Qualification Methodology of AlSi10Mg for Spaceflight

Bryan W. McEnerney, R. Peter Dillon, J.P. Borgonia, Andrew A. Shapiro-Scharlotta

Jet Propulsion Laboratory, California Institute of Technology

August 27, 2015

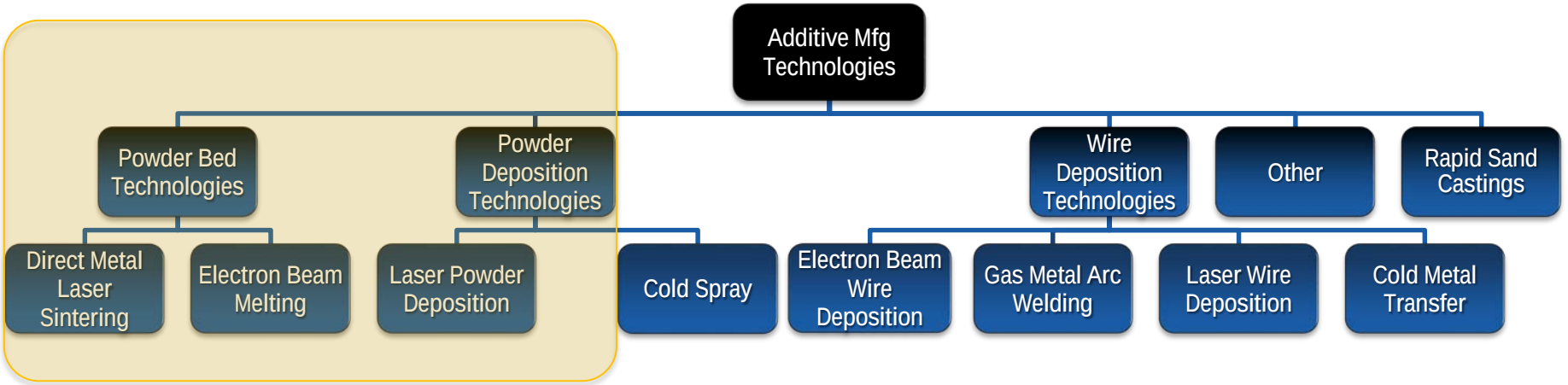
Jet Propulsion Laboratory
California Institute of Technology

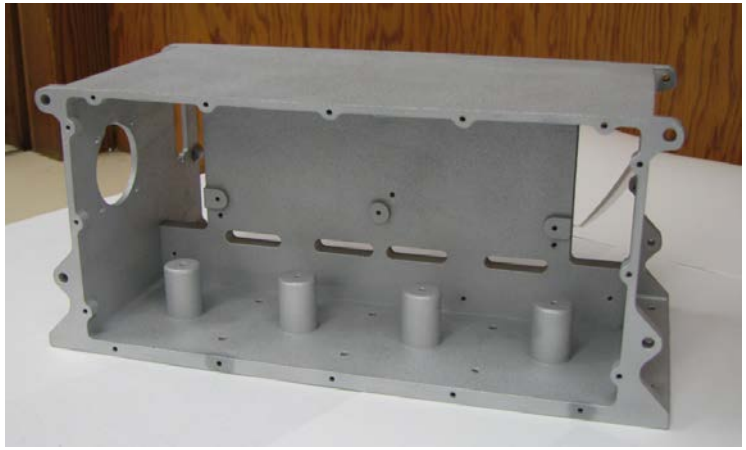
Agenda

1. Overview of AM at JPL
   - Processes
   - Machines
   - Materials
2. Flight Insertion & Qualification Opportunities
   - OCO-3/Ecostress
   - Cold Shaft Encoder
   - Cubesats
3. Qualification Approach

Additive Manufacturing Technologies Overview

Additive Manufacturing at JPL, briefing





Direct Metal Laser Sintering (DMLS)
SEP Electronics Chassis (AlSi10Mg)

Direct Metal Laser Sintering (DMLS)
MAHLI Bracket (AlSi10Mg)

