National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Mechanical Trends in Spacecraft Development

Raytheon Corporate Mechanical, Materials, and Structures Technology Network Symposium

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NASA Jet Propulsion Laboratory (JPL)
California Institute of Technology
September 21, 2016

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Symposium Theme

Global, Innovative Products using

Systems-level Thinking for

Mechanical and Materials Engineering

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JPL's Mission

We enable the nation to explore space for the benefit of humanity. Our Mission is:

1. *To explore our own and neighboring planetary systems*
2. *To search for life outside the Earth's confine*
3. *To further our understanding of the origins and evolution of the Universe and the laws that govern it*
4. *To make critical measurements to understand our home planet and help protect its environment*
5. *To apply JPL's unique skills to address problems of national significance and security*
6. *To enable a virtual presence throughout the solar system by creating the Interplanetary Network*
7. *To inspire the next generation of explorers*

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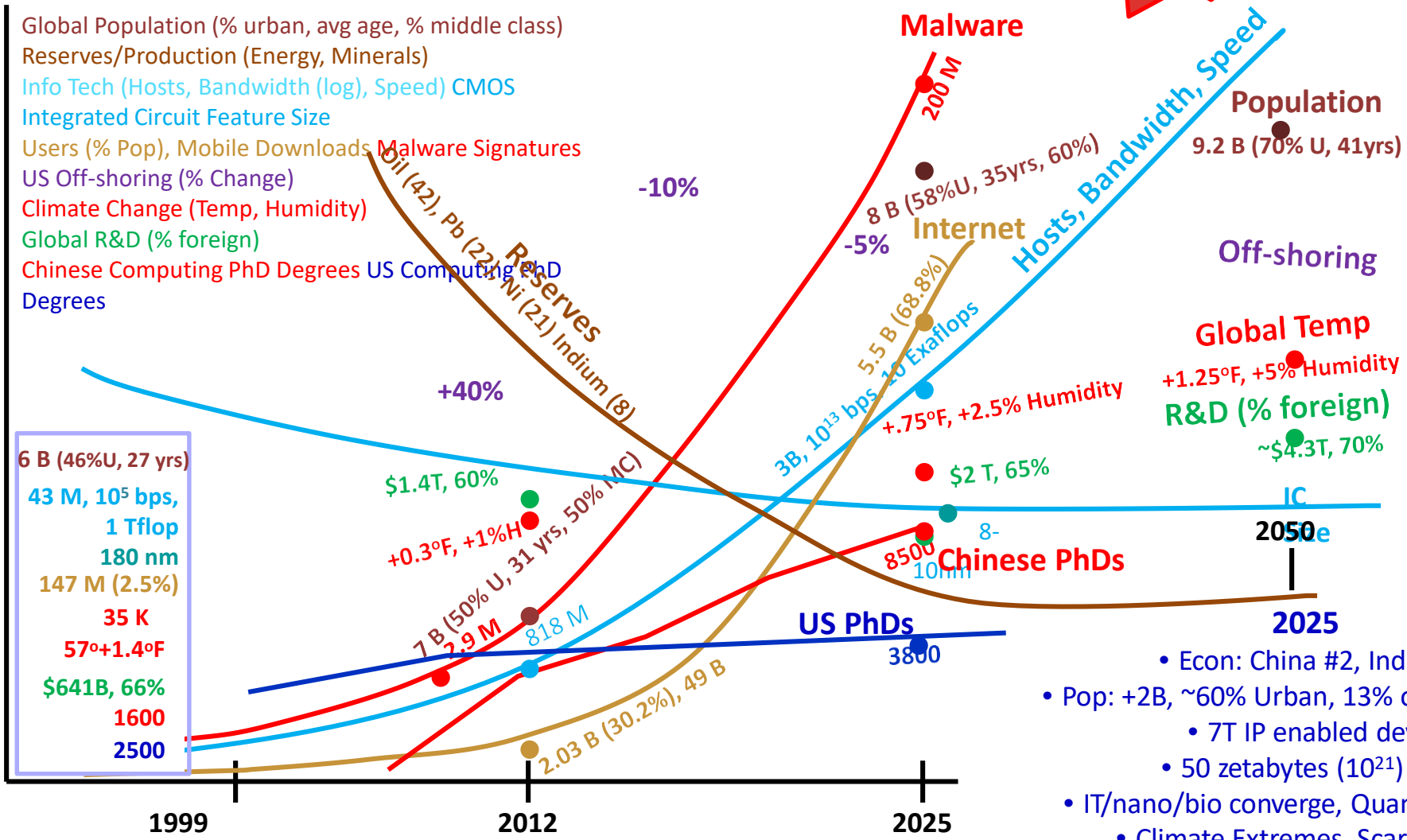
Global Horizons 1999-2025+

