The Evolving Launch Vehicle Market Supply and the Effect on Future NASA Missions

Presented at the
2007 ISPA/SCEA Joint International Conference & Workshop
June 12-15, New Orleans, LA

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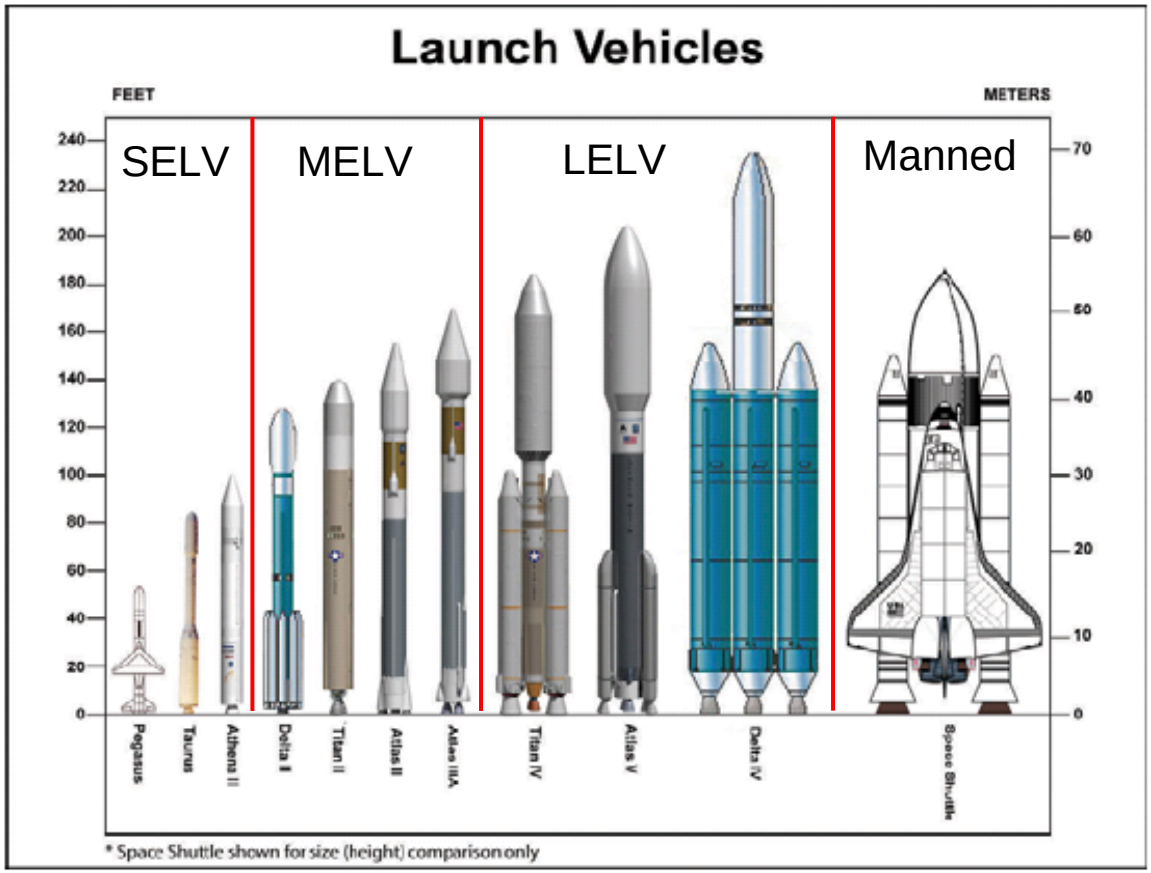
Abstract

- The upcoming retirement of the Delta II family of launch vehicles leaves a performance gap between small expendable launch vehicles, such as the Pegasus and Taurus, and large vehicles, such as the Delta IV and Atlas V families
- This performance gap may lead to a variety of progressions including
  - large satellites that utilize the full capability of the larger launch vehicles,
  - medium size satellites that would require dual manifesting on the larger vehicles or
  - smaller satellites missions that would require a large number of smaller launch vehicles
- This paper offers some comparative costs of co-manifesting single-instrument missions on a Delta IV/Atlas V, versus placing several instruments on a larger bus and using a Delta IV/Atlas V, as well as considering smaller, single instrument missions launched on a Minotaur or Taurus
- This paper presents the results of a parametric study investigating the cost-effectiveness of different alternatives and their effect on future NASA missions that fall into the Small Explorer (SMEX), Medium Explorer (MIDEX), Earth System Science Pathfinder (ESSP), Discovery, Mars Scout and New Frontiers category of mission classes