Additive Manufacturing Materials, Metallics

Additive Manufacturing at JPL, briefing

Aluminum and titanium alloys comprise 85% of flight structural components

- Ti-6Al-4V produced via EBM (Arcam) process is baseline for flight use due to robust database
- JPL primary aluminum alloys are Al 2024, 6061, 7050, 7075
  - Current AM offering, AlSi10Mg (SAE 4032), doesn't correspond to existing alloy classes
  - Challenge to integration due to lack of familiarity

Challenges

- Manned spaceflight and Class A missions require A-basis for primary structure, B-basis for secondary structure
  - Database for AlSi10Mg is not publicly available and is expensive for limited part set
- JPL's missions are generally single build, so total cost cannot be amortized over a single part or part-family

Qualification Methodology

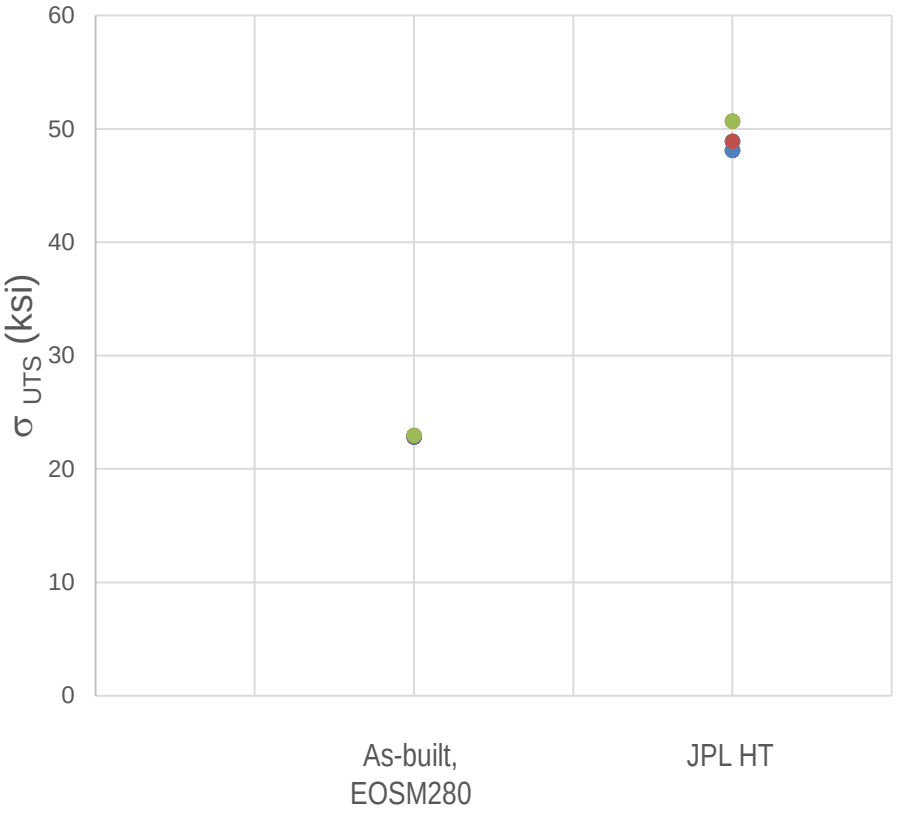
Additive Manufacturing at JPL, briefing

- Mechanical Testing
  - Detailed testing required for applications
  - Testing incorporates a wide range of parameters (-150 °C < T < 200 °C) for standard systems
  - Typical minimum data set shown at right
  - Expensive (~$0.5 – 2M per alloy)
- Proof Testing
  - Additional expensive and potential risk if test isn't properly designed or executed
  - Can act as a schedule reduction

Mechanical Property	Mechanical Property
LCF (Strain Controlled Fatigue)	Stress Rupture
Room temp	Elastic Modulus
Cryogenic temp	Room temp
Elevated temp	Cryogenic temp
Tensile Strength	Elevated temp
Room temp	Elongation
Cryogenic temp	Dynamic Modulus
Elevated temp	FCGR Properties
Thermal exposure	Crack Growth
Hydrogen Environment	Toughness, Plane Strain
Other	Toughness, Plane Stress
Reduction of Area	HCF (Load Controlled Fatigue)
Shear Strength	Room temp
Stress Strain Curves (Full)	Cryogenic temp
Physical Properties	Elevated temp
Density	
Thermal Conductivity	
Poisson's Ratio	
Specific Heat	
Thermal Expansion Coefficie	

