Thermal Margins for Flight Electronics Review and Assessment

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Agenda

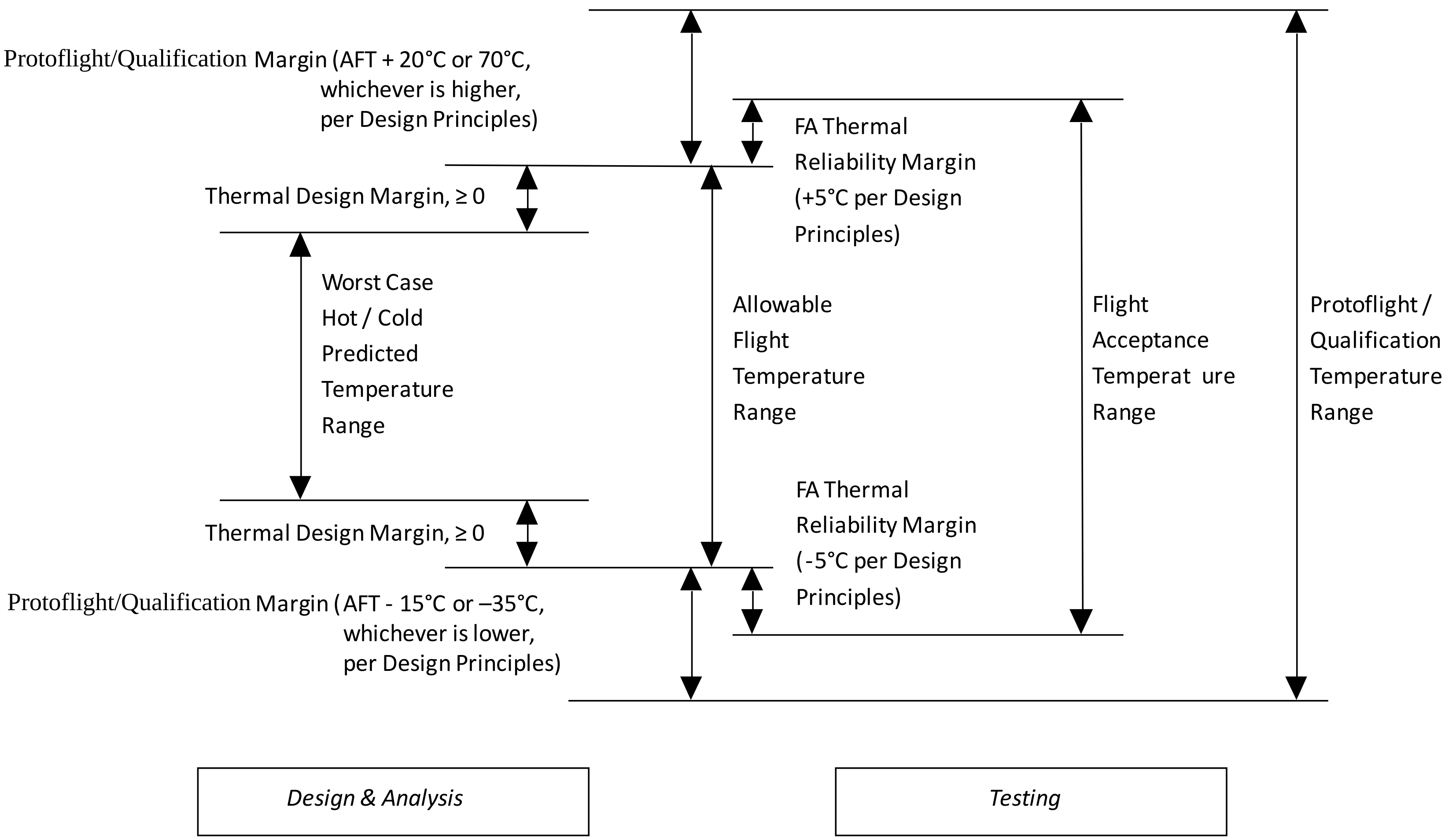
- Scope of the Investigation
- JPL Thermal Margins
- Comparison of Thermal Margins
- Margins by Domain
  - Qualification / Protoflight
  - Thermal Control System
  - Parts and Derating
  - Reliability
- Integrated Margin and Conservatism
- Observations and Assessment
- Conclusions

Scope

The scope of this investigation is limited to

- Electronic assemblies (typically instruments or bus mounted)
- Hot operating conditions

JPL Thermal Margins



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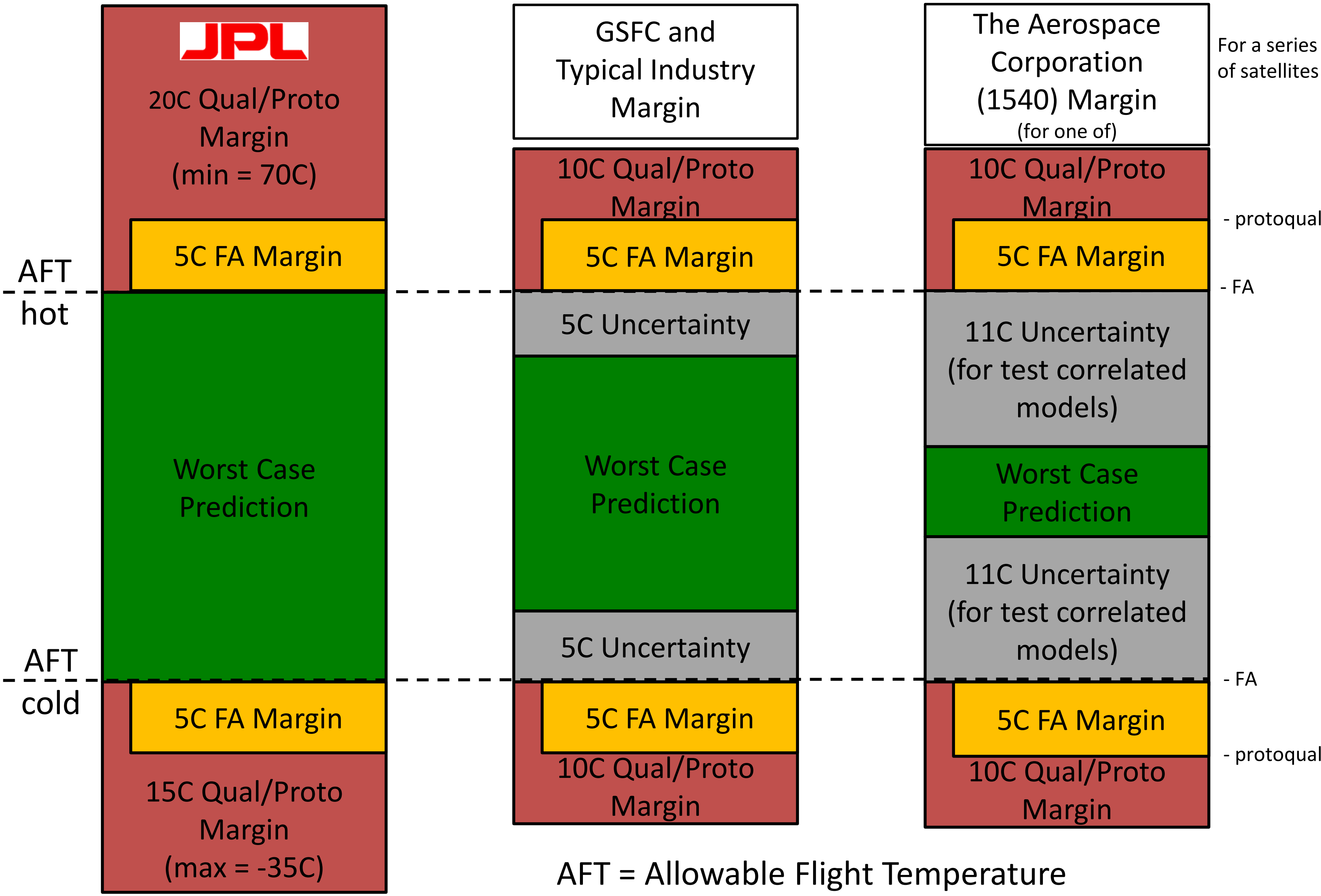
Comparing JPL Margins



