National Aeronautics and Space Administration

Commercial Orbital Transportation Services (COTS) Program Lessons Learned

HEOMD Knowledge Sharing Forum

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NASA HQ

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COMMERCIAL ORBITAL TRANSPORTATION S ICES

Agenda

- **COTS Summary**
  - **SpaceX**
  - **Orbital**
- **Key Lessons Learned**
  - **From Program**
  - **From SpaceX**
  - **From Orbital**

SpaceX COTS Summary

- COTS Space Act Agreement awarded August 2006 and amended in December 2010 with additional risk reduction milestones
- All 40 milestones completed in August 2012 for payments totaling $396M
  - Demo Mission 1: December 8, 2010
  - Demo Mission 2/3: May 22-31, 2012
- Key Facts:
  - New medium class Falcon 9 U.S. launch vehicle
  - New autonomous Dragon cargo spacecraft capable of carrying cargo to and from the ISS and LEO
  - New commercial launch facility at CCAFS, FL

Falcon 9

ISS Capture of Dragon

Cape Canaveral Launch Site

COMMERCIAL ORBITAL TRANSPORTATION SERVICES

SpaceX COTS Demonstration Launches

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

SpaceX COTS Demo Mission C2+ Cargo Return

Dragon splashdown in Pacific May 31,2012

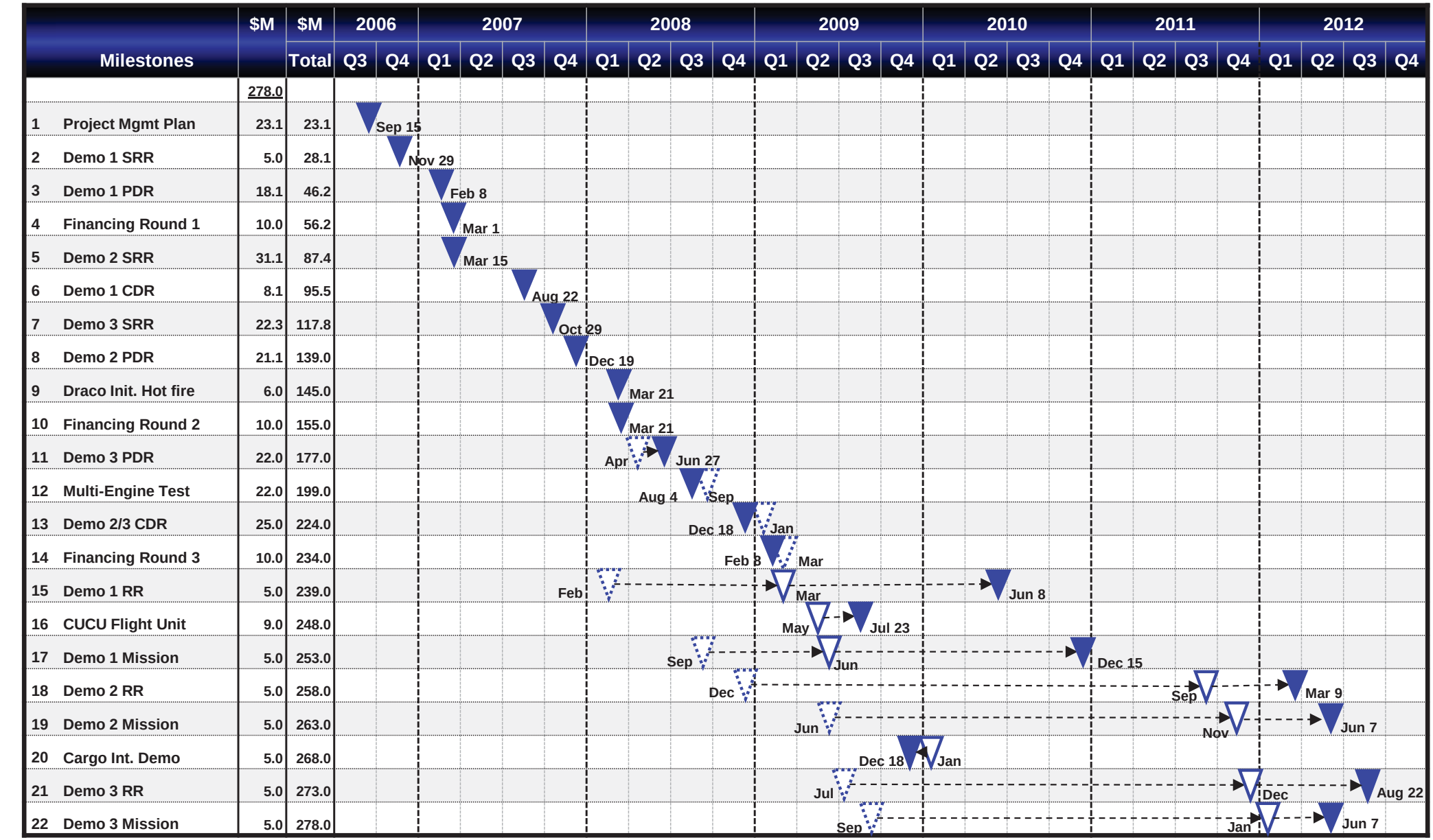
On recovery ship

Dragon in McGregor, TX

Returned ISS cargo

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

SpaceX COTS Milestones



	Milestones	$M	$M Total	2006 Q3	2006 Q4	2007 Q1	2007 Q2	2007 Q3	2007 Q4	2008 Q1	2008 Q2	2008 Q3	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
		278.0																										
1	Project Mgmt Plan	23.1	23.1	Sep 15																								
2	Demo 1 SRR	5.0	28.1		Nov 29																							
3	Demo 1 PDR	18.1	46.2			Feb 8																						
4	Financing Round 1	10.0	56.2			Mar 1																						
5	Demo 2 SRR	31.1	87.4			Mar 15																						
6	Demo 1 CDR	8.1	95.5					Aug 22																				
7	Demo 3 SRR	22.3	117.8						Oct 29																			
8	Demo 2 PDR	21.1	139.0							Dec 19																		
9	Draco Init. Hot fire	6.0	145.0								Mar 21																	
10	Financing Round 2	10.0	155.0								Mar 21																	
11	Demo 3 PDR	22.0	177.0								Apr		Jun 27															
12	Multi-Engine Test	22.0	199.0									Aug 4	Sep															
13	Demo 2/3 CDR	25.0	224.0										Dec 18	Jan														
14	Financing Round 3	10.0	234.0											Feb 8	Mar													
15	Demo 1 RR	5.0	239.0								Feb				Mar				Jun 8									
16	CUCU Flight Unit	9.0	248.0												May	Jul 23												
