The Importance of Aerospace Power System Reliability:

Keeping the Lights On

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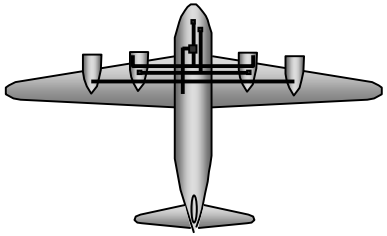
Outlined Topics

- The Past
- Today's Technical Challenges
- The Future – Requirements
- Conclusion

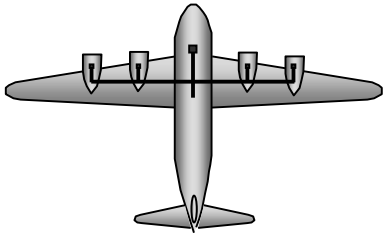
Historical Perspective

1940's | 1980's | 1990's | 2000...

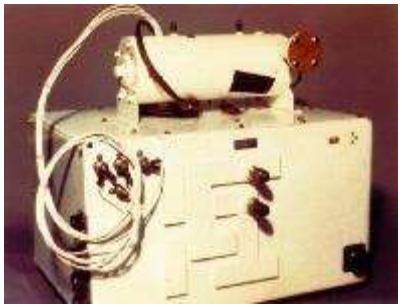
HYDRAULIC



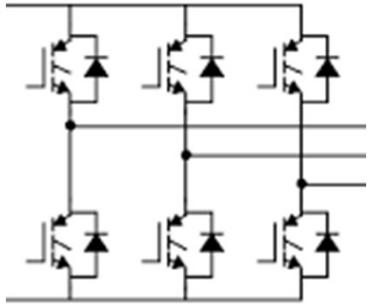
ELECTRICAL



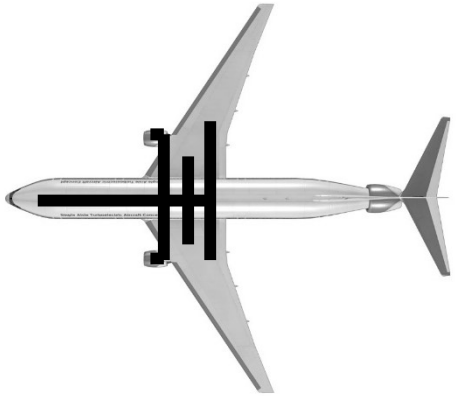
- 1943- XB-30 STUDIES COMPARED POWER-ASSISTED CONTROLS
- HYDRAULICS WON!



- 1984 - 85 HP (63 KW) ELECTRIC FUEL PUMP & CONTROLLER FOR F-16 (>5 ft^3, >100 lbs)
- ELECTRIC DRIVE STILL INFEASIBLE



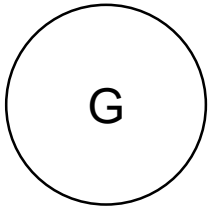
- 1992 – IGBT EFFORTS REVOLUTIONIZED POWER ELECTRONICS WEIGHT / VOLUMES
- ENABLES AIRCRAFT FLIGHT-WEIGHT ELECTRICALLY-BASED HARDWARE



- 1993 - PRESENT POWER THRUST R&D TO DEMONSTRATE A "NO HYDRAULICS" AIRCRAFT (MORE ELECTRIC, MEA)
- 787 MEA NO-BLEED SYSTEM ELIMINATED PNEUMATIC BLEED SYSTEM

Today's Standards Based on 1940's Requirements

Today's Power Quality Standards Based on 1940's Requirements



	W/in^3
1939	2
1944	30
Today	100-500

(1944) "The output of a cubic inch of space and material has been doubled, quadrupled, and doubled again. The engine-driven generator is the best example of this progress. Almost since the beginning of modern aviation the generator designer has been confined to a space of 6 inches diameter and 14 inches length, a volume of 400 cubic inches. Until 1939 this space produced 750 Watts, less than 2 watts per cubic inch. **Today (1944) , nearly 30 Watts per cubic inch."**