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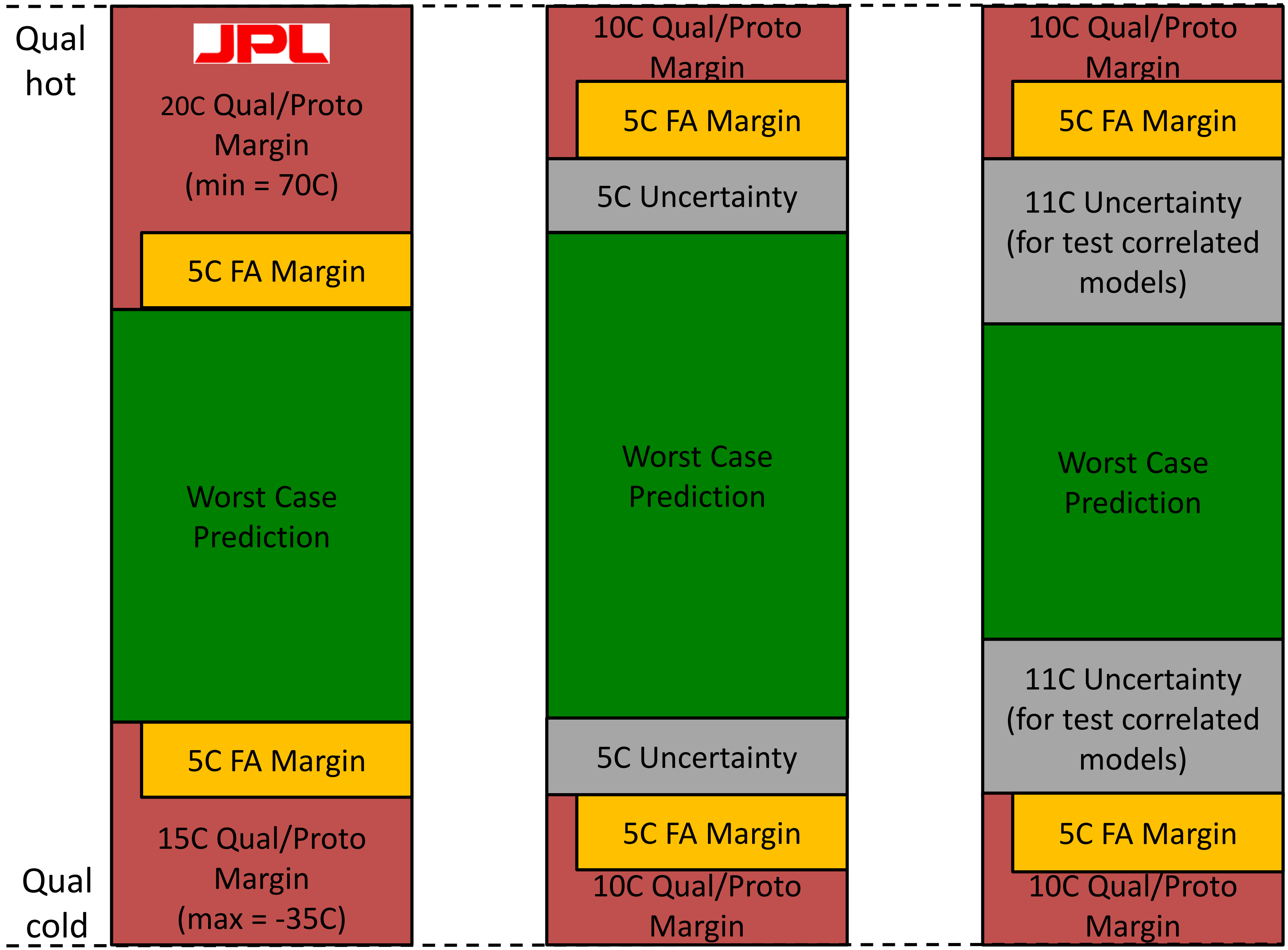
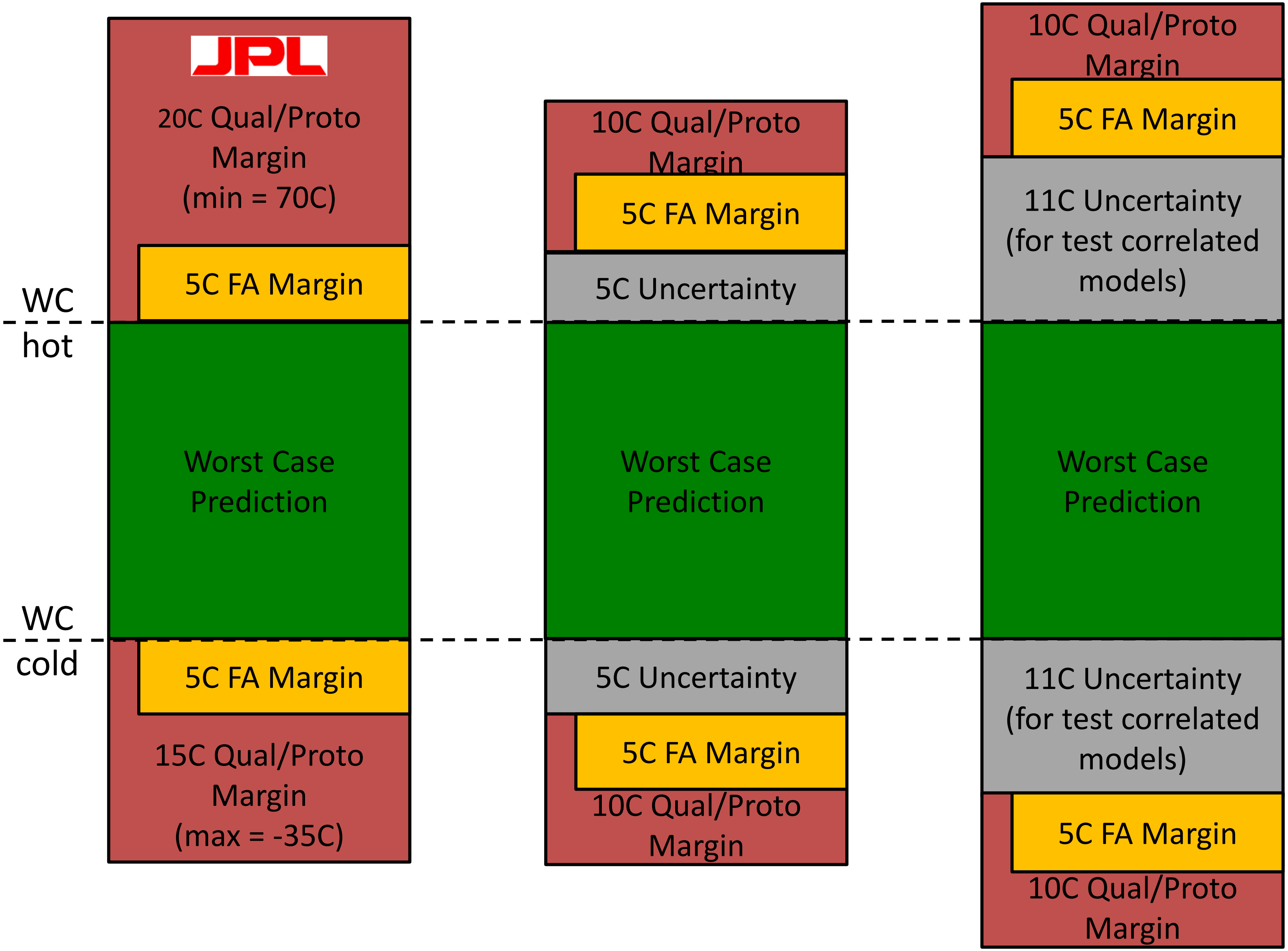