Heat treatment effects

Additive Manufacturing at JPL, briefing



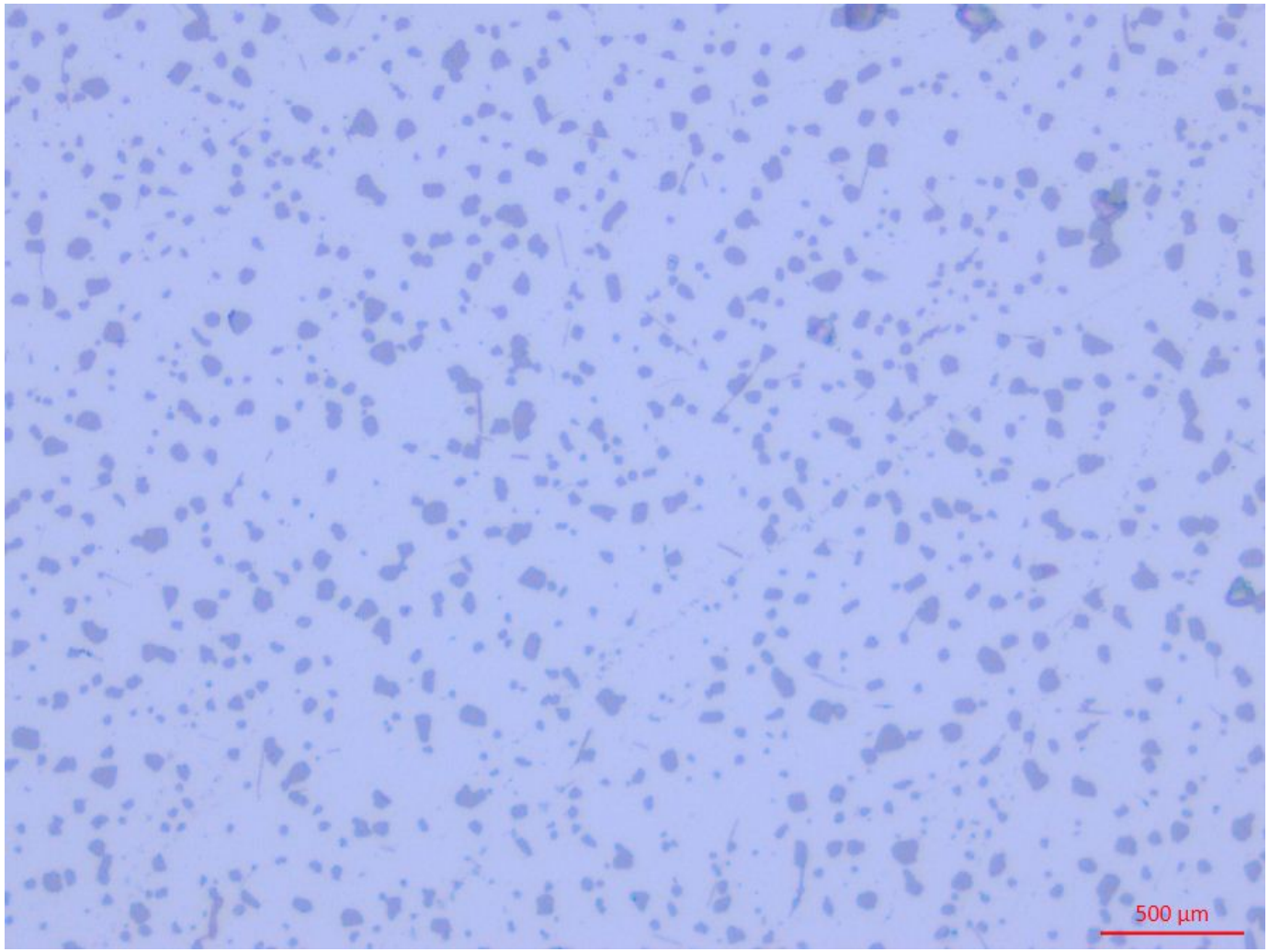
Standardized heat treatment
6 hrs at 538 °C (Ar)
Quench (H_2O) to 25 °C
158 °C, 2 – 4 hrs

Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

Alexopoulos and Pantelakis, *Materials & Design*, 25 (2004) 419-430.
Rometsch and Schaffer, *Materials Science & Engineering A*, A325 (2002) 424-434.