17	Demo 1 Mission	5.0	253.0									Sep				Jun				Dec 15								
18	Demo 2 RR	5.0	258.0										Dec								Sep			Mar 9				
19	Demo 2 Mission	5.0	263.0												Jun							Nov		Jun 7				
20	Cargo Int. Demo	5.0	268.0														Dec 18	Jan										
21	Demo 3 RR	5.0	273.0													Jul							Dec	Aug 22				
22	Demo 3 Mission	5.0	278.0														Sep						Jan	Jun 7				

Current Plan

Initial SAA Plan

Actual Completion Date

COMMERCIAL ORBITAL TRANSPORTATION SERVICES

SpaceX Augmented COTS Milestones

	Milestones	$M	$M Total	2007 Q1	2007 Q2	2007 Q3	2007 Q4	2008 Q1	2008 Q2	2008 Q3	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4
		118.0																								
23	Modal Test Plan	5.0	5.0																							
24	Modal Test	5.0	10.0																							
25	LIDAR Test (open loop)	5.0	15.0																							
26	Solar Array Deploy Test	5.0	20.0																							
27	LIDAR Test Plan (closed loop)	5.0	25.0																							
28	Thermal Vacuum Test Plan	5.0	30.0																							
29	Infrastructure Plan	10.0	40.0																							
30	Thermal Vacuum Test	20.0	60.0																							
31	Test site Infrastructure Implementation	5.0	65.0																							
32	Dragon Trunk Acoustic Test	10.0	75.0																							
33	LIDAR Test 6 DOF (closed loop)	5.0	80.0																							
34	Design Rev. Enhanced Powered Cargo Accom.	5.0	85.0																							
35	Design Rev. Pressurized Cargo Vol Increase	5.0	90.0																							
36	Dragon EMI/EMC Test (HITL)	10.0	100.0																							
37	Dragon Cargo Racks & Hatch Simulator	3.0	103.0																							
38	Ground Demo Enhanced Powered Cargo	5.0	108.0																							
39	Launch site Infrastructure Implementation	5.0	113.0																							
40	Production Infrastructure Implementation	5.0	118.0																							
	SAA Total	396.0	396.0																							

Current Plan

Actual Completion Date

Initial SAA Plan

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

Orbital COTS Summary

- Space Act Agreement awarded February 2008 and amended in December 2010 with additional risk reduction milestones
- All 29 milestones completed in November 2013 for payments totaling $288M
  - Maiden Test Flight: April 21, 2013
  - ISS Demo Mission: Sep. 18-23, 2013
- Key Facts:
  - New medium class Antares U.S. launch vehicle
  - New autonomous Cygnus cargo spacecraft capable of carrying cargo to the ISS and disposing cargo from the ISS
  - New commercial launch facility at Wallops Island, VA