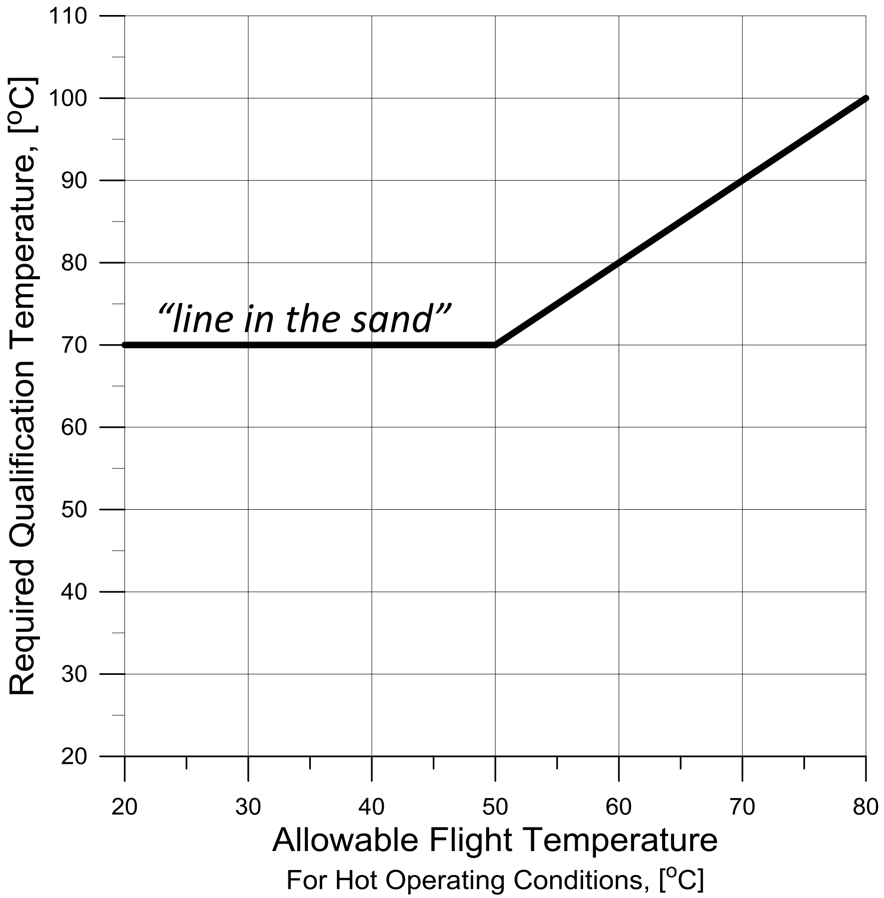
Comparing JPL Margins



Qual/PF Margin Requirement

Bus electronics design temperature range

Bus electronics shall be designed to operate within specification over the temperature range of -35°C to + **70°C** or AFT temperature limits extended by -15°C and **+20°C**, whichever is more severe.