Shocks
(Health, Env, Econ, Soc, Pol)



2025

- Econ: China #2, India #3
- Pop: +2B, ~60% Urban, 13% older
- 7T IP enabled devices
- 50 zetabytes (10^{21}) data
- IT/nano/bio converge, Quantum
- Climate Extremes, Scarecity
- World Bank, WTO, IMF

CMOS – Complimentary Metal-Oxide Semiconductor; IC – Integrated Circuit World Trade Organization (WTO), International Monetary Fund (IMF)
PhD Degrees in Computer Science/Computer Engineering/Computational Mathematics

Big Mechanical Themes

1. Suppliers are becoming more and more capable
2. The pressure to reduce electronics size, weight, power, and cost (SWaPC) is relentless, significantly impacting mechanical implementations
3. These are exciting times in materials and manufacturing; the additive manufacturing (AM) revolution is real
4. Advanced modeling and simulation (M&S) of mechanical systems is becoming more and more critical

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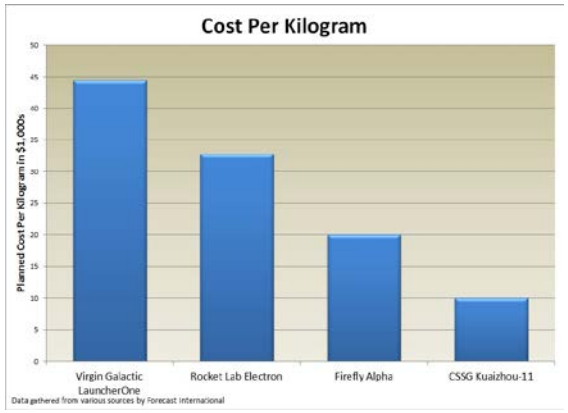
Suppliers are becoming more and more capable

The trend of suppliers providing an increasing level of hardware (H/W) capability at all scales will continue: Commercial potential will drive down L/V costs and commoditize increased H/W capabilities

- Launch providers are in a first mover to market phase. After that shakeout, L/V and access to LEO costs will decrease significantly



http://blog.forecastinternational.com/wordpress/wp-content/uploads/2016/03/2016-03-16-light-launch-vehicle-cost-comparison.jpg

- Space H/W at the subsystem/component level is becoming more capable and available as a commodity

