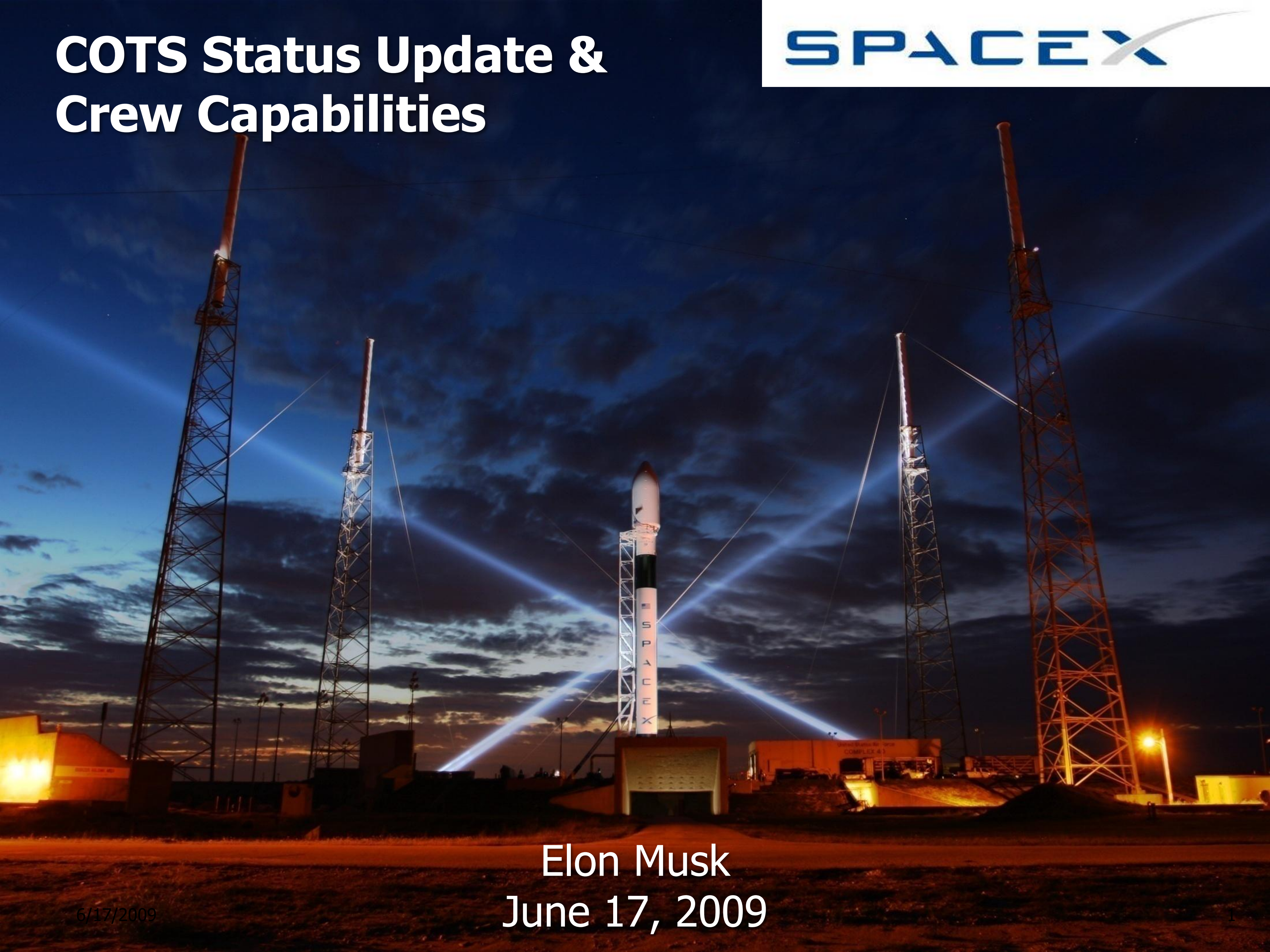
COTS Status Update & Crew Capabilities



Elon Musk
June 17, 2009

SpaceX Overview

- Founded in 2002 with the singular goal of providing **<u>highly reliable, low cost space transportation</u>**
  - Expand into human transportation once technology is proven
- 800 employees — growing ~50% per year
- Facilities:
  - 550,000 sqft of offices, manufacturing & production in Hawthorne, CA
  - 300 acre state-of-the-art Propulsion and Structural Test Facility in central Texas
  - Launch sites at Kwajalein & Cape Canaveral

Kwajalein

Hawthorne Headquarters

Central Texas

SLC-40, Cape Canaveral

SpaceX Manifest

Customer	Launch	Vehicle	Departure Point
ATSB (Malaysia)	Q3 2009	Falcon 1	Kwajalein
Falcon 9 Maiden Flight	2009	Falcon 9	Cape Canaveral
NASA COTS - Demo C1	2010	Falcon 9/Dragon	Cape Canaveral
Avanti Communications (UK)	2010	Falcon 9	Cape Canaveral
NASA COTS - Demo C2	2010	Falcon9/Dragon	Cape Canaveral
MDA Corp (Canada)	2010	Falcon 1	Kwajalein
NASA COTS - Demo C3	2010	Falcon9/Dragon	Cape Canaveral
NASA CRS1	2010	Falcon 9/Dragon	Cape Canaveral
DragonLab Mission 1	2010	Falcon 9/Dragon	Cape Canaveral
Swedish Space Corp. (Sweden)	2011	Falcon 1	Kwajalein
Bigelow Aerospace	2011	Falcon 9	Cape Canaveral
NASA CRS2	2011	Falcon 9/Dragon	Cape Canaveral
DragonLab Mission 2	2011	Falcon 9/Dragon	Cape Canaveral
CONAE 1A (Argentina)	2012	Falcon 9	Kwajalein
CONAE 1B (Argentina)	2013	Falcon 9	Kwajalein
NASA CRS3-12 (10 additional missions)	2012-15	Falcon 9/Dragon	Cape Canaveral