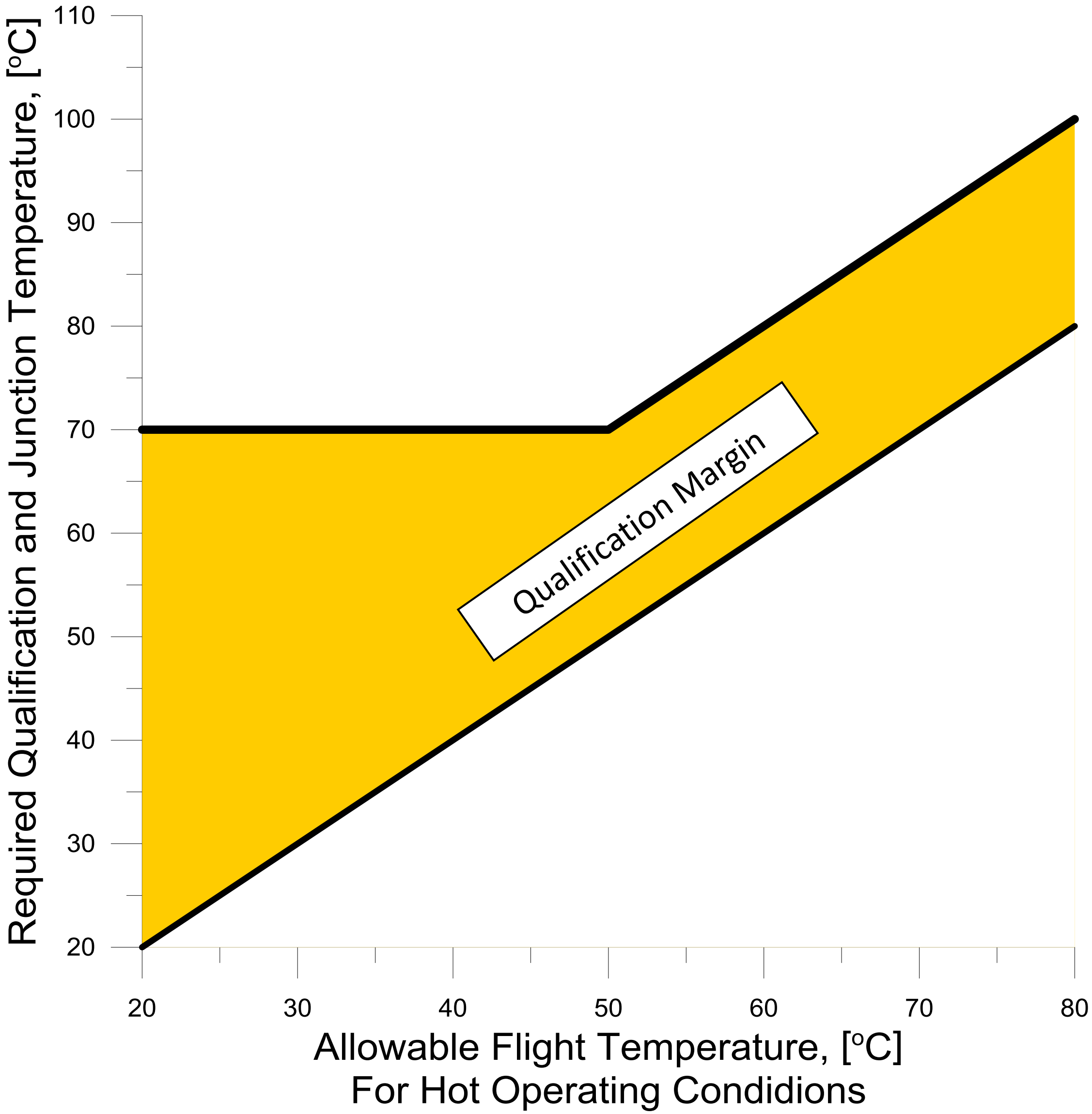
Historic Background

- Historic background from early Ranger missions:
  - Upper limit of 50C based on max temperature of a white painted surface at full sun exposure between earth and moon
  - Lower limit of 5C based on freezing temperature of Hydrazine
  - Anticipated planetary mission to Venus and potential passage through earth's shadow resulted in 25 margin
    - -20C/75C, later changed to -20C/70C

Qualification

- The minimum electronics Qual/PF temperature limit of 70°C promotes a robust and reliable hardware design that will lead to successful missions.
- Designing to a 70°C Qual/PF temperature constrains thermal rise from the assembly baseplate to the electronic part junctions, resulting in lower in-flight junction temperatures, than would otherwise result from lower Qual/PF limits.
- It decouples the electronic assembly thermal design from flight system thermal design, allowing both disciplines to proceed with their designs in parallel with little chance for margin deterioration.

Qualification



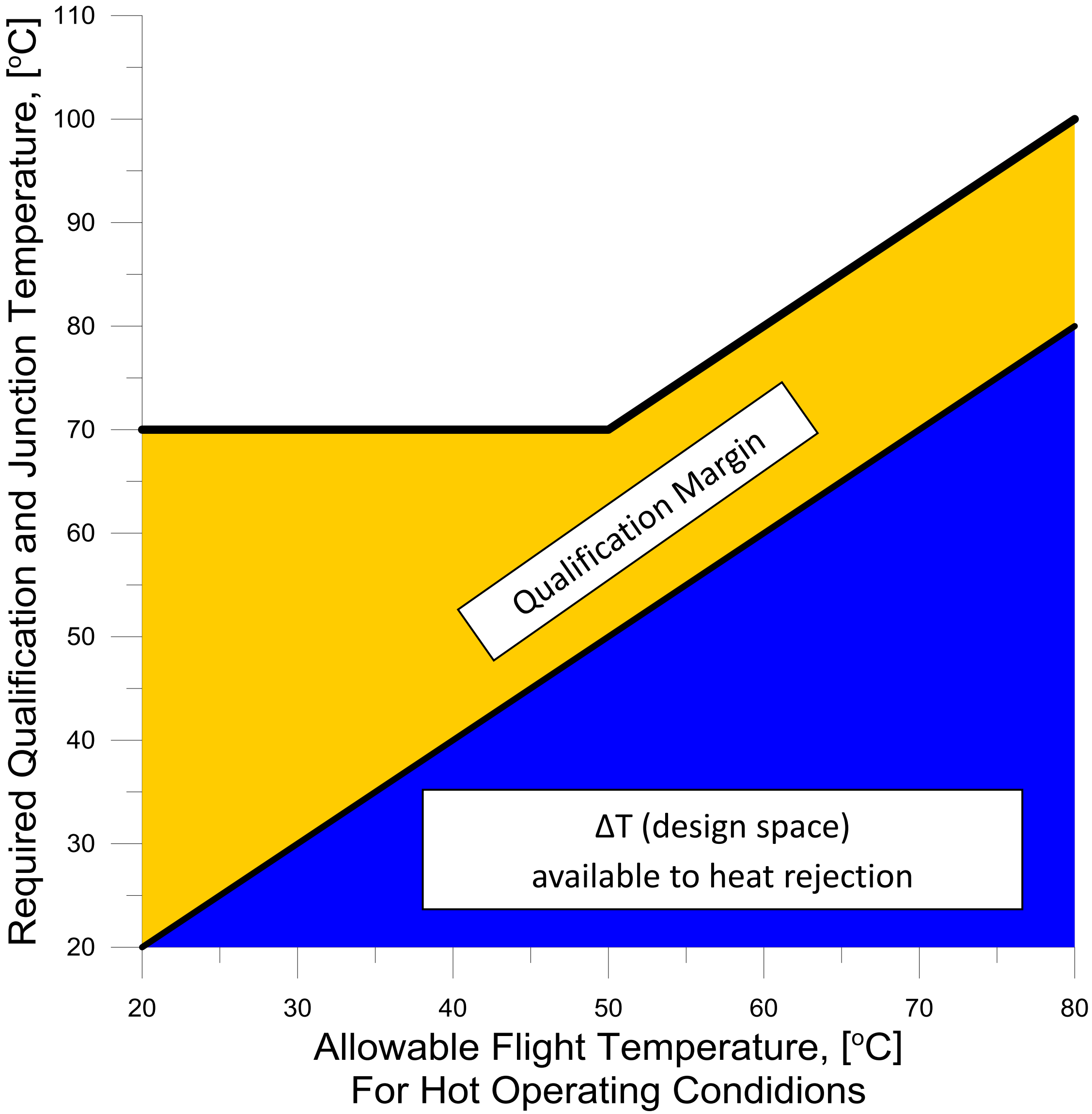
- Requirement as stated

- AFT

Thermal Control System

- The thermal control system is designed to maintain the payload and the spacecraft subsystems within their Allowable Flight Temperature [AFT] requirements
  - for all operating modes, in all thermal environments it may be exposed to, throughout the mission lifetime.
- JPL's standard thermal engineering practice prescribes worst case methodologies for design
- Uncertainty in absolute temperatures and, consequently, in margins is usually estimated by sensitivity analyses