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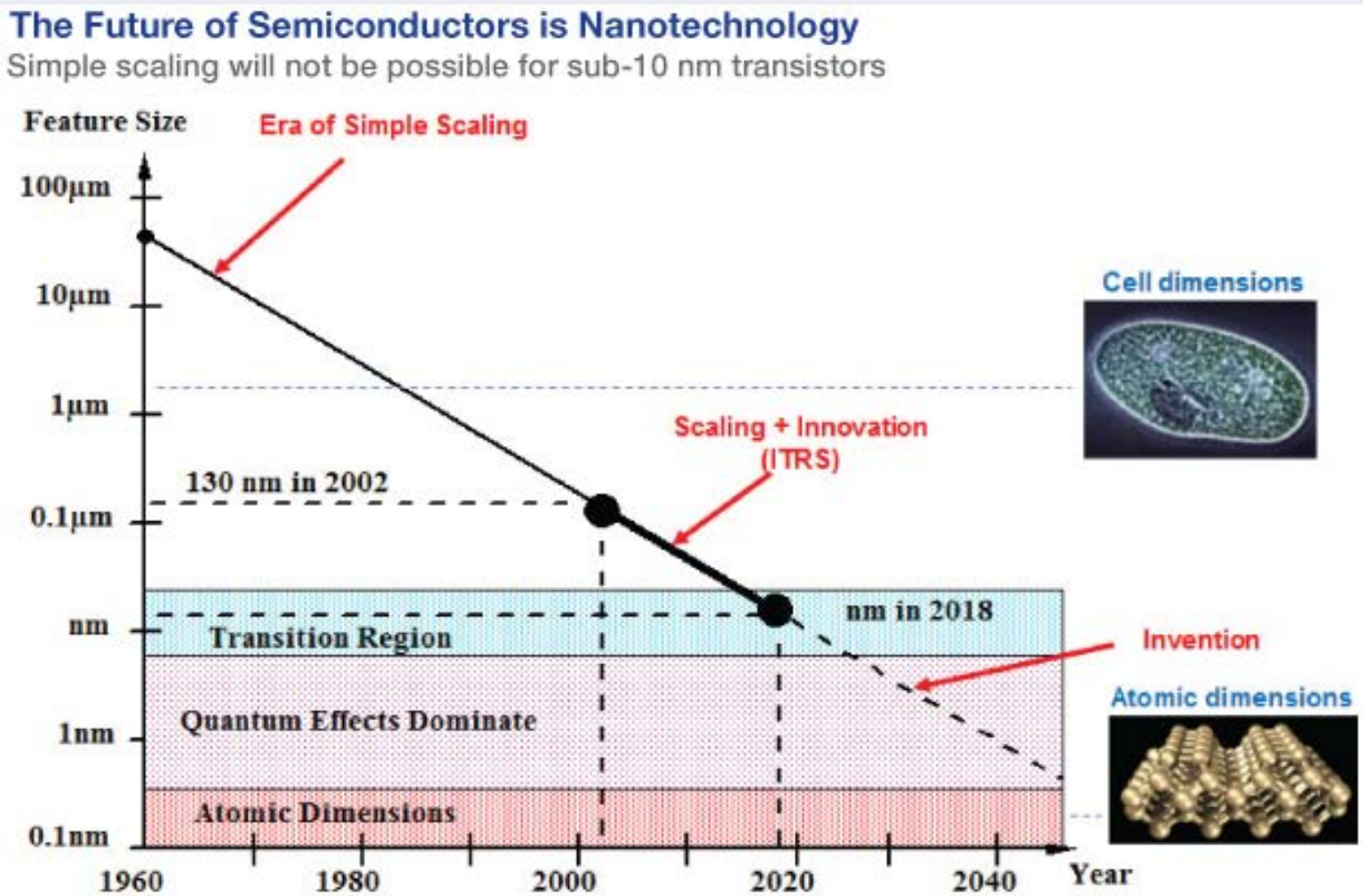
The pressure to reduce SWaPC is relentless, impacting mechanical systems



Source: From Silicon VLSI Technology, by professors James D. Plummer, Michael D. Deal, and Peter B. Griffin. Stanford University, 2000.

2018: The End of Easy Scaling and the Dawn of Nanotechnology
Abe Michelen 12 February 2013
http://electronics360.globalspec.com/article/16/2018-the-end-of-easy-scaling-and-the-dawn-of-nanotechnology

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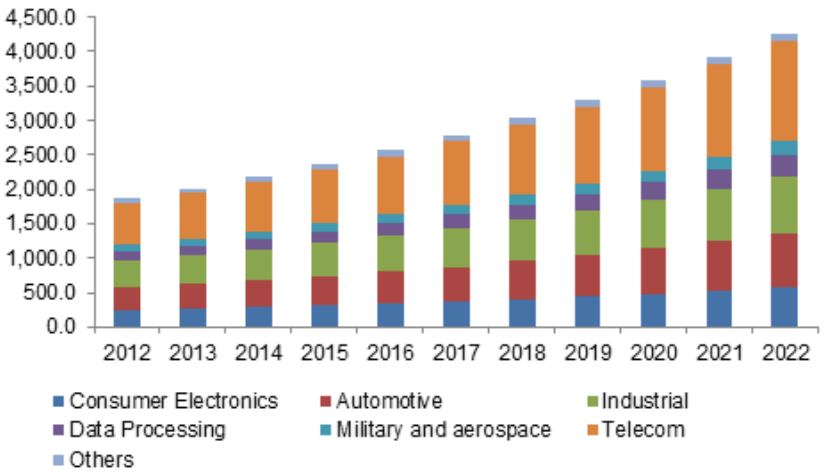
The pressure to reduce SWaPC is relentless, impacting mechanical systems

- Advances in electronics packaging and miniaturization are now driven by the consumer market. That market now dwarfs the one for space and defense.



https://www.gminsights.com/assets/img/field-programmable-gate-array-fpga-market-size.png

- Consequently, commercial-off-the-shelf (COTS) parts will become the new norm for space. The availability of MIL-STD parts is already rapidly dwindling.