Antares

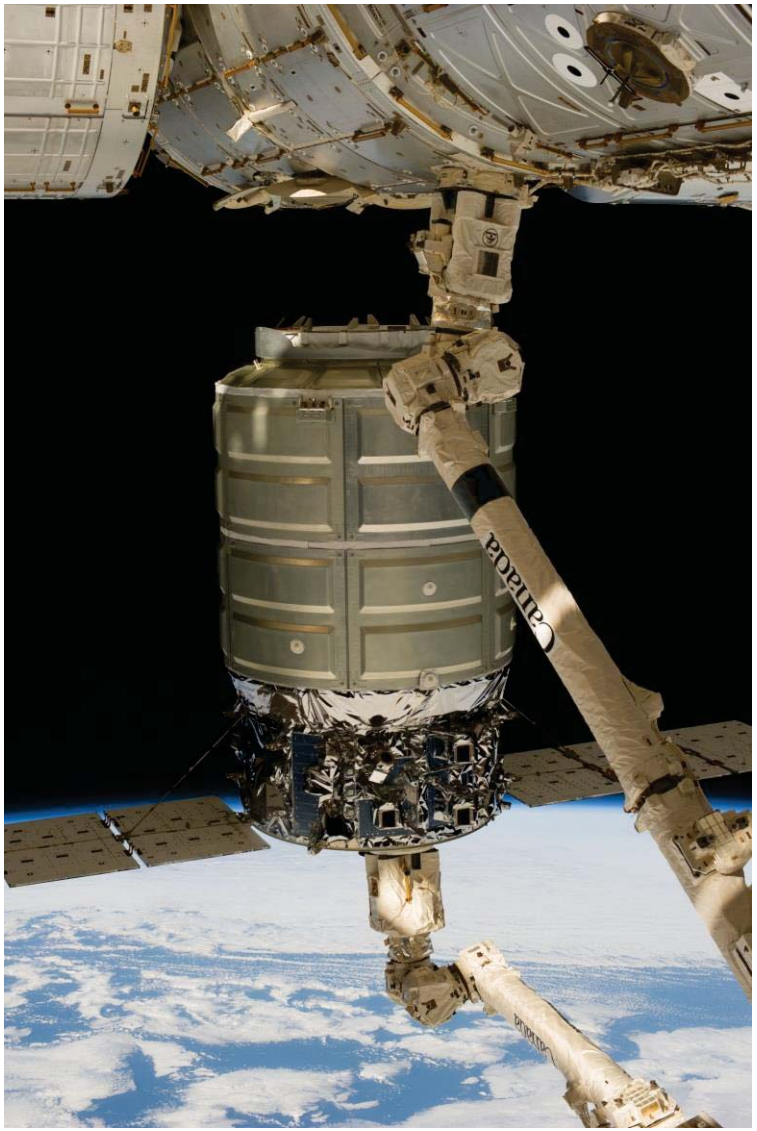

Cygnus Approaching ISS


MARS/Wallops Launch Site

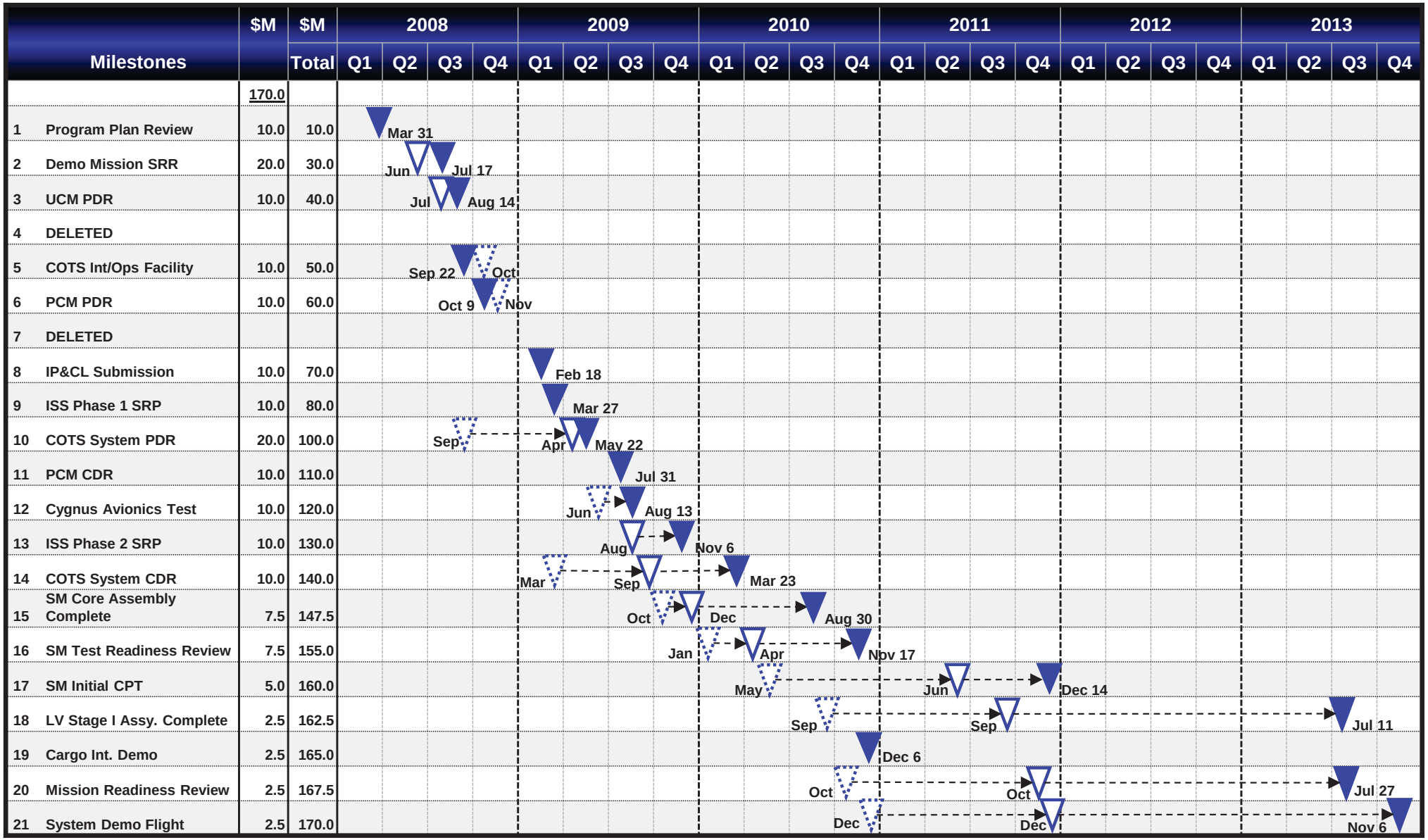
Orbital COTS Demonstration Launches

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

Orbital D-1 ISS Demonstration Mission



Orbital COTS Milestones



Current Plan

Actual Completion Date

Initial SAA Plan

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

Orbital Augmented COTS Milestones

	Milestones	$M	$M Total	2008 Q1	2008 Q2	2008 Q3	2008 Q4	2009 Q1	2009 Q2	2009 Q3	2009 Q4	2010 Q1	2010 Q2	2010 Q3	2010 Q4	2011 Q1	2011 Q2	2011 Q3	2011 Q4	2012 Q1	2012 Q2	2012 Q3	2012 Q4	2013 Q1	2013 Q2	2013 Q3	2013 Q4
		118.0																								
22	Test Flight Mission Review	20.0	20.0													Dec 15										
23	Test Flight Mission Analys.	10.0	30.0													Feb 23										
24	Cygnus Mass Sim. (CMS) Design Review	10.0	40.0													Mar 03										
25	Install Add'l PITL Simulators	5.0	45.0													Apr	May 6									
26	PROX FEU Test Unit	5.0	50.0													May	Jun 17									
27	Maiden Flt Stg 1 Core Del.	24.0	74.0													Apr 28										
28	Maiden Flt Uppr Stage Del.	20.0	94.0													Jun 21										
29	Maiden Flt CMS Delivered	10.0	104.0													Jun 20										
30	Maiden Flt Stage 1 Assy.	10.0	114.0													Jul				Sep 17						
31	Maiden Test Flight	4.0	118.0													Oct								May 9		
	SAA Total	288.0	280.5																							

Current Plan

Actual Completion Date

Initial SAA Plan

COTS COMMERCIAL ORBITAL TRANSPORTATION SERVICES

Key Lessons Learned from Program

- Government seed money was highly leveraged
  - Commercial partners funded over 50% of COTS development costs
- Fixed price milestone payments maximized incentive to control cost and minimize schedule delays
- Minimum firm requirements along with commensurate Government oversight were key to fostering innovation and reducing life cycle development costs
  - Goals (vs. requirements) were established to open trade space and optimize design
  - Firm requirements were identified only where necessary to assure the safety of the ISS and crew
  - ISS interface requirements evolved over time and were coordinated in a collaborative manner with the commercial partners
- A portfolio of multiple partners with different capabilities assured a balanced approach to technical and business risks
  - Increased the chances of at least one successful partner
  - Market forces kept development and operational costs in check
- Commercial friendly intellectual property/data rights and limited termination liability encouraged investment of private capital

Lessons Learned from Program (Cont.)