Qualification and Thermal Control



- Requirement as stated

- AFT

Parts and Derating

- Derating prevents small changes in operating characteristics from creating large increases in failure rates.
- Present derating policy is intended to reduce the occurrence of stress related failures and help assure long-term reliability.
- JPL derating guidelines provide derating factors to be applied as a percentage of maximum rated values for critical device parameters
- The derating factor needed depends on the tolerance of the design to variation in operating parameters
- A key derating parameter for microcircuits and discrete semiconductors (diodes, transistors, optoelectronics) is junction temperature

Parts and Derating

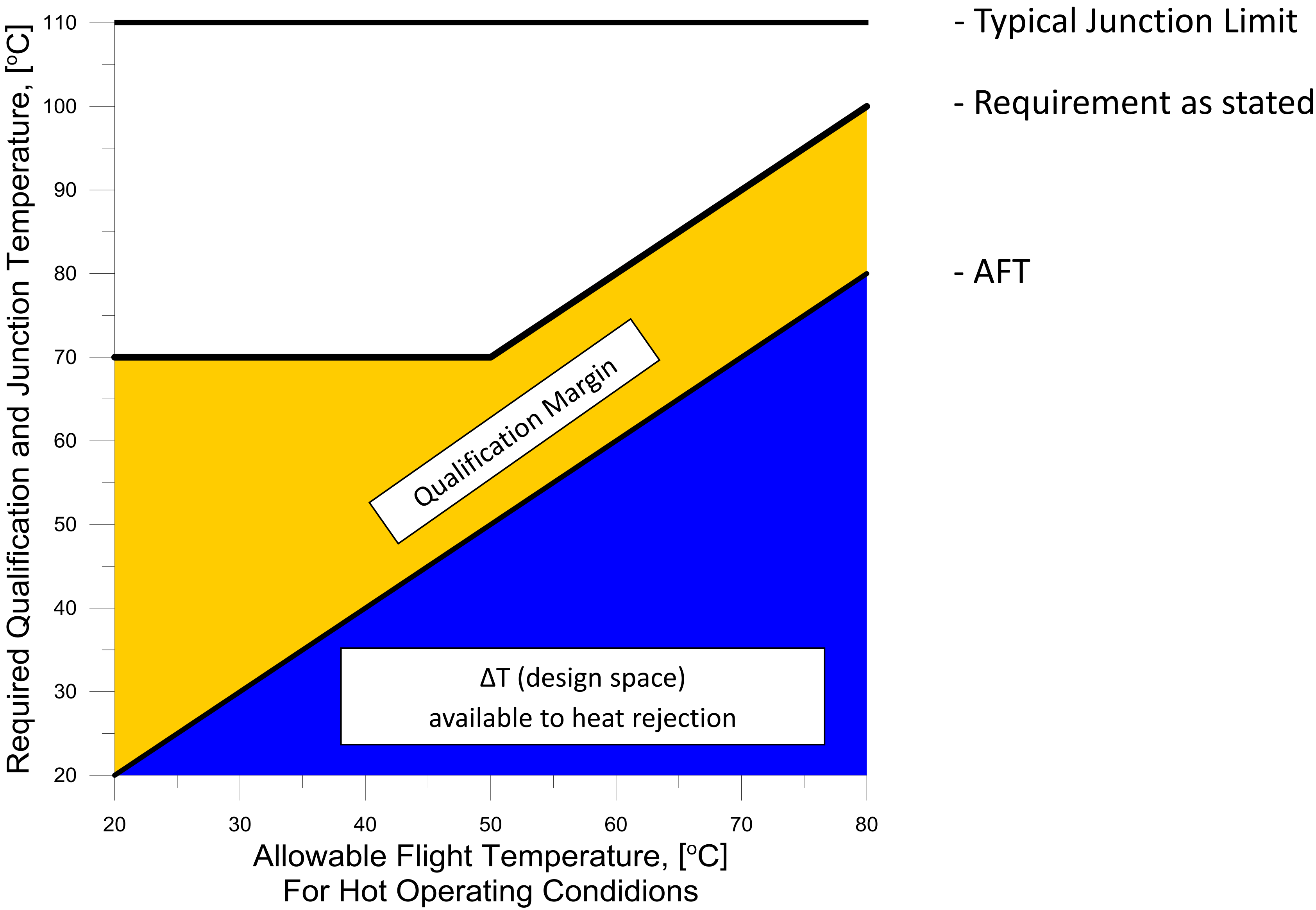
- Historically, junction temperature (Tj) derating for silicon microcircuits in ceramic hermetic packages has been limited to between 110°C and 115°C.
- The basis of this calculation can be described as follows:

$$MTTF \propto e^{-\frac{E_a}{kT}}$$

$MTTF$ = mean time to failure
E_a = activation energy, a constant
k = Boltzmann's constant
T = Temperature, [K]

- In order to achieve twice the lifetime, the junction temperature must be lowered such that the MTTF is twice the nominal values
- For a 125°C max rated Tj device, assuming an Ea = 0.6 eV, the typical 10-year MTTF can be extended by a safety margin of two by lowering the junction temperature by 15°C to 110°C.

Qualification, Thermal Control and Parts



Packaging

- Packaging designs are dominated by multilayer circuit board technology using mostly packaged and screened electrical components.
- Thermal performance is dominated by heat conduction, with no convection and usually minor radiation transfer.
- The primary margin is in the protoflight temperature used for analysis compared to the allowable flight temperature (AFT).
  - No other margin is intentionally added in the thermal analysis process.
  - But there is likely to be some margin in the power dissipations used for analysis.

