Component Specific Environmental Conversion Factors

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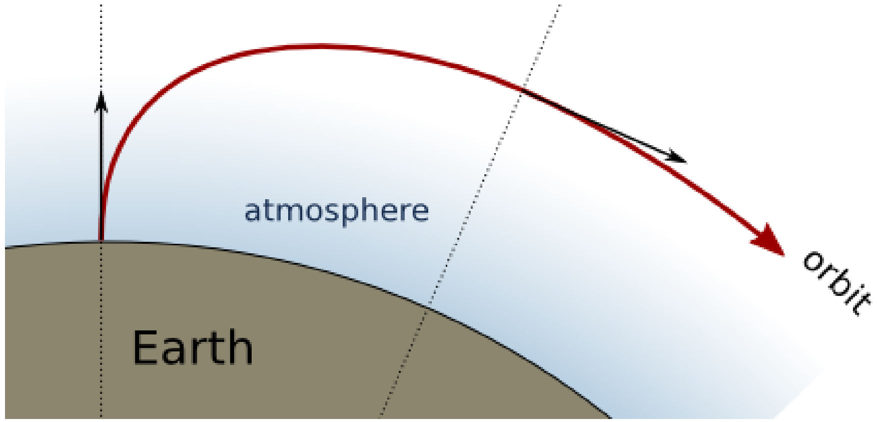
Introduction

- Spacecraft face the unique challenge of experiencing several different environments (e.g. temperature, pressure, gravitational forces) over the course of a single mission.
- Risk and reliability analyses must consider the period of performance within and the impacts of each environment to the mission.
- Unfortunately data for operating environments of interest is often unavailable for the operating environment.
- Therefore it is common practice in reliability analyses to refer to a handbook (e.g. MIL-HBK-338B) to provide guidance and environmental conversion factors for electrical components to apply data across multiple environments.
- However due to the wide range of differences between mechanical and electrical components, using a standard set of environmental conversion factors for all components could result in over- or underestimating the reliability for components based on their sensitivity to various environments.

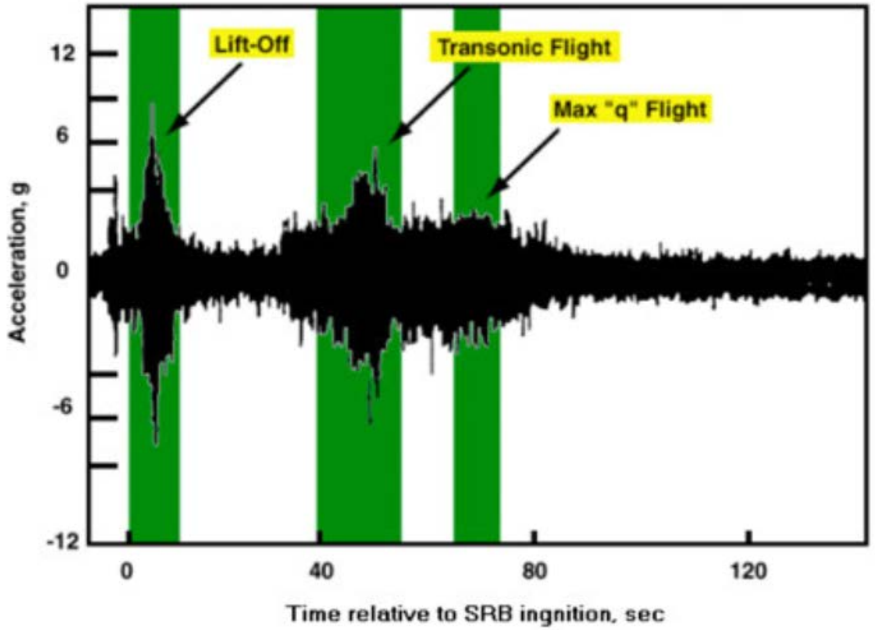


The Environments

- The three commonly recognized environments that a spacecraft must undergo over the course of a mission are on-pad , ascent (through atmosphere), and space operations.
- Depending on the environment, the impact of natural and induced factors vary in their effect on a given component's reliability.