1944 AIEE – "Aircraft Electrical Horizons" Godsey, et al.

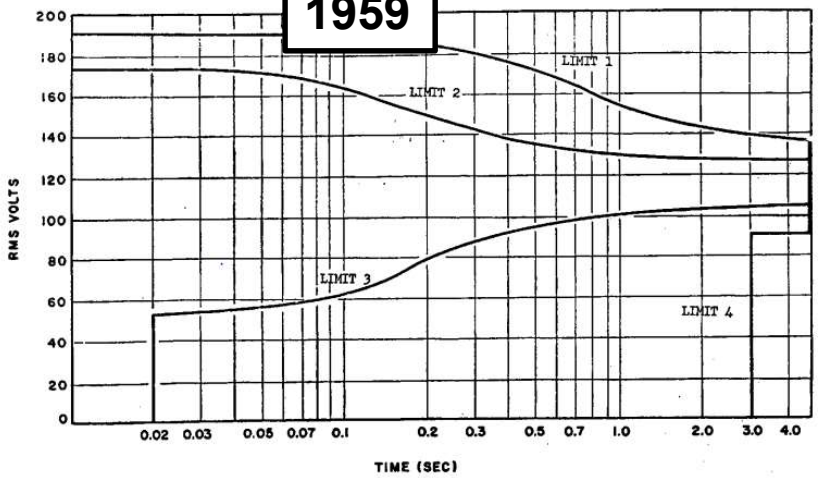
Today & Emerging Requirements ~ 100-500 W/in3

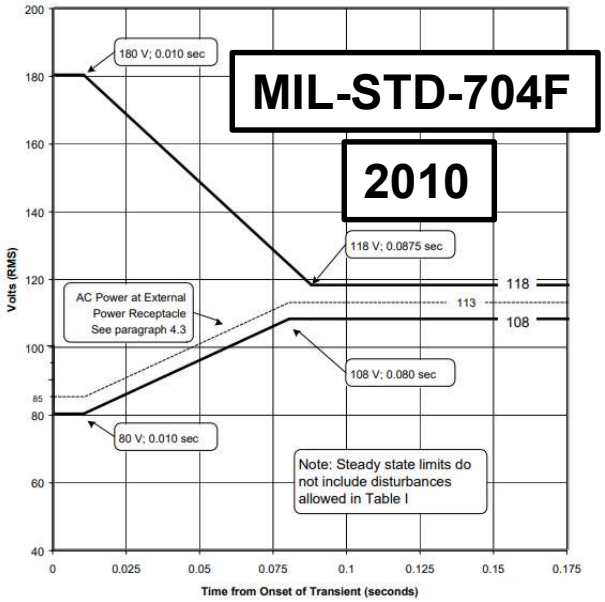
Power Quality… Arbitrary Origins & Trends Toward Relaxing the Standards

An arbitrary and already lenient PQ standard selected for legacy loads.

MIL-STD-704

1959



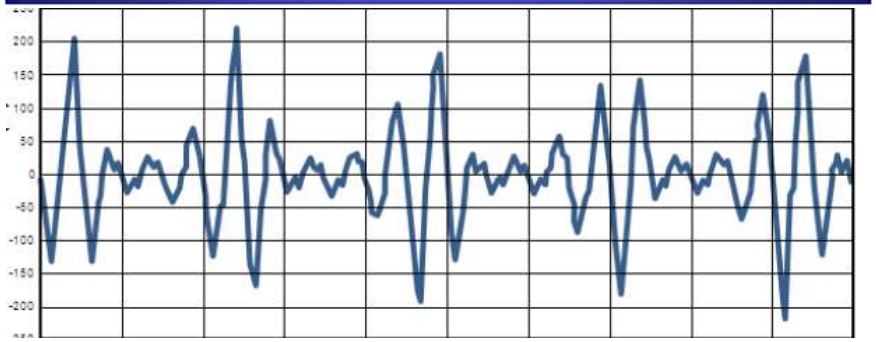


5,000-10,000 life hours → 100 life hours…

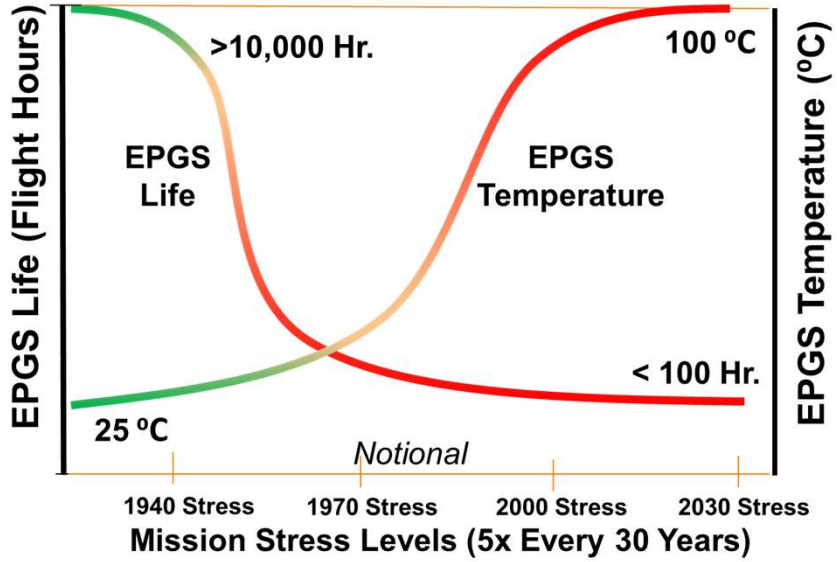
Standards relaxation allows higher power density but impacts power quality & shortens component life