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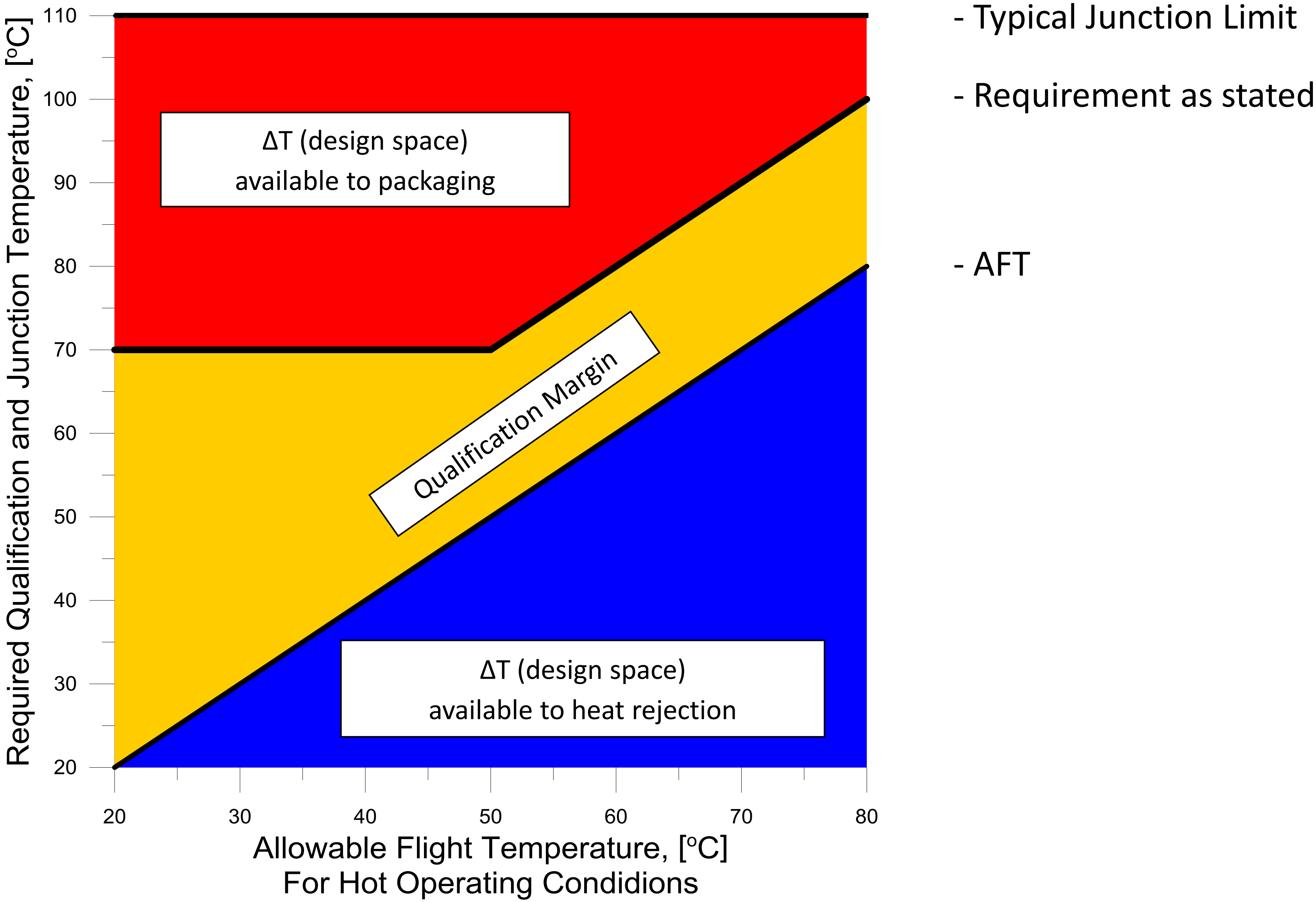
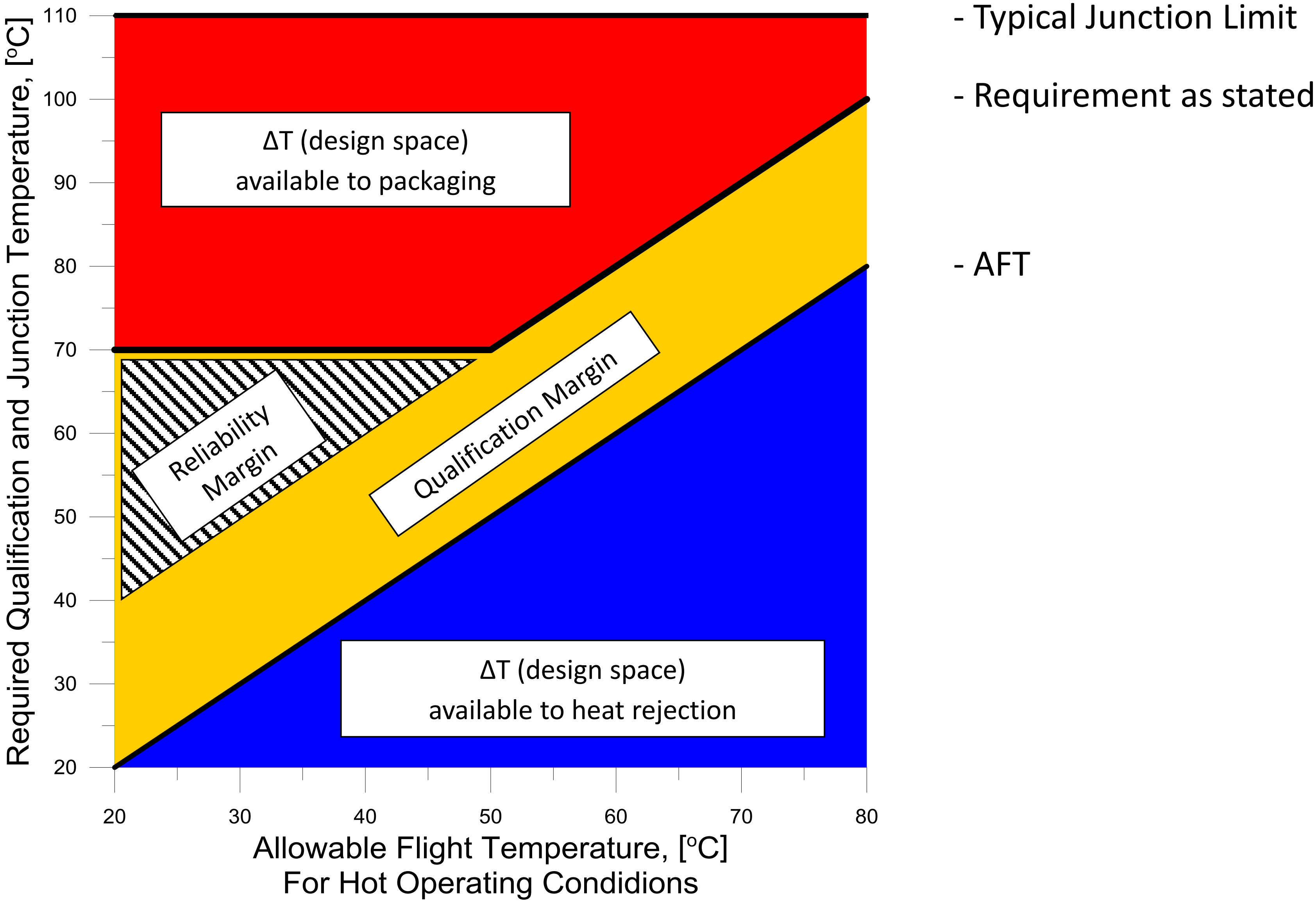
Qualification, Thermal Control, Parts and Packaging