NATURAL		INDUCED
Clouds	Rain	Acceleration
Fog	Salt Spray	Electromagnetic, Laser
Freezing Rain	Sand and Dust	Electrostatic, Lightning
Frost	Sleet	Explosion
Fungus	Snow	Icing
Geomagnetism	Hail	Radiation, Electromagnetic
Gravity, Low	Ice	Radiation, Nuclear
Temperature, High	Wind	Shock
Temperature, Low		Temperature, High, Aero. Heating
Humidity, High		Temperature, Low, Aero. Cooling
Humidity, Low		Turbulence
Ionized Gases		Vapor Trails
Lightning		Vibration, Mechanical
Meteoroids		Vibration, Acoustic
Pollution, Air		
Pressure, High		
Pressure, Low		
Radiation, Cosmic, Solar		
Radiation, Electromagnetic		

MIL-HBK-337F: Table 7.6-1[1]



Vibration Time History During Space Shuttle Launch[2]

Military Handbooks

- Mll-HDBK-217F provides environmental tables for converting the provided failure rate point estimate from one environment to another, but does not estimate the uncertainty associated with this conversion.[3]
- Using a microelectronic part-type as an example, the environmental factor (π_E) conversion formula was first derived from the failure rate (λ_p) reference
  - $\lambda_P = (C_1\pi_T + C_2\pi_E)\pi_Q$
  - C_1 is the circuit complexity, C_2 is the packaging complexity
  - π_T is the component joint temperature factor, π_Q is the component quality factor
  - π_L is the learning factor (assumed 1 by the handbook)

- Solving for π_E , the equation becomes

$$\pi_E = \frac{\left(\frac{\lambda_p}{\pi_Q}\right) - C_1\pi_T}{C_2}$$

Military Handbooks (cont.)

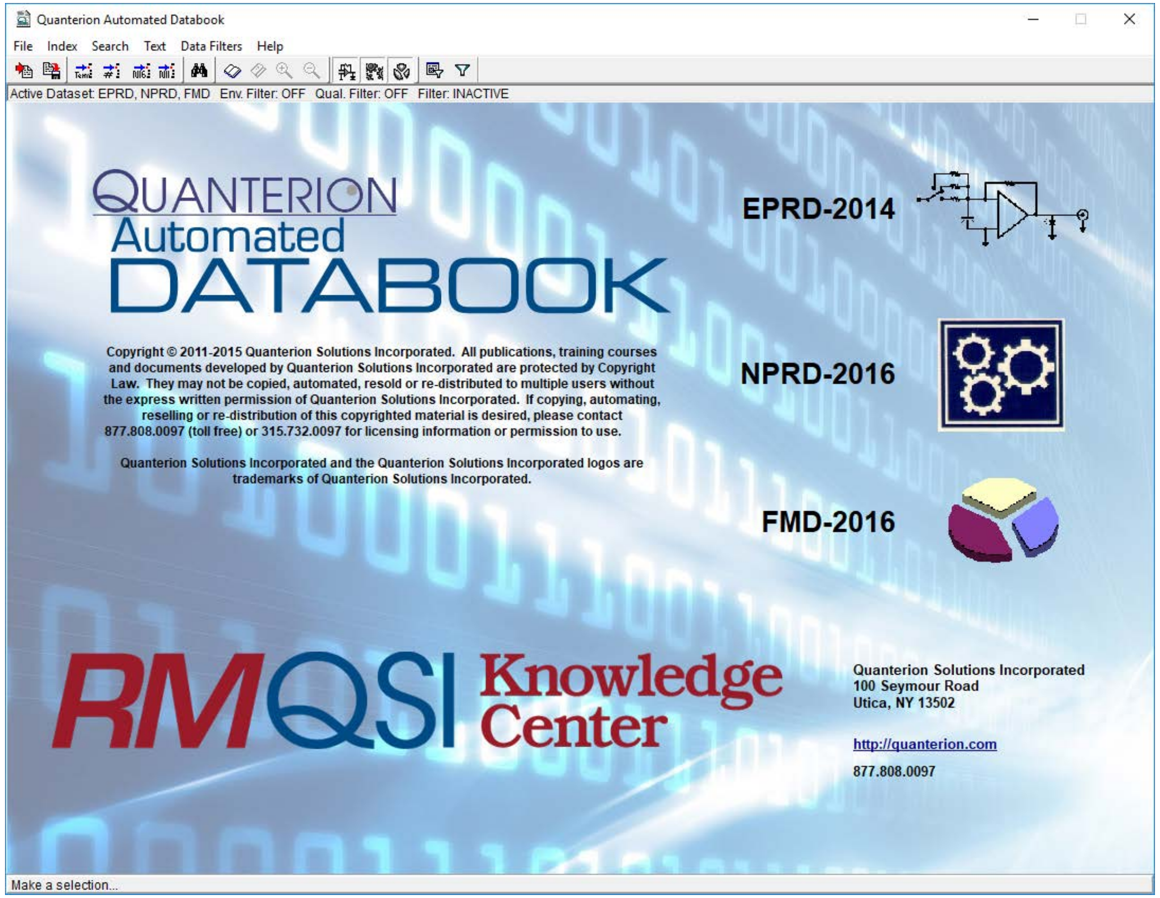
- MIL-HBK-338B provides guidance to determine an electrical component's reliability by evaluating performance shaping factors, including environmental factors.
- Table 10.3-3 provides a conversion factor to apply to a failure rate when transitioning from one environment to another.