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The pressure to reduce SWaPC is relentless, impacting mechanical systems

COTS parts: The Pluses

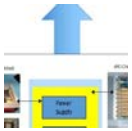
- Greatly improved SWaPC
- Greatly improved capability
- Available

COTS parts: The Minuses

- Reliability in space environments unknown, particularly in high radiation environments
- Thermal control is more challenging
- Space is a niche market

OCO3/DPU

UNIIBUS



SWaP	OCO3 / DPU	UNIIBUS	% SAVINGS
SIZE	14850 cm^3	276 cm^3	98
WEIGHT	8.0 Kg	1.2 Kg	85
POWER	28W	18W	36

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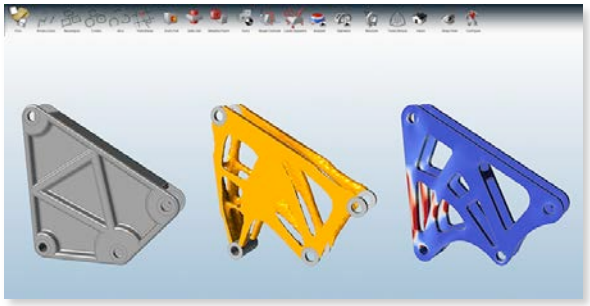
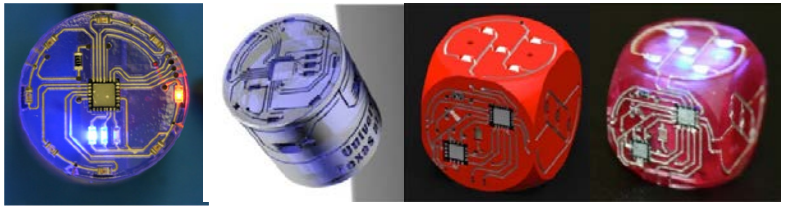
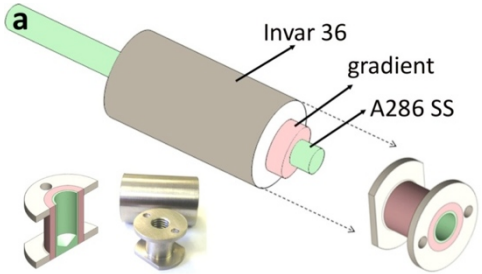
These are exciting times in materials and manufacturing; the AM revolution is real

- Complex parts are completed with less fabrication and integration time/cost than with traditional subtractive manufacturing
- Structures can be “topologically optimized” to produce optimal strength-to-weight designs
- Structural components can be made multifunctional by embedding other functionality during manufacturing (4D printing)
- Gradient alloy materials can be designed, fabricated, and tailored for a specific application







http://www.nature.com/articles/srep05357

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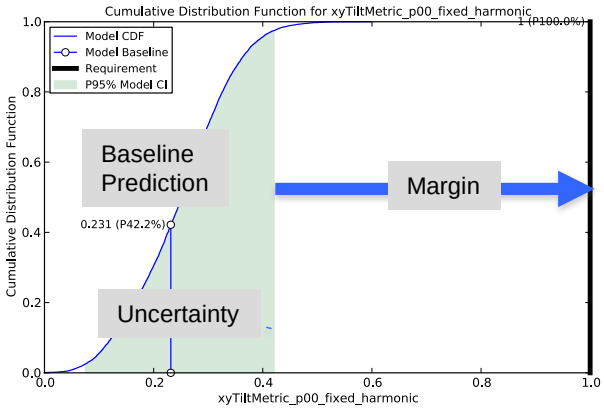
Advanced M&S of mechanical systems is becoming more and more critical

Recent advancements in high performance computing enable high fidelity, physics-based M&S of engineering systems. M&S can now be incorporated into the entire engineering product lifecycle, from design through test.
It can be used to

