous quantity of flammable fluid may drain into any designated fire zone after shutoff
  - Note: In practice requirements lead to redundant fuel shutoff means (normal fuel-cut off valve at engine and spar valve in wing (discharge with fire handles)).
    - Each have redundant, independent wire routing (e.g., wing LE and TE)

Explicit Powerplant Fire Protection Requirements

- §25.1191 Firewalls –
  - Each engine must be isolated from the rest of the airplane by firewalls
  - Firewalls must be
    - Fireproof
    - Constructed so no hazardous quantity of air, fluid, or flame can pass from the compartment to other parts of the airplane
    - Constructed so each opening is sealed with close fitting fireproof grommets, bushings, or firewall fittings
    - Protected from corrosion

Explicit Powerplant Fire Protection Requirements

- §25.1193 Cowling and nacelle skin – Must:
  - Meet drainage & ventilation requirements (§25.1187)
  - Be constructed so that no fire originating in any fire zone can enter any other zone where it would create additional hazards either through openings or by burning through external skin
  - Have fireproof skin in any area subject to flame

Explicit Powerplant Fire Protection Requirements

- §25.1195 Fire extinguishing systems –
  - Fire zones must have a fire extinguishing system
  - System must be shown by tests that it has appropriate
    - Quantity of extinguishing agent
    - Rate of discharge
    - Discharge distribution

    to extinguish fires and minimize probability of reignition; two discharges must be provided for engine installations
  - Nacelle fire extinguishing systems must be able to simultaneously protect each zone of subject nacelle

Explicit Powerplant Fire Protection Requirements

- §25.1197 Fire extinguishing agents;
- §25.1197 Extinguishing agent containers;
- §25.1201 Fire extinguishing system materials –
  - Collectively outline performance requirements for agents and their containers
  - Each fire extinguishing system component in an engine compartment must be fireproof

Explicit Powerplant Fire Protection Requirements

- §25.1203 Fire detector system –
  - Approved, quick acting fire/overheat detectors must be present in sufficient numbers & locations to ensure prompt detection of fire in fire zones
  - Each detector must be constructed and installed to
    - Withstand vibration & other loads it is subjected to in operation
    - Warn the crew as necessary in event of system malfunction (short, severed connection)
  - Detector system may not be affected by any oil, water, other fluids or fumes that may be present
  - Crew must have ability to check functionality in flight
  - Wiring must at least be fire resistant

Engine/Installation Certification Summary

- Engines certified to provide robust operation
- Engines certified to eliminate fires
- Installation certification accounts for engine failures
  - Result: most failures occur with no safety effect - e.g., only loss of power and services
  - Preponderance of engine wiring failures/malfunctions manifest in maintenance flag or powerloss
- Installation certification assumes fires are going to occur and ensure that they are adequately addressed
  - Severe nacelle environment under normal operations
  - Fires assumed to be due to extremely severe, realistic threats (e.g, flammable fluids, case burn through)
    - Encompasses threat from engine wiring fire

Maintenance Practices

- Engine maintenance largely “on-condition”
- Operators regularly provide reports to manufacturers on a wide array of maintenance, reliability, and potential safety issues
- FADECs continuously monitor engine operation
  - Detect any anomalies
  - Significant faults registered in memory and may be enunciated to flight crew (e.g., engine surge, limit exceedances)
  - Minor faults registered in memory and downloaded to maintenance crews via maintenance computer
    - Used to facilitate maintenance scheduling
    - Most wiring issues affecting the engine would lead to a minor fault

Maintenance Practices - Continued

- In addition, frequent checks in service
  - Engine wiring readily accessible by design (& cert requirement)
  - Visual inspections called out during normal periodic under-cowl inspections (e.g., “A-check”)
  - Engine changes force inspection of wiring
    - Engine &/or nacelle go to shop
    - Nacelle remains on-wing (e.g, EBU may remain with aircraft)
    - Either case requires removal, inspection, repair as necessary, and reinstallation to complete actions associated with change

Safety Experience

- Safety experience for engine wiring and engine fire in general is exemplary
  - Experience validates design approach
  - No safety issues with engine wiring
    - Very low occurrence rate for any wiring issue – even reliability metrics
    - Modern engines extremely reliable – overall IFSD rates on order of 0.001 per thousand hours operation
      - Wiring contribution to this is extremely low
  - No uncontrolled fires with intact cowls (i.e., no through-nacelle uncontained engine failure)
- NO SAFETY BENEFIT FOR INCLUDING ENGINES & INSTALLATIONS IN ATSRAC RECOMMENDATIONS
  - Data showing a safety benefit must be presented to justify their inclusion and the resulting increased costs