Reliability

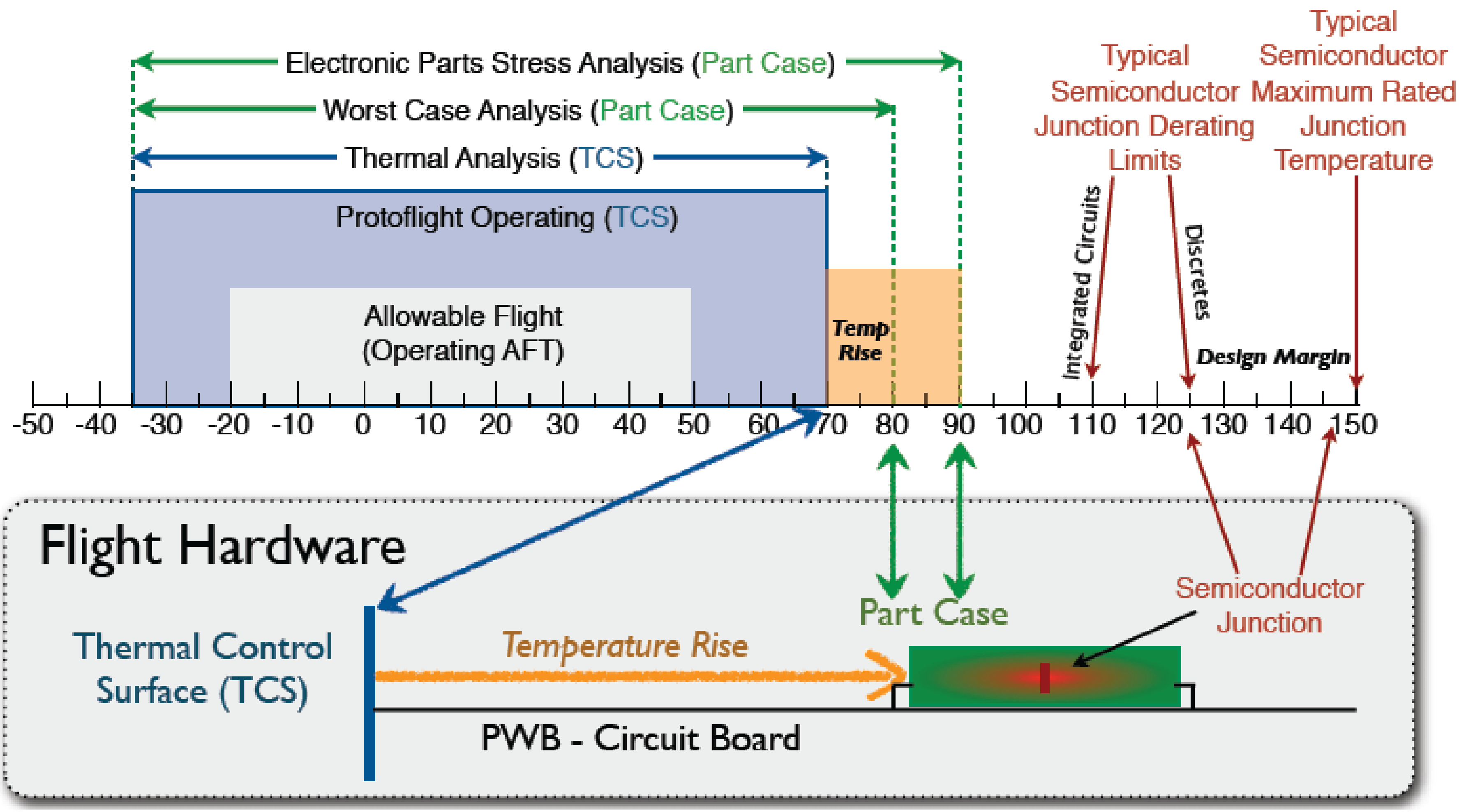
- Temperature is one of many factors for key reliability design analysis
- These temperatures are based upon Qual/Protoflight temperatures at the thermal control surface (TCS).
- Electronic Parts Stress Analysis (EPSA)
  - Identifies highly stressed parts
  - Commonly, the EPSA is completed first using the assumption of a 20°C rise from the thermal control surface (70°C) to the part case
- Worst-Case Analysis (WCA)
  - Demonstrates margined performance under extreme conditions
  - Assumes a 10°C rise from the thermal control surface (70°C) to the part case for the hot condition
- Temperature rise assumptions used in the EPSA and WCA must be verified and reconciled with the Thermal Analysis once the results are available.

Qualification, Thermal Control, Parts, Packaging and Reliability



Integrated Margins

- The figure depicts an integrated picture of JPL's margin. The complexity of the approach becomes readily apparent.



Conservatism

- In addition to margins, domains apply conservatism. To the degree that actual flight temperatures are lower than predictions because of this conservatism, actual junction temperatures are lowered by the same amount. The degree of applied conservatism is experience-based and can be fine-tuned if resources permit.

Domain	Conservatism	Margin
Parts		Derating/Screening
Packaging	worst case power	
	worst case material properties	
	worst case operating conditions	
		70°C heat sink boundary
Qualification		AFT + 20°C
Reliability	worst case voltage/current	70°C heat sink boundary
Thermal Subsystem	worst case power	
	worst case material properties	
	worst case operating conditions	
	worst case environment	
	worst case attitude	
	worst case configuration	

Observations

- Existing margin requirements
  - Are applied in a *one size fits all* fashion
  - Are agnostic to mission class

- Over time, responsibility for elements of the overall thermal design has been segregated into different disciplines and organizations

- The relevant margin elements are
  - *Reliability* (Line In The Sand, aka *LITS*)
  - *Qualification* (AFT + 20°C)
  - *Derating* (of allowable junction temperatures)