TABLE 10.3-3: ENVIRONMENTAL CONVERSION FACTORS
(MULTIPLY SERIES MTBF BY)

From Environment	To Environment: G_B	G_F	G_M	N_S	N_U	A_{IC}	A_{IF}	A_{UC}	A_{UF}	A_{RW}	S_F
G_B	X	0.5	0.2	0.3	0.1	0.3	0.2	0.1	0.1	0.1	1.2
G_F	1.9	X	0.4	0.6	0.3	0.6	0.4	0.2	0.1	0.2	2.2
G_M	4.6	2.5	X	1.4	0.7	1.4	0.9	0.6	0.3	0.5	5.4
N_S	3.3	1.8	0.7	X	0.5	1.0	0.7	0.4	0.2	0.3	3.8
N_U	7.2	3.9	1.6	2.2	X	2.2	1.4	0.9	0.5	0.7	8.3
A_{IC}	3.3	1.8	0.7	1.0	0.5	X	0.7	0.4	0.2	0.3	3.9
A_{IF}	5.0	2.7	1.1	1.5	0.7	1.5	X	0.6	0.4	0.5	5.8
A_{UC}	8.2	4.4	1.8	2.5	1.2	2.5	1.6	X	0.6	0.8	9.5
A_{UF}	14.1	7.6	3.1	4.4	2.0	4.2	2.8	1.7	X	1.4	16.4
A_{RW}	10.2	5.5	2.2	3.2	1.4	3.1	2.1	1.3	0.7	X	11.9
S_F	0.9	0.5	0.2	0.3	0.1	0.3	0.2	0.1	0.1	0.1	X

Databases (Historical Experience)

- The Nonelectric Part Reliability Data (NPRD-2016)[5] and the Electric Part Reliability Data (EPRD-2014)[6] provide one of the largest existing general collections of failure data today.
- By comparing the failure rates for the same component in different environments, it is possible to generate an environmental conversion factor for that given component based on historical experience.
- The resulting environmental conversion factor will then be compared to the value within MIL-HBK-338B.



Ground Rules & Assumptions/Limitations

- Ground Rules & Assumptions
  - Only Military Grade equipment are considered in this evaluation.
  - Any data used in the evaluation must have at least 100,000 hours of operating experience and at least 1 failure.
  - Since data is often provided in the context of an Airborne Uninhabited (AUF) environment, the cases evaluated will be limited to conversions between the AUF and Space Flight (SF) and the AUF to Ground Mobile (GM) environments.