New Mission Stresses on EPS Impacts PQ, Temp & Life

MEA Loads Stress EPS



Stress Reducing Life by >50x



Stress on System:

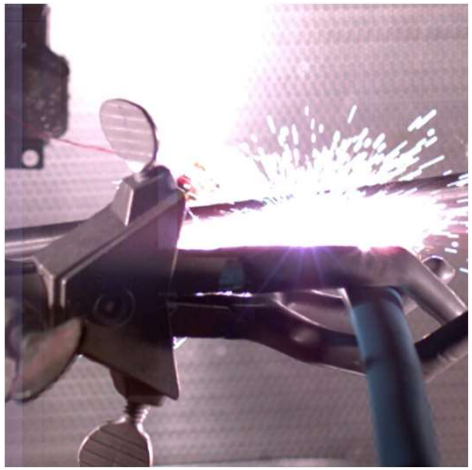
- Power Quality (λ distortion)
- Dynamic Loads (↑ dPower/dt)
  - ↑ intense stress (ΔPower)
  - ↑ frequent stress (↓ Δtime)
  - ↑ demanding (↑ dv/dt)
- Frequency content & distortion (↑di/dt & ↓ ΔXs, neg. impedance)
- Regenerative Power
- Power Dense Design (↑ kW/kg)
  - ↑ ΔXs Source Impedance

Impact on System

- Thermal Heating Effects
- Power Stability Margin
- Mechanical Interactions
- Lower Life of Generator in turn

AF Experiencing "Lights Out" Electrical Systems Failure Events

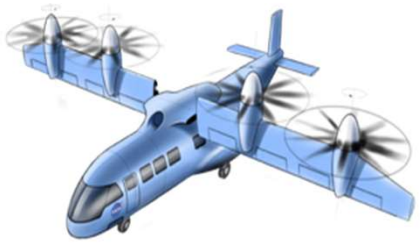
- Arc fault in electrical actuation system can cause total EPS failure = Loss of vehicle control
- Feeder fault can cause EPS fire = Total loss of vehicle
- Ground fault issues can cause total EPS main channels failures during early flight testing = Mission aborts
- Generator failures can cause EPS failure = Mission aborts / Total loss of vehicles



Electrical Power Systems (EPS) are flight critical

Emerging Aircraft / Power Systems

- **High Voltage, High Power Systems**
  - Flight Critical & Primary Power
- **Historical MEA problems are only amplified**
  - Increased Fault Energy and Power System Stresses
  - Increased Safety Requirements
- **Extreme Power Densities & Efficiencies Required for Designs to Close**



There is a need to balance Power Density, Efficiency, and Reliability Simultaneously

Design Rules-of-Thumb and Standards Need Reevaluated & Understood for Emerging Requirements

Moving Towards Reliable Solutions

- **Literature suggests 10^{-7} to 10^{-9} catastrophic failures per operational hour at the aircraft level**
  - Mission Dependent
  - Still needs to be defined
- **Standardization & Certification Requirements are required to help ensure reliability**
  - In progress by Standards Bodies and FAA for HV Systems
- **Research in Progress for Flight-Weight Reliable Solutions (Components & Systems)**
  - Machines, Power Electronics, Cables, and associated Cooling Systems
  - Fast and Selective Fault Protection

Summary
"Keeping the Lights On"

- **Flight Critical**
  - Past - Battery & Mechanical/hydraulic systems
  - Now/Future – Electric Power System can be both mission and flight critical for Electric Propulsion
- **"Lights-out" events cause loss of missions and can cause loss of aircraft**
- **Survivability = Keeping the Lights On**
- **Standards Developed for 1940's**
  - Several iterative degradations starting in the 1960's through modern 5th gen aircraft to allow for power density
  - EPS reliability severely limited, life of a/c to 10's missions
- **Power Standards have not been established for future loads & new requirements**
  - Major Challenge from design to regulations & standards
  - Work in progress across industry, academia, govt.