Assessment

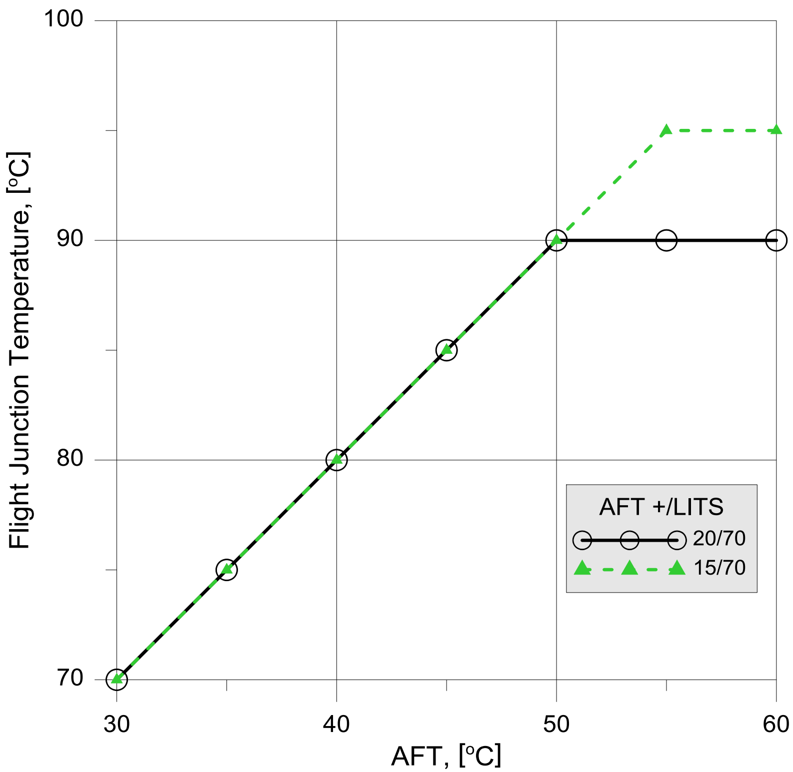
- Segregation facilitates concurrent design but does not consider uncertainties, risk and margin in a holistic way
- The introduction of a considerable number of new parts to the design, which were not in use when margin requirements were originally established, complicates the situation.
- Higher packaging density and resulting heat concentration make it increasingly difficult to keep the chassis to junction temperature rise within the currently required 40°C.

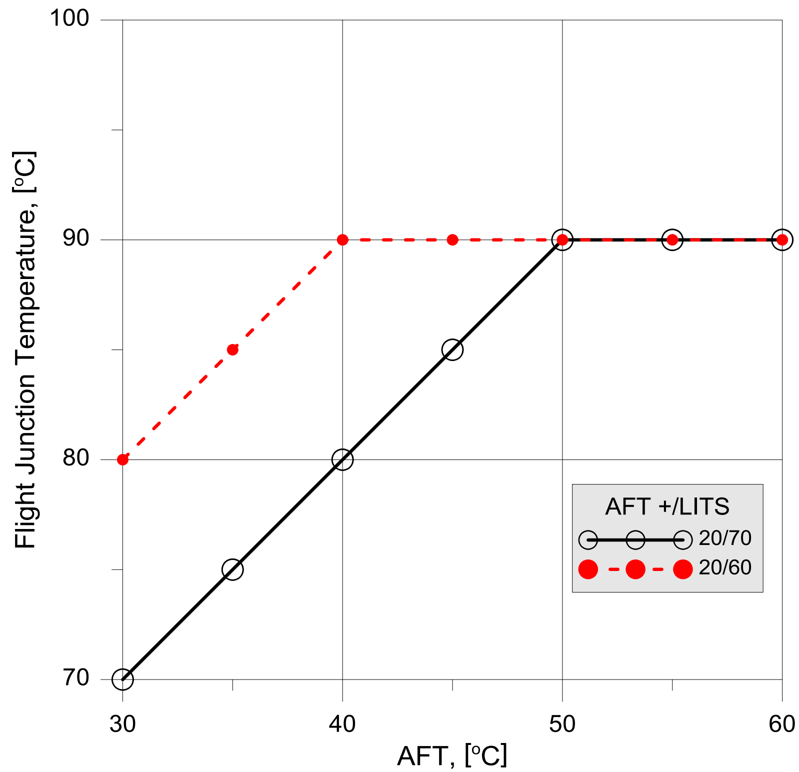
Assessment

- Benefits of a JPL margin reduction
  - vendor hardware qualification will be in family
  - compatibility with the margin approach of the Goddard Space Flight Center (GSFC) is established
  - the inherent risk posture of different mission classes is acknowledged
  - the thermal "headroom" for parts packaging is increased
  - the number of waivers will be reduced

Assessment

- Downside of reduced qualification and reliability margins
  - design or hardware heritage for future use is limited
  - inflight anomalies need to be met with lower margins
  - junction temperatures can potentially increase





Conclusions

- This study has reinforced that robust margins are inherently tied to JPL's mission success.
- It also has become apparent that today's diversity of missions will benefit from a more flexible approach to defining margin requirements than the currently practiced *one size fits all* approach.
- The complexity of determining the margin approach over the spectrum of applicable scenarios has so far prevented our institution from converging on a specific set of recommendation.
- This work provides a point of departure for future discussion that is soundly based on past experience and a renewed understanding of the intent and merits of our margin.

Thank you for your attention.

Any questions?

Appendix

NASA NPR 8705.4

Characterization	Class A	Class B	Class C	Class D
Priority (Criticality to Agency Strategic Plan) and Acceptable Risk Level	High priority, very low (minimized) risk	High priority, low risk	Medium priority, medium risk	Low priority, high risk
National significance	Very high	High	Medium	Low to medium
Complexity	Very high to high	High to medium	Medium to low	Medium to low
Mission Lifetime (Primary Baseline Mission	Long, >5years	Medium, 2-5 years	Short, <2 years	Short < 2 years
Cost	High	High to medium	Medium to low	Low
Launch Constraints	Critical	Medium	Few	Few to none
In-Flight Maintenance	N/A	Not feasible or difficult	Maybe feasible	May be feasible and planned
Alternative Research Opportunities or Re-flight Opportunities	No alternative or re-flight opportunities	Few or no alternative or re-flight opportunities	Some or few alternative or re-flight opportunities	Significant alternative or re-flight opportunities
Achievement of Mission Success Criteria	All practical measures are taken to achieve minimum risk to mission success. The highest assurance standards are used.	Stringent assurance standards with only minor compromises in application to maintain a low risk to mission success.	Medium risk of not achieving mission success may be acceptable. Reduced assurance standards are permitted.	Medium or significant risk of not achieving mission success is permitted. Minimal assurance standards are permitted.
Examples	HST, Cassini, JIMO, JWST	MER, MRO, Discovery payloads, ISS Facility Class Payloads, Attached ISS payloads	ESSP, Explorer Payloads, MIDEX, ISS complex subrack payloads	SPARTAN, GAS Can, technology demonstrators, simple ISS, express middeck and subrack payloads, SMEX

Class D
(DOD-HDBK-343 (USAF))

Minimum Acquisition Cost.
Class D is defined as a higher-risk, minimum-cost effort. The characteristics for Class D usually involve some combination of the following features: medium to low national prestige, short life. Low complexity, small size, single string designs, simple interfaces. hard failure modes, no flight spares, lowest cost, short schedule, and a noncritical launch schedule. Vehicle and experiment retrievability or in-orbit maintenance may or may not be possible.

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Projects in the Context of Requirements

Thermal Margin Assessment

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