Falcon 1 commercial | Falcon 9 commercial | COTS Demo | ISS Cargo Delivery | DragonLab

Falcon 1 Status

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- **Reached orbit Sept 28, 2008**
- Next launch July 2009
- Launch facility on Omelek Island, Kwajalein Atoll
- World's lowest-cost dedicated orbital mission
- Substantial Lessons-Learned & feed-forward for Falcon 9 vehicle

All structures, engines, most avionics and all ground systems designed (and mostly built) by SpaceX

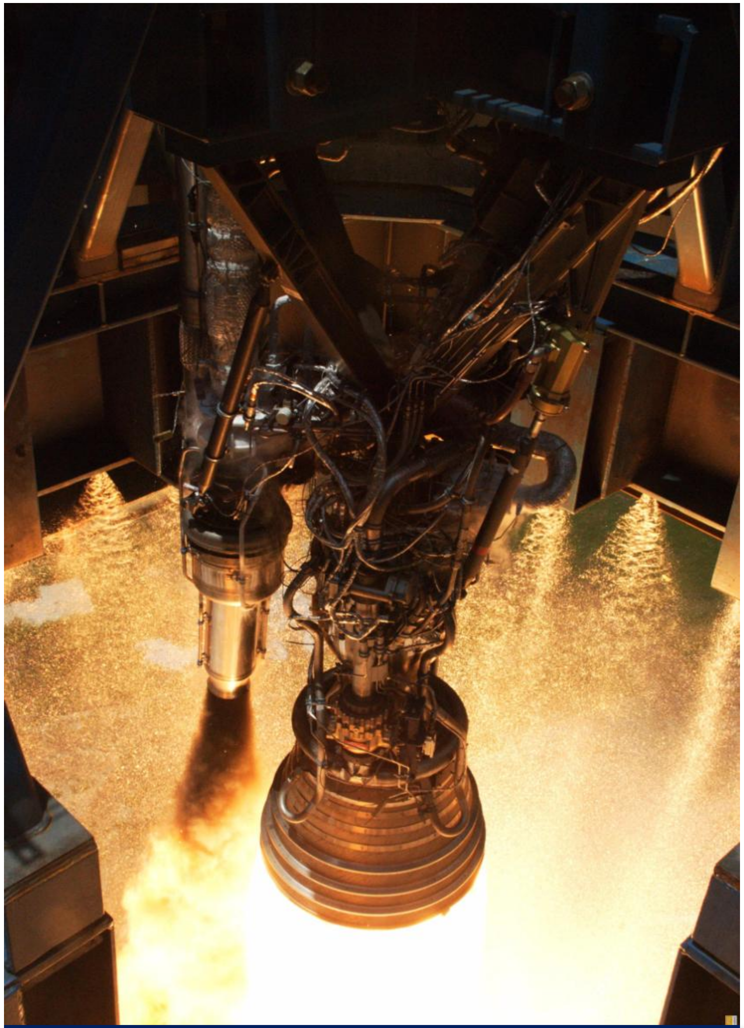
Falcon 1 Flight 5 on Omelek

Falcon 9 Status

- **Inaugural mission Q4 2009**
- >5x cost reduction compared to domestic competitors
- Designed from inception for crew transportation
  - Simple, high-reliability architecture
  - Engine-out reliability, similar to Saturn I & V
  - Meets NASA crew-rated safety margins and failure tolerances

All structures, engines, most avionics and all ground systems designed (and mostly built) by SpaceX

Falcon 9 Status - Merlin



Acceptance Test of Flight Merlin Engine
(Qualification complete)

Full Mission-Duration (360 second) Test of Merlin-Vacuum Engine for Falcon 9 2nd Stage

Falcon 9 Status: 9-Engine Tests

1st Stage Full Duration Static Fire (177 seconds) 11/22/08

View of 9 engines post-test, including heat shield/close-out panels

Falcon 9 Status - Merlin

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Falcon 9 Engines, Truss & Skirt

Merlin Production Line

Falcon 9 Status

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Falcon 9 1st Stage & Interstage in Qualification Testing