Heat treatment microstructure

Additive Manufacturing at JPL, briefing

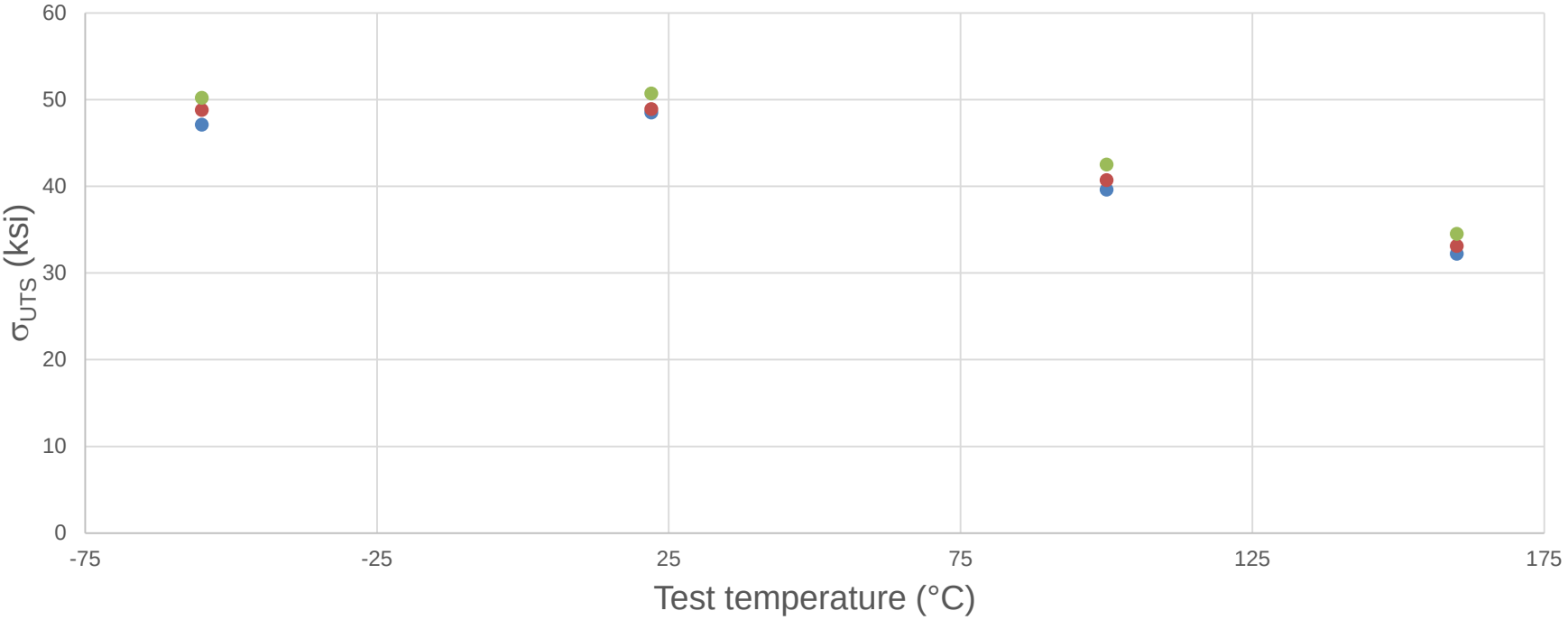


Surface finish effects

Additive Manufacturing at JPL, briefing

Test Temperature	Specimen Number	% Elongation	Initial Gauge Area²	Final Gauge Area²	% Reduced Area	Modulus (Msi)	Ly (lb)	σ_y (ksi)	Ultimate Stress (ksi)	Ultimate Load (lbs)
22 ˚ C	1	10.34	0.0481	0.0361	24.89	10.07	1390.21	28.90	41.02	1973.37
	2	14.26	0.0483	0.0358	25.89	10.78	1220.20	25.26	37.13	1793.59
	3	13.11	0.0481	0.0335	30.39	10.34	1208.18	25.11	36.93	1776.51
	4	14.90	0.0485	0.0333	31.28	10.97	913.57	18.84	30.99	1503.03
	5	13.65	0.0485	0.0325	32.94	10.62	1131.64	23.33	35.35	1714.62
	Average	13.253	0.048	0.034	29.076	10.558	1172.758	24.288	36.283	1752.223
	STDEV.	1.761	0.000	0.002	3.507	0.357	172.960	3.657	3.620	169.353
	COV %	13.286	0.403	4.698	12.061	3.385	14.748	15.057	9.978	9.665