Overview

- NASA Launch Vehicle Background
  - NASA Launch Vehicle Fleet
  - Launch Vehicle Performance Gap
  - Mission Launch Histories
  - Current Launch Vehicles Available from Announcements of Opportunity (AO)
- Problems Presented by LV Gap
  - Effect on Earth Orbiting Missions
  - Effect on Planetary Missions
- Considerations for Future AOs
- Emerging Launch Vehicles
- Summary

NASA Launch Vehicles*



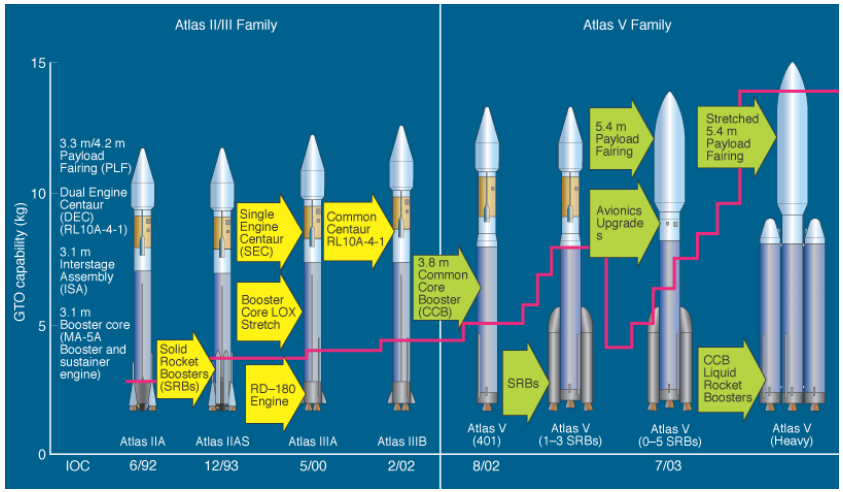
- Small Expendable Launch Vehicles (SELV)
  - Pegasus
  - Taurus
  - Athena II (Retired)
- Medium Expendable Launch Vehicles (MELV)
  - Titan II (Retired)
  - Atlas II (Retired)
  - Delta II
- Large Expendable Launch Vehicles (LELV)
  - Titan IV (retired)
  - Atlas V
  - Delta IV
- Manned Reusable
  - Space Shuttle

NASA launch vehicle families provide a variety of performance and cost choices

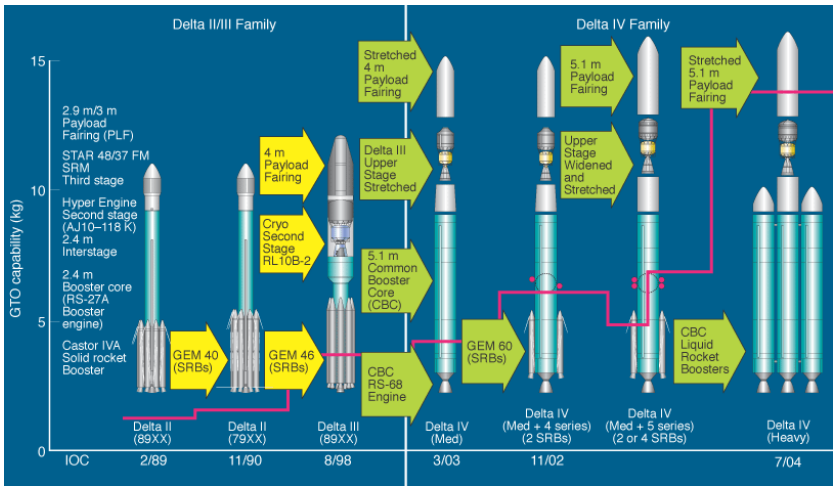
*Note: As taken from "Major NASA ELV Launches, Volume 2 (1990 to Present)", IS-2006-02-007-KSC

Progression of Atlas & Delta Launch Vehicle Families Into Evolved Expendable Launch Vehicles (EELV)*

Progression of Atlas II to Atlas V EELV



Progression of Delta II to Delta IV EELV



Evolved to the United Launch Alliance (ULA)

Delta II Retirement is following similar path as Retirement of Atlas II

*Note: As taken from "EELV: The Next Stage of Space Launch", Randy Kendall, The Aerospace Corporation, Crosslink Magazine, Winter 2004, http://www.aero.org/publications/crosslink/winter2004/07.html