- Perform quick upfront conceptual design trades
- Quantify engineering margins (QMU)
- Resolve anomalies
- Enable approaches that support test-as-you-fly (TAYF) exceptions

https://merveeakiss.wordpress.com



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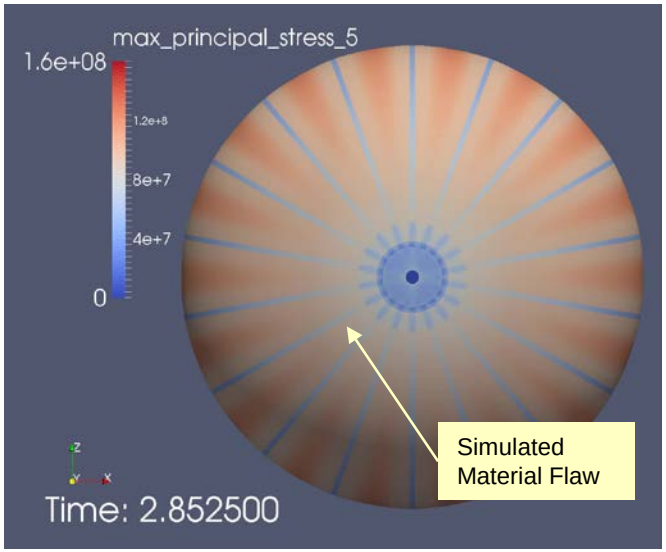
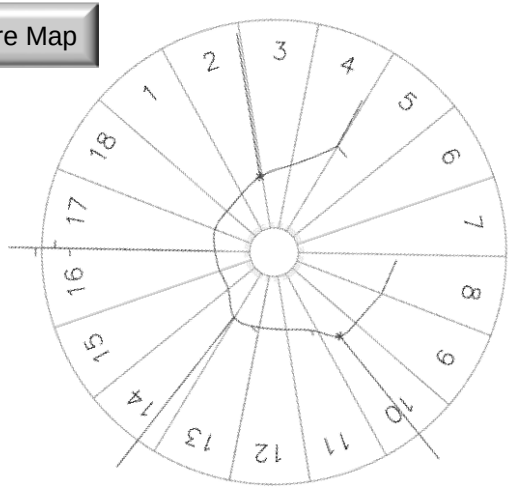
Advanced M&S of mechanical systems is becoming more and more critical

Frame Capture of Rupture at 30% of Rated Proof Pressure

Simulated Inflation and Rupture

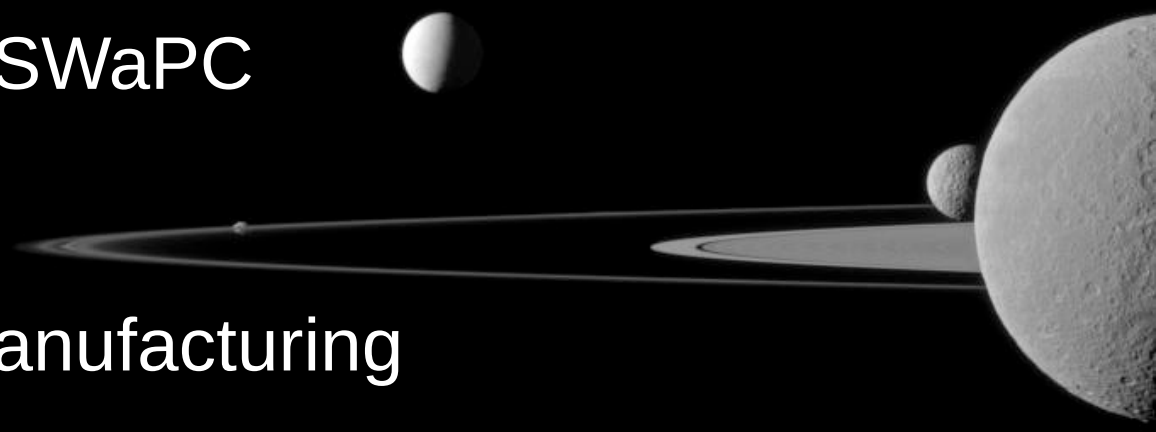


Test Failure Map



To summarize key themes…

1. Supplier capability
2. Electronics and SWaPC
3. Materials and Manufacturing
4. M&S



Quintet of Moons
Cassini

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