Tensile behavior of AlSi10Mg

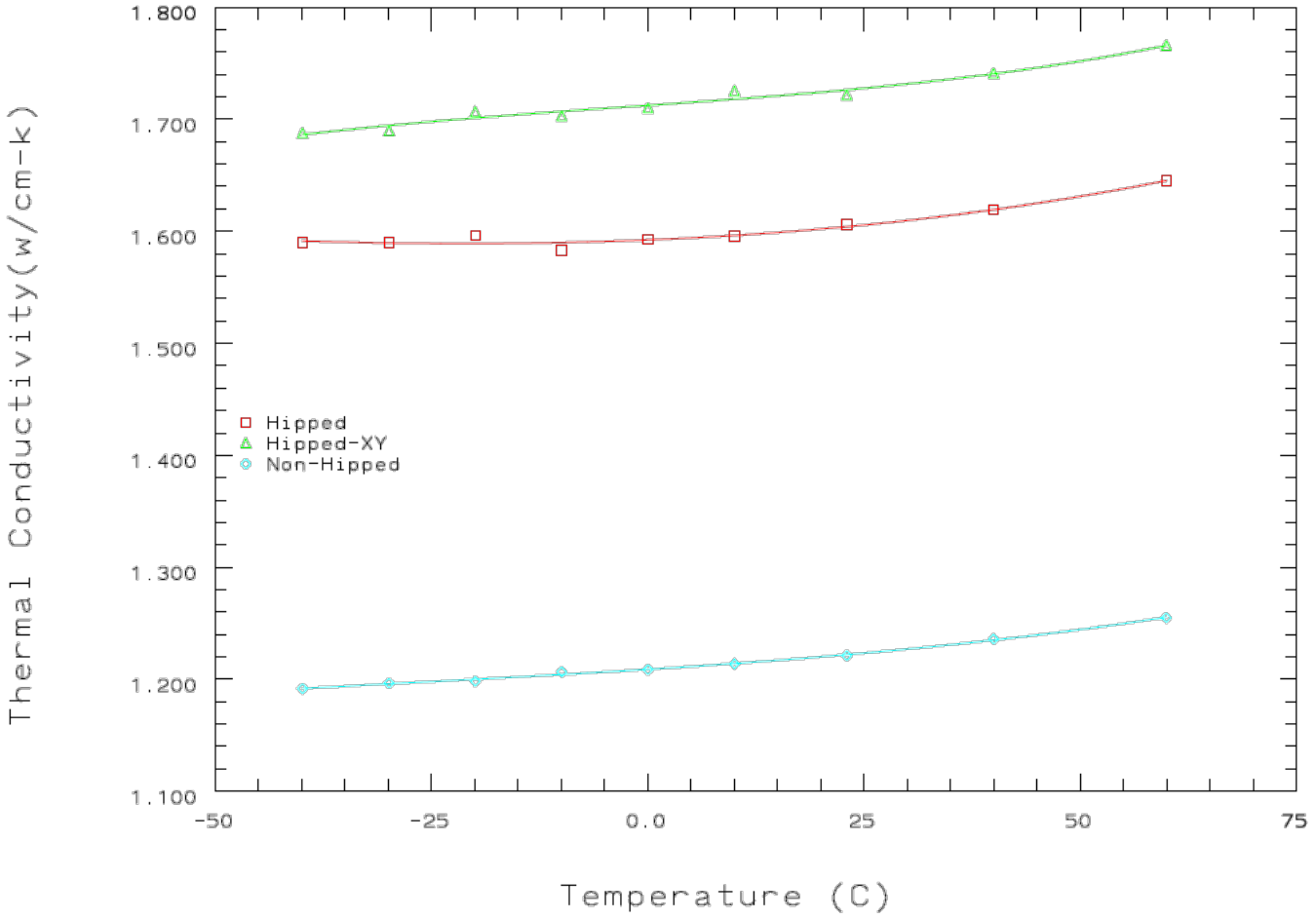


Testing performed with JPL standard heat treatment
Bemco thermal control chamber

Instron 1331 #395182
Strain-controlled, 0.005 in/in/min
ASTM E8

Additively Manufactured Aluminum Insertion (cont.)

Additive Manufacturing at JPL, briefing



Data courtesy A.J. Mastropietro & D. Forgette (353K)

Additively Manufactured Aluminum Insertion

Additive Manufacturing at JPL, briefing

Using industry base for production of parts

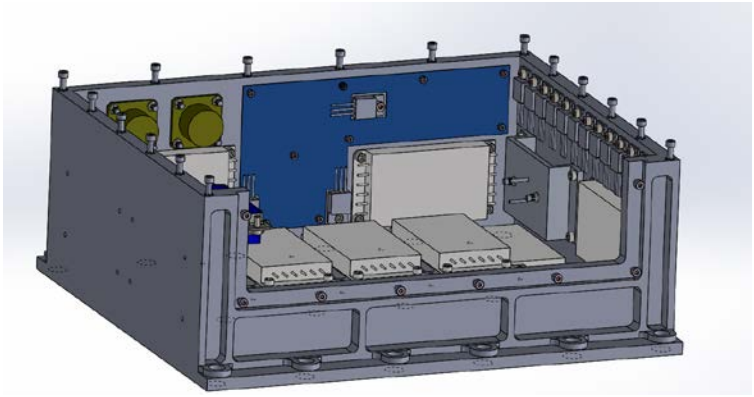
- Generation of thermophysical and mechanical property data from suppliers
- Developed internal heat treatment process

Initial targeted flight opportunities

- Orbital Carbon Observatory – 3 (OCO-3)
- ECOSTRESS
- Development SEP electronics chassis (NASA LaRC)

Selection process

- Initial parts are electronics enclosures; low risk, low structural requirements
- Data sets are limited and parts are not fracture critical
- Class D missions



OCO-3, ECOSTRESS
Common Electronics Chassis

Qualification Approach

Additive Manufacturing at JPL, briefing

1. **Organic development** of mechanical properties based upon program need.
    1. Require all projects to build standard geometry specimens and perform limited testing.