Falcon 9 Flight 2nd & 1st Stages

Falcon 9 Lithium-Polymer Battery in Qualification Testing

Merlin Engine Controller on Qualification Engine

Falcon 9 Skirt & Truss in Qualification Test Stand

Falcon 9 on launch pad

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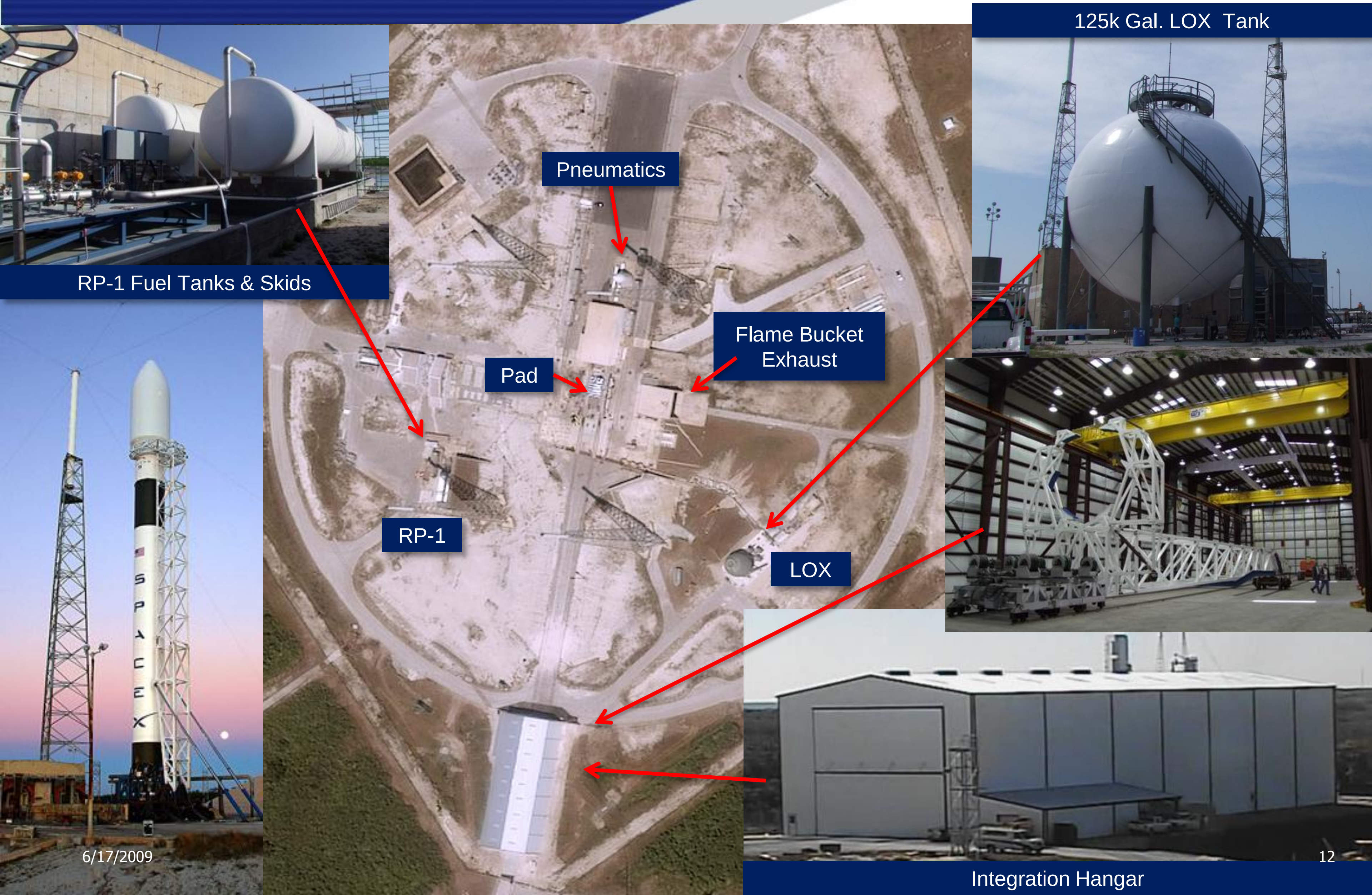
SLC-40 Cape Canaveral, January 2009

Cape Canaveral Launch Site



Dragon Status

- **Inaugural mission Q1 2010**
- 1st flight Qualification testing 90% complete
- 1st flight hardware in fabrication
- Designed from inception for crew transportation
  - Meets NASA crew-rated safety margins and failure tolerances

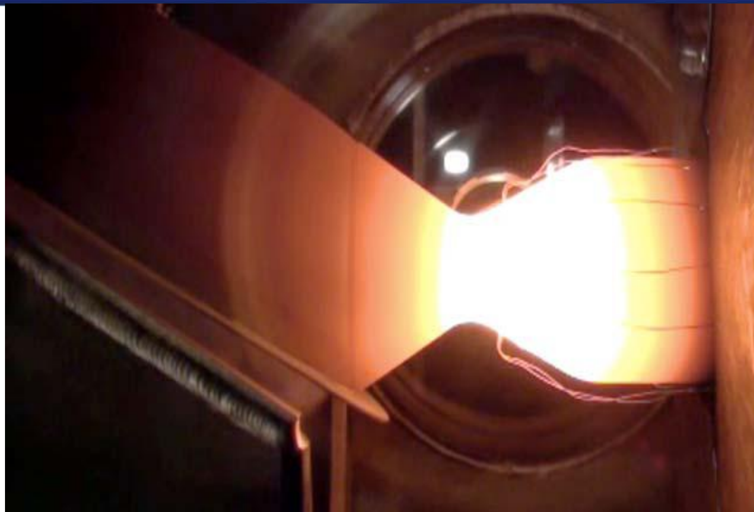
All structures, engines, most avionics and all ground systems designed (and mostly built) by SpaceX

Dragon Status

Dragon Acoustic Testing

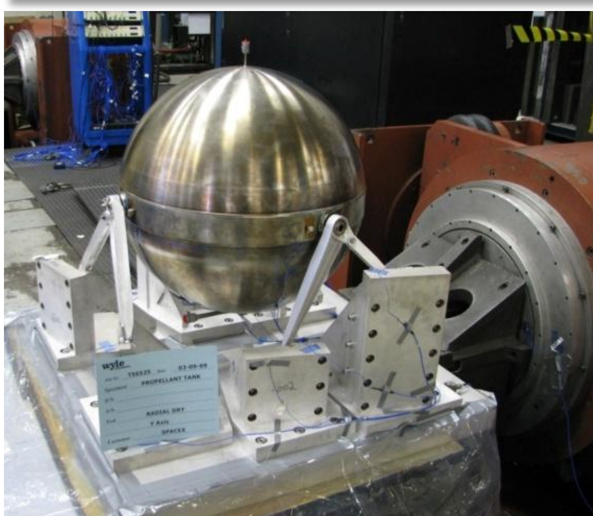
Dragon Structure in Qualification Testing