- NASA commitment to purchase operational services greatly improves the ability for companies to raise funds
- NASA does not have the statutory authority to provide Government Furnished Equipment (GFE) under a SAA
  - Even though originally contemplated in the SAA and in the best interest of the Government, COTS had to revert to loan agreements and cumbersome GSA excess procedures to transfer equipment to facilitate berthing with the ISS
- Augmentation of funding late in the program enabled additional risk reduction testing not initially affordable
  - Directly contributed to the successful first attempt berthing of SpaceX Dragon to ISS
  - Would be difficult to predict how much, if any, to hold in reserve during program formulation and initialization to protect for such milestone adjustments
- COTS model for public-private partnerships worked!

Key Lessons Learned from SpaceX

- **Design, Test and Repeat (engineering units prior to qualification)**
  - **This philosophy can be better than just detailed analysis and only one test –learn much more**
  - **Need to have a team that can react and make changes quickly**
- **Use of COTS electronics parts is feasible (instead of all S-level parts) thru use of some radiation screening/tests and better architecture decisions (redundancy and reboot capability)**
  - **Saves significant cost and schedule over traditional avionics**
  - **Previous Cost "GE Price" modeling experience was ”No matter how many runs done with varying complexity, similarity vs new design, etc– the cost and schedule of the Avionics and software drove the project cost.” Much more expensive than even massive structure or thermal systems.**
    - Note: if total length of a project can be reduced 6-12 months by using readily available parts and processes, you really save the monthly burn rate of the whole project for that many months.
  - **Just gets projects done faster, so NASA could be more responsive and can do more things**
- **Design with cost in mind**
  - **SpaceX paid much more attention to the cost of parts and component in the initial design phases than NASA contractors traditionally do; to the point of building many things in house, because it was perceived to be too expensive to buy vendor part. They always questioned why it can’t be done less expensively and pushed back on costly requirements.**
  - **In-house production has the added benefit of allowing better schedule control than from sub-tier suppliers and allows a streamlined change/update process.**

Key Lessons Learned from SpaceX (Cont.)

- **NASA observed SpaceX's use of "WIKI tools" for multiple critical business and engineering processes saves time—trying to move to a paperless environment.**
  - **Microsoft SharePoint and Confluence primarily for team processes and general info that they want teams to have instead of some team meetings**
  - **Provided models instead of large documents in some cases (FEM models and summary vs structural analysis report)**
  - **TRAC tickets are being used for issues, changes and risks by many teams.**
    - Provides a "virtual" meeting to ask questions and throw out ideas. Tracks all the comments for others to look at. Eventually, bringing them to closure and having all the managers and responsible engineers sign off on it.
    - Saves time (schedule) by letting people look at ticket when they can fit it in their schedule and not have to wait for a meeting to be called when everyone can attend. → a Virtual board/review if you will.
  - **NASA use suggested for simple issues, changes and risk (identify them as such), but move quickly to a meeting if not coming to timely closure or unclear questions arise.**

Key Lessons Learned from Orbital

- **Design Review Process – Independent Review Teams**
  - **Use of independent review team (IRT) of "experienced" experts to serve as design review team can be very effective**
  - **IRT typically not bound by cost or schedule and can serve as a common sense sounding board for design and programmatic decisions**
  - **Membership of team should remain consistent throughout program (to the extent practical)**
  - **Review team findings should go to level of management above program manager for disposition/review**
- **Use of "standard building block" designs**
  - **NASA standard practices typically utilize custom or first use designs, whereas commercial leverages existing "product line" designs**
  - **Lowers technical risk due to vast experience with designs/components**
  - **Could also potentially lower cost & schedule due to potentially eliminating the need for additional qualification testing (where applicable)**
- **Leveraging common goals with all constituents (i.e. States, local governments, DOD,…)**
  - **NASA frequently "goes it alone" on programs and supplies all funding**
  - **Commercial industry realizes the benefits of competition and synergistic desires**
    - Example – State of Virginia had interests in developing spaceport (i.e. MARS) and supplied significant funding
    - Example – Industry partners, in some cases, provided funding for unique hardware in exchange for IP rights


A New Era In Spaceflight Is Beginning...
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