    2. Aim for common property needs (e.g. thermal conductivity, stress vs. strain, etc.)
    3. Programs requiring non-standard properties pay for testing (e.g. fatigue)
2. Focus on a **limited set** of alloys.
    1. AlSi10Mg is a potential replacement for some Al alloys
    2. Ti-6Al-4V can be utilized as a drop in (ELI version for specialty needs).
3. Materials & Processes focused on informed decisions for AM insertion onto flight programs.
    1. Avoiding improper usage (e.g. flat plate)
    2. Understanding complete process flow for post-build challenges (e.g. joining, surface finish, etc.)
    3. Understand nature of desired component
4. **Non-destructive evaluation** investigation.
    1. Building sample targets with engineered defects

Acknowledgements

- Funding for this work was provided by various accounts, including CIF, SR&TD, and Advanced Concepts Office. We would like to acknowledge Dr. F. Hadaegh, Dr. J. Zmuidzinas, Dr. A.A. Shapiro and Dr. T. Cwik for funding.
- Internal collaborators include Mr. D. Forgette, Mr. A.J. Mastropietro, Mr. A. Aljabri, Dr. S. Roberts, Mr. D. Lewis and Mr. A. Nuss.

Jet Propulsion Laboratory
California Institute of Technology

Acknowledgements

OCO-3 PDR