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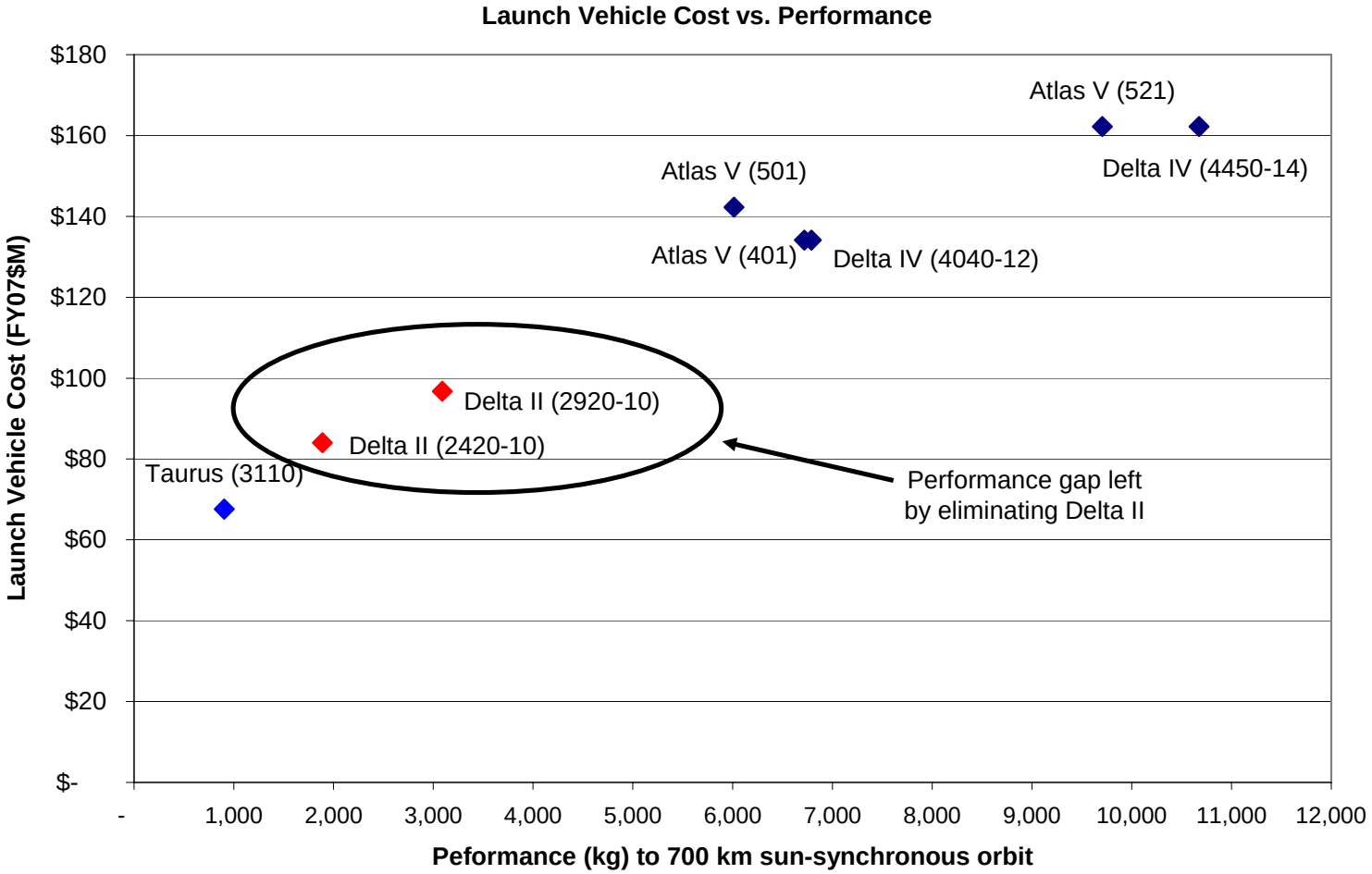
Performance Gap Left by Delta II Retirement*



Gap Left by Delta II Retirement is Large in Both Cost ($65M) & Capability (5,000 kg)

*Note: Cost taken from DISCOVERY 12 AO ELV Launch Services Program Information Summary 01/06/2006, and MARS SCOUT AO ELV Launch Services Program Information Summary 01/25/2007. Launch vehicle performance from http://elvperf.ksc.nasa.gov.

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