Dragon Status



Draco Thruster in Qualification Testing

NSA Certified Crypto Module



Propellant Tank in Qual

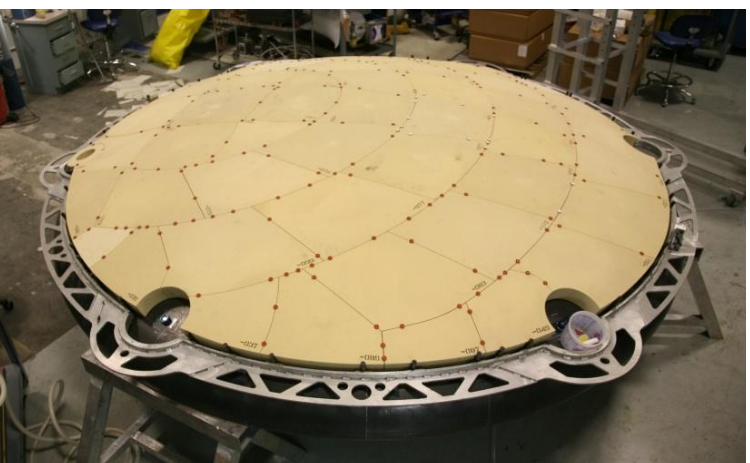
Draco Flight Thrusters

Dragon Status

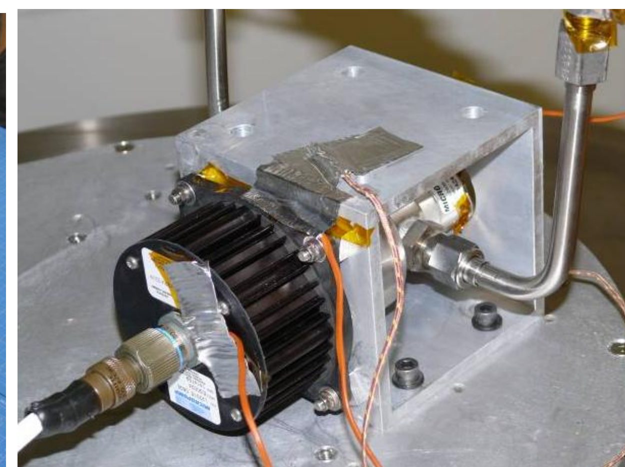

Qualification Li-P Battery


Demo C1 Flight Unit in Fabrication

Demo C1 Forward Bulkhead Flight Unit


Primary Heatshield Tile Lay-up


PICA-X Flight Tile

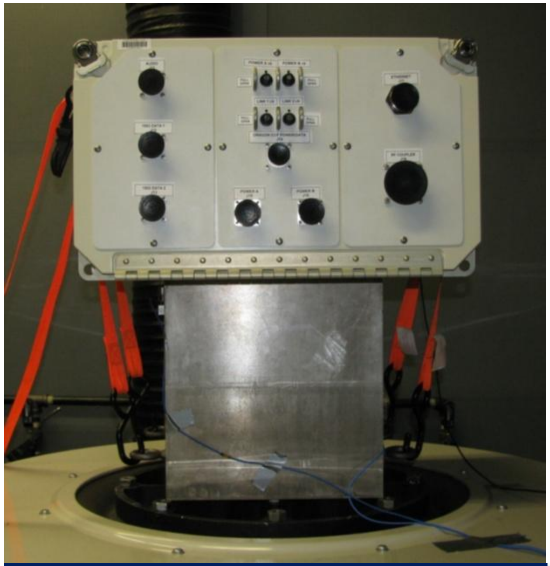

Thermal Control Pump in Qual

CUCU Status

- **C**OTS **U**HF **C**ommunications **U**nit
  - UHF cross-link with ISS
  - Dragon health & status telemetry → ISS crew
  - Basic commands from ISS crew → Dragon

- Flight Unit for ISS installation on-track for delivery to NASA this month
  - In Qualification testing

- Crew Command Panel
  - Completed Human Factors Review
  - In Qualification testing



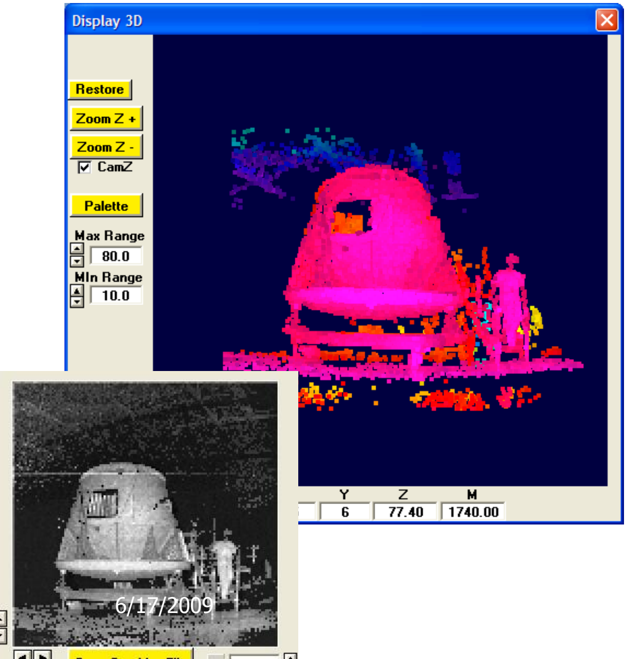
CUCU in Qualification Test

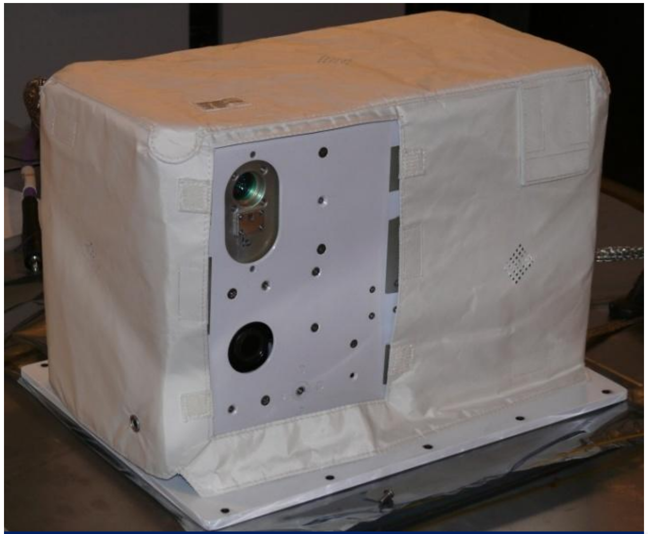
Crew Command Panel

DragonEye LIDAR Status

- DragonEye is primary prox-ops sensor on Dragon
- DTO payload on STS-127 (currently on pad)
- Will collect data during approach to ISS
- Substantial risk mitigation

DragonEye DTO installed in shuttle cargo bay





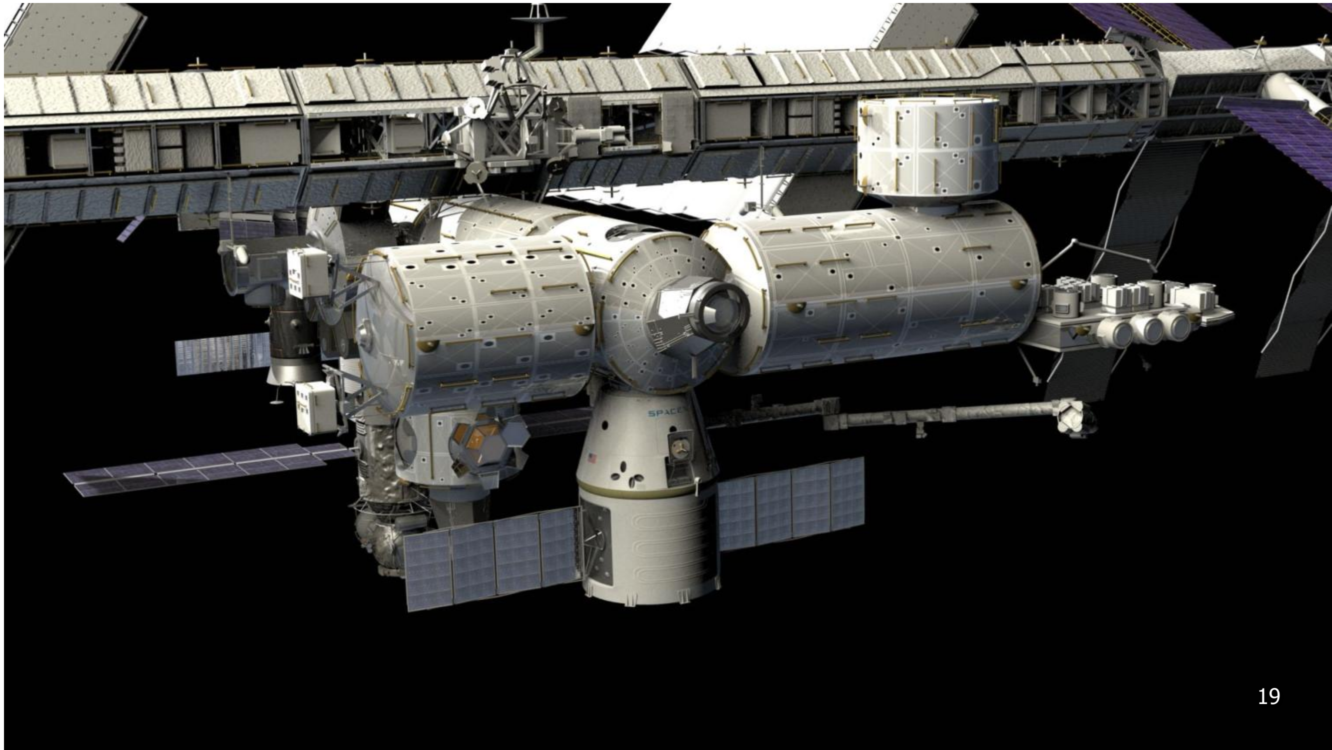
DragonEye DTO Flight Unit

ISS Integration Status

SPACEX

- Completed ISS Safety Review Panel (SRP) Phase 1 & most of 2
  - Phase 3 (final) scheduled early 2010
- Cargo integration planning in-work with both COTS and CRS programs
- Integration testing (including Joint Integration) is underway

- Also, end-to-end tests of integrated SpaceX-NASA ground system successfully completed



COTS Program Status

- Completed 14 of 22 milestones on schedule
  - Including all 3 financing rounds
  - Including SRR, PDR and CDR for each Demo
  - CUCU delivery scheduled for June 30th

- Some slips expected in remaining milestones
  - NASA has been fully informed regarding progress toward these milestones

- Demo flights now scheduled for:
  - Demo C1: January 2010 (2 months after inaugural F9 flight)
  - Demo C2: June 2010
  - Demo C3: Aug. 2010

Crew Capability

- Both Dragon & Falcon 9 were designed from inception to readily accommodate crew

This is why SpaceX was founded

- Immediate focus is on cargo for COTS & CRS commitments, BUT…

- In every design decision, the ability to attain human rating rapidly & at low additional cost is paramount

Note: Many human-rating requirements are mandated on the cargo vehicle because it must be safe for ISS crew

Dragon Already Designed to Accommodate ISS Crew

- For COTS Capabilities A-C, astronauts will enter (and temporarily inhabit) the Dragon spacecraft for loading and unloading of cargo to and from the International Space Station
- Therefore, Dragon already meets the manned requirements to allow this activity, as called out in SSP 50808
  - Air sampling and circulation
    - ISS crew sample Dragon's air supply through the Air Revitalization System (ARS) port before entering the spacecraft, breathing in the air as provided by the Dragon Environmental Control System.
    - Air circulation is provided to ensure safe breathability throughout the spacecraft
  - Temperature and humidity requirements
  - Touch temperature limits: between 39 F and 113 F
  - Human Factors
    - Protection from shock
    - Restrictions on sharp corners, sharp edges, exposed screw threads, burrs, and pinch points.
    - All fonts, colors, and labels are consistent with SSP 50005.

Additional Dragon Design Features Added for Crew Accommodation

- **Factors of Safety:** primary structures designed to 1.4 or 1.5 on ultimate factors of safety per SSP 30559 (instead of 1.25)
- **Driving Design Load Cases** are specific to crewed missions:
  - Launch escape system ignition, burn & worst-case abort reentry
  - These loads are 30% higher than any loads potentially occurring on a cargo mission
- **Usable Volume:** Selected to accommodate at least 6 crew
- **Fault Tolerance:** At least 2-fault-tolerant, as required for human rating, including Flight Computers & Propulsion systems
- **3.5 g's nominal reentry acceleration** (similar to Gemini)
- **Crew Egress:** 2 hatches one opens outwards, the other inwards
- **Three windows**, even in cargo version
- **Thermal Control System & radiator** are sized for crew requirements
- **>210 days orbital life span:** Positive energy balance, lots of propellant for station-keeping etc.

Additional Development Required to Fly Crew

- **Launch Escape System**
  - Preliminary designs already defined
  - Leverages heavily off existing SpaceX designs and capabilities
- **Crew Accommodations**
  - Seats, monitoring & overrides
- Up-rate Environmental Control System to full **Life Support**
  - Add CO_2 & Humidity Control
- **2.5 years** required for first crewed mission
- "**Life-boat Dragon**" (return only) capability could be achieved within 1.5 years

…and NASA is NOT the only customer…

Value of COTS (so far…)

- **In under 4 years & $234M the SpaceX COTS program has achieved:**
  - Retirement of major risks and established launch site for first all-American new launch vehicle in over 30 years
    - Main engine qualification
    - 9-engine full-duration firing
  - Post-CDR-level spacecraft design
  - Near complete set of Qualification hardware for inaugural mission
  - Interface concurrence with ISS
  - In-house fabrication & qualification of primary heatshield material
  - Design & qualification of hypergolic thrusters & propellant tanks
  - Delivered ISS cross-link radio capability

  (and about to flight-test proximity-operations LIDAR sensor on ISS approach on STS-127)

- As a direct result, **SpaceX could supply** to NASA at extremely low-cost by aerospace standards:
  - PICA-X **heatshield material**
  - Merlin **engines**
  - Draco **hypergolic thrusters & propellant tanks**
  - NSA-certified communications **en/decryption module**
  - In-space **cross-link communications transceiver** (CUCU)
  - **Proximity-operations LIDAR sensors** (DragonEye)
  - Extremely small, light-weight **S-band/TDRSS transceivers**
  - Large-structure **Friction-Stir Welding manufacturing** capability & expertise
  - Highly flexible, low-cost **avionics I/O module** (RIOs)

  …amongst other things

Remarkable Return on Investment!

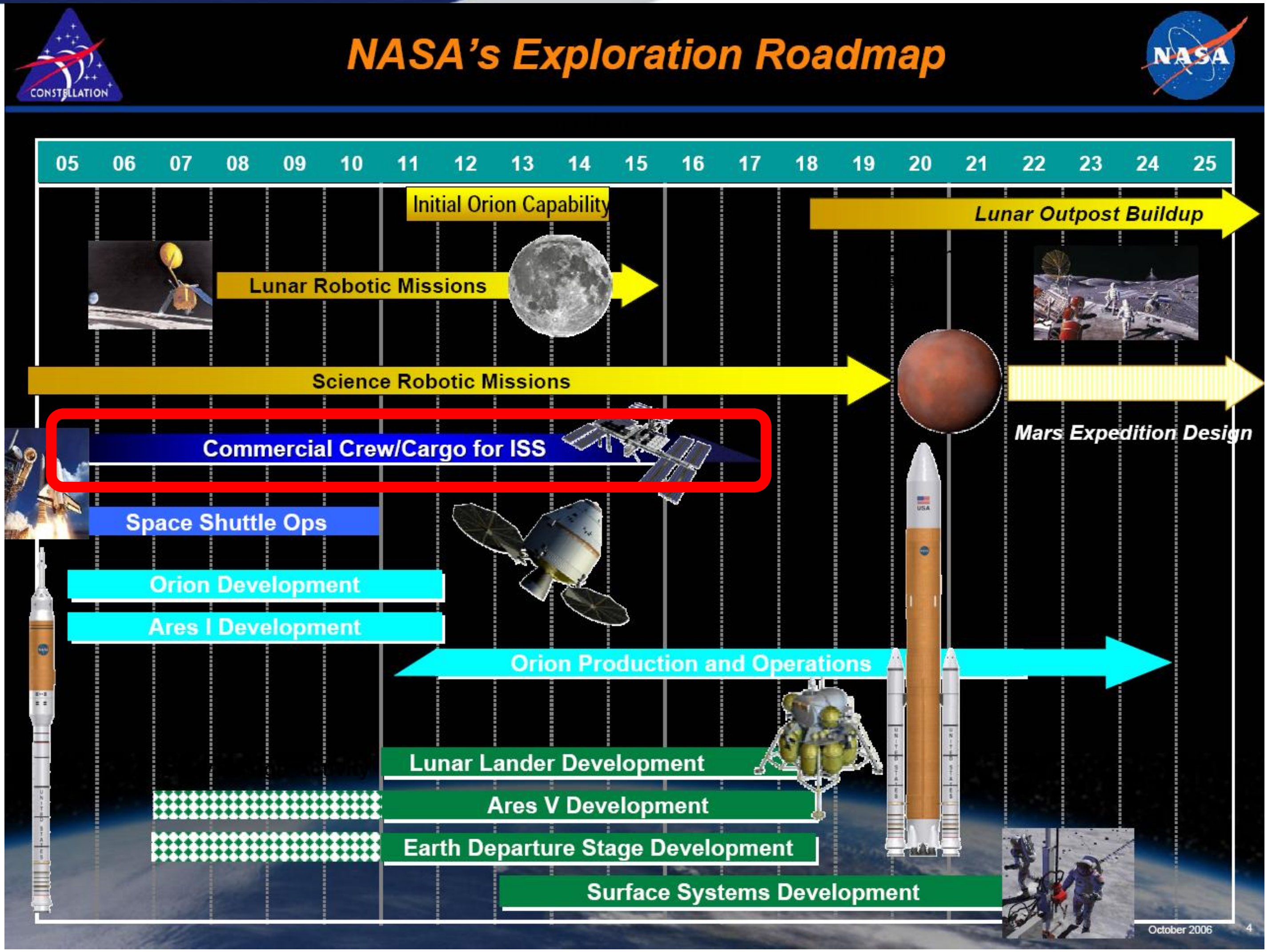
COTS Benefits

- **Commercial services & benefits derived from COTS could include:**
  - Cargo ↔ ISS (currently under contract)
  - Crew ↔ ISS
  - Crew Rescue ("Life-boat Dragon")
  - Components → Constellation & other programs
  - Rendezvous, inspection & robotic servicing of spacecraft

The COTS paradigm delivers maximum results at minimum cost & risk

COTS is integral to Exploration

SPACEX



Commercial Crew/Cargo was always part of the plan

COTS is Enabling…

…by providing housekeeping & logistics services, at commercial rates, allowing NASA to focus **personnel, facilities & money** on the main objective – the Moon & beyond

Earth → Moon → Mars → beyond…

Back-up Slides

"Life-Boat" Dragon

SPACEX

- Dragon could be certified as a "lifeboat" to return ISS crew to Earth in an emergency
- Lifeboat Dragon would be launched without crew, berth with ISS (like Cargo Dragon), and remain on standby for crew rescue and return
- Lifeboat Dragon could be certified for this return trip independent of (and in parallel with) other crew system developments
  - Lead-time for **Initial Operational Capability (IOC) to ~18 months**
  - By far, the biggest development for full crew capability is the Launch Escape System (LES). By launching Lifeboat Dragon empty the LES is not required.
- This allows US crew to be maintained on ISS without depending on Russian Soyuz vehicles for rescue
  - Shuttle would still be needed for crew delivery to ISS until Crewed Dragon comes online ~30 months after ATP
  - Remaining shuttle flights could be spaced out to cover the "Gap" (currently ~9 months), or additional flights could be added
- Besides the shuttle, only Dragon can accommodate an entire ISS crew of 6

Cargo Dragon will have proven itself capable of safe, autonomous return to Earth at least four times before a Lifeboat Dragon is even launched

"Life-Boat" Dragon

- Lifeboat Dragon could actually be a simpler vehicle than Cargo Dragon
  - Would not require solar arrays (or possibly a radiator), due to short mission duration
  - Cargo Dragon is already two-fault tolerant, as required for ISS safety
- The only significant developments are:
  - Upgraded Environmental Control to sustain crew for return trip duration
  - Crew accommodations (seats etc.) instead of cargo racks
  - Vehicle overrides and monitoring for the crew, as mandated by Human Rating Requirements
    - Note: Dragon cargo vehicle is capable of fully autonomous return to Earth
  - Docking/berthing adapter capable of rapid departure

All other necessary capabilities are already provided by Cargo Dragon

Design-to Standards

- NPR 8705.2B: Human-Rating Requirements for Space Systems
- NASA Std 3000: Man-Systems Integration Standards
- SSP 50005: ISS Flight Crew Integration Standard
- SSP 50808: ISS-COTS Interface Requirements Document
- SSP 50809: ISS to COTS Interface Control Document
- NASA STD 5001: Structural Design and Test Factors of safety for Spaceflight Hardware
- SSP 30559: ISS Structural Design and Verification Requirements (ISS document which is often more strict than human-rating documents)
- AFSPCMAN 91-710: Range Safety User Requirements (tailored)
- MIL-STD-1540: Test Requirements for Space Vehicles

Design-to Standards

Structures:

- NASA Standard 3000
- NASA Standard 5007
- NASA Standard 5017
- SSP 30233
- SSP 30550, Rev C
- SSP 30560, Rev A
- SSP 30558, Fracture Control Requirements for Space Station
- SSP 41000
- SSP 41004, Rev H and J (Parts 1 and 2)
- SSP 41167, Rev G
- SSP 42004, Rev H
- MIL-HDBK-5
- MIL-HDBK-7
- MIL-STD-1246
- MIL-STD-1522
- NSTS 08307
- NSTS 21000-IDD-ISS
- JSC 28918
- NASA PRC-6506
- AMS-QQ-A250/30
- AMS 2772D

Design-to Standards

Propulsion:

FAA Guide to Verifying Safety Critical Structures for Reusable Launch Vehicles
JANNAF LPS Test Guide
MIL-STD-1522 - Standard General Requirements for Safe Design and Operation of Pressurized Missile and Space Systems
MIL-PRF-25508 - Propellant, Oxygen, Liquid
MIL-DTL-25576 - Propellant, RP-1, Liquid
MIL-PRF-25567 - Leak Detection Compound, Oxygen Systems
MIL-PRF-26539 - Propellants, Dinitrogen Tetroxide
MIL-PRF-27404 - Propellant, Monomethyl Hydrazine
MIL-PRF-27407 - Propellant Pressurizing Agent, Helium
MIL-C-38999 - Connectors, Electrical, Plug, Circular, Straight, Removal Crimp Contacts, Series III
MSFC-STD-3029 - Selection of Metallic materials for Stress Corrosion Cracking Resistance in Sodium Chloride Environments
NASA STD-5012 - Strength and Life Assessment Requirements for Liquid Fueled Space Propulsion System Engines
AS478 - Identification and marking Methods
IEST-STD-CC1246 - Product Cleanliness Levels and Contamination Control Program
TT-I-735A - Isopropyl Alcohol
AWS D17.1 - Specification for Fusion Welding for Aerospace Applications

Avionics:

JPL-D-8545 Rev. D (EEE Derating Standard)
NASA-STD-8739 (harnesses, soldering, staking etc.)
IPC-2221 (Printed circuits)
IPC-2222 (Printed circuits)
IPC-6011 (Printed circuits)
IPC-6012 (Printed circuits)
IPC-A-610 Class III (Printed circuits)
IPC-CC-830 (Printed circuits)
GSFC Supplement S-312-P003 (Printed circuits)

Design-to Standards

Quality Management System Standards:

ISO 9001:2000 QMS Standard
ISO 10011-1, 2, 3 Guidelines for QMS Auditing
ISO 10012 Measurement management systems
AS9100B QMS Aerospace Standard
AS9101 QMS Assessment
AS9102 First Article Inspection Requirements –Guidance document
ANSI / ISO 1007 Guidance on Configuration Mgt
ISO17025 Calibration and Testing Labs –Guidance document

Production / Test / Certification:

ASTM Standards, Specifications, Test Methods and guidance documents
AIA/NAS Standards and Specifications
AMS Material Specifications for raw materials
SAE Aerospace Quality Standards and Material Specifications
AWS – American Welding Society Standards – some examples below
AWS D17.1 Specification for Fusion Welding for Aerospace Applications
AWS B2.1 Standard for Welding Procedure and Performance Qualification
AWS D1.1 / D1.2 Structural Steel Welding code
AWS QC1, standard for Certification of Welding Inspectors
AMS 2681B Welding Electron Beam
AMS 2700 Passivation of Corrosion Resistant Materials
ASME Boiler Codes B31.1 and section IX
ASNT-TC1A Qualification and Certification of NDT Personnel
MIL-STD 410 / NAS 410 Qualification and Certification of NDT Personnel
ASTM E 164 Standard Practice for Ultra Sonic Inspection
ASTM 1742 Standard Practice for Radiography Inspection
ASTM E 1417 Standard Practice for Penetrant Inspection
ASTM E 1444 Standard Practice for Magnetic Particle
IEST-STD-CC1246 Contamination Control –Guidance document
AS478 Identification Marking Methods

Design-to Standards

Safety:

29CFR1910 OSHA regulations

SUBPART D - Walking Working Surfaces
.21-.30 including guards for floor and wall openings as well as proper use of ladders.

SUBPART E – Exit Routes, Emergency Action Plans, and Fire Prevention Plans
.33 - .39 including exit routes and their designation and upkeep, emergency action plans which designate those routes, and fire prevention plans to avoid fires and the need to evacuate.

SUBPART F – Powered Platforms, Manlifts, and Vehicle-Mounted Work Platforms
.66 - .68 personal fall arrest systems are dealt with here.

SUBPART G - Occupational Health and Environmental Control
.94 - .98 occupational noise exposure, monitoring and control are included here.

SUBPART H – Hazardous Materials
.101 - .126 the proper handling of compressed gasses and flammable and combustible liquids, and the training required for their safe use are here.

SUBPART I – Personal Protective Equipment
.132 - .138 this is one of the most important sections and provides key topics for our training programs.

SUBPART J – General Environmental Controls
.141 - .147 two very important areas are included here; Permit required confined spaces and Lockout/Tagout.

SUBPART K – Medical and First Aid
.151 - .152 Sets the minimum requirements for a first aid program which we meet and exceed with our placement of Automatic External Defibrillators in our facility and an on-going First Aid/CPR/AED training and certification program with an internal company trainer, as well as full coverage with first aid kits and supplies.

SUBPART L – Fire Protection
.155 - .165 includes sections on fire extinguishers, sprinkler systems and alarms systems.

SUBPART N – Materials Handling and Storage
.176 - .184 important sections on powered industrial trucks, forklifts, and overhead cranes. Our active compliance program includes an onsite trainer for initial and refresher classroom and hands- on training.

SUBPART 0 – Machinery and Machine Guarding
.211 - .219 details methods of compliance in this critical area.

SUBPART P – Hand and Portable Power Tools and Other Hand Held Equipment
.241 - .244 details the safe use and care of these vital workplace items.

SUBPART Q – Welding, Cutting, and Brazing
.251 - .255 details the requirements for all types of welding which we perform here.

SUBPART S – Electrical
.301 - .399 a very important section that lists requirements for design, installation and safe work around energized electrical components.

SUBPART Z – Toxic and Hazardous Substances
.901 - .1450 a huge section that contains one of the most important standards. Hazard Communication, .1200, affects everyone throughout our business and is the topic of universal employee training.

Design-to Standards

SpaceX Internal:

- Dragon Requirements
- SpaceX Human Rating Plan
- SpaceX System Safety and Mission Assurance Plan
- SpaceX COTS Environments Document
- 00002720 - Fastener Installation Torque Specification
- 00005453 - Procedure for Orbital GTAW of Stainless Steel and Titanium Tubing
- 00006876 - Component Cleaning Process