- Limitations
  - Data pertaining to components operating in a space flight environment is limited, thus reducing the possible number of comparisons.
  - Data does not account for specific manufacturing processes.

AUF to GM Comparison – Electrical Components

- The following table is a comparison of components operating within the AUF and GM environments.
  - The conversion factor from AUF to GM is 3.1.

Component	Type	Airborne Uninhabited (AUF) Environment				Ground Mobile (GM) Environment				Demonstrated Conversion Factor	% Difference Between MIL-338B (Demonstrated/MIL-338B)
		Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source	Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source		
Circuit Card	Electrical	0.81	33	40,739,000	17718-000	0.03	1	30,420,000	17718-000	24.64	694.88%
Connector	Electrical	1.07	40	37,229,582	265827-000	0.31	2	6,404,060	14851-000	3.44	10.98%
Power Transmitter	Electrical	5.41	12	2,217,000	16953-000	0.44	7	15,774,000	NPRD-106	12.20	293.46%
Relay	Electrical	3.49	20	5,727,628	265827-000	1.38	9	6,528,340	23037-000	2.53	-18.29%
Switch	Electrical	17.09	6	351,096	23035-000	17.48	23	1,315,971	23037-000	0.98	-68.46%
Transformer	Electrical	0.70	6	8,591,442	265827-000	0.21	2	9,606,090	14851-000	3.35	8.20%

AUF to GM Comparison – Mechanical Components

- The following table is a comparison of components operating within the AUF and GM environments.
  - The conversion factor from AUF to GM is 3.1.

Component	Type	Airborne Uninhabited (AUF) Environment				Ground Mobile (GM) Environment				Demonstrated Conversion Factor	% Difference Between MIL-338B (Demonstrated /MIL-338B)
		Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source	Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source		
Actuator	Mechanical	48.13	76	1,579,000	16953-000	2.21	1	453,000	10812-000	21.80	603.34%
Filter	Mechanical	8.55	1	117,000	16953-000	2.75	14	5,098,000	NPRD-106	3.11	0.40%
Generator	Mechanical	256.41	60	234,000	16953-000	18.87	2	106,000	NPRD-095	13.59	338.38%
Heat Exchanger	Mechanical	13.31	6	450,900	13514-000	0.69	3	4,354,000	NPRD-106	19.31	522.98%
Valve (Hydraulic)	Mechanical	104.11	147	1,412,000	16953-000	14.42	3	208,000	NPRD-095	7.22	132.84%

AUF to SF Comparison

- The following table is a comparison of components operating within the AUF and SF environments.
  - The conversion factor from AUF to SF is 16.4
  - Lack of data in the space flight environment results in limited comparisons.

Component	Type	Airborne Uninhabited (AUF) Environment				Space Flight (SF) Environment				Demonstrated Conversion Factor	% Difference Between MIL-338B (Demonstrated/MIL-338B)
		Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source	Failure Rate (per million hours)	Failures	Data Time (hrs)	Data Source		
Relay	Electrical	3.491847	20	5,727,628	265827-000	0.714796	2	2,798,000	10219-034	4.89	-70.21%
Switch	Electrical	17.089343	6	351,096	23035-000	0.418235	1	2,391,000	NPRD-106	40.86	149.15%
Generator	Mechanical	256.410256	60	234,000	16953-000	1.223446	11	8,991,000	NPRD-056	209.58	1177.93%

Summary & Conclusions

- When comparing the conversion factor based on demonstrated data against the conversion factor in the handbook, applying a conversion factor intended for electrical components to mechanical components results in under- and over-estimating the risk contribution.
    - Potential significant reliability assessment impacts (i.e. single point failures)
    - Furthermore, historical experience reveals a wide variance in environmental conversion factors on a component by component basis.

- Implementing component specific environmental conversion provides a path forward to aptly estimate the reliability rates for components operating across multiple environments.
    - However, in order to do so, more work needs to be performed into gathering component reliability data across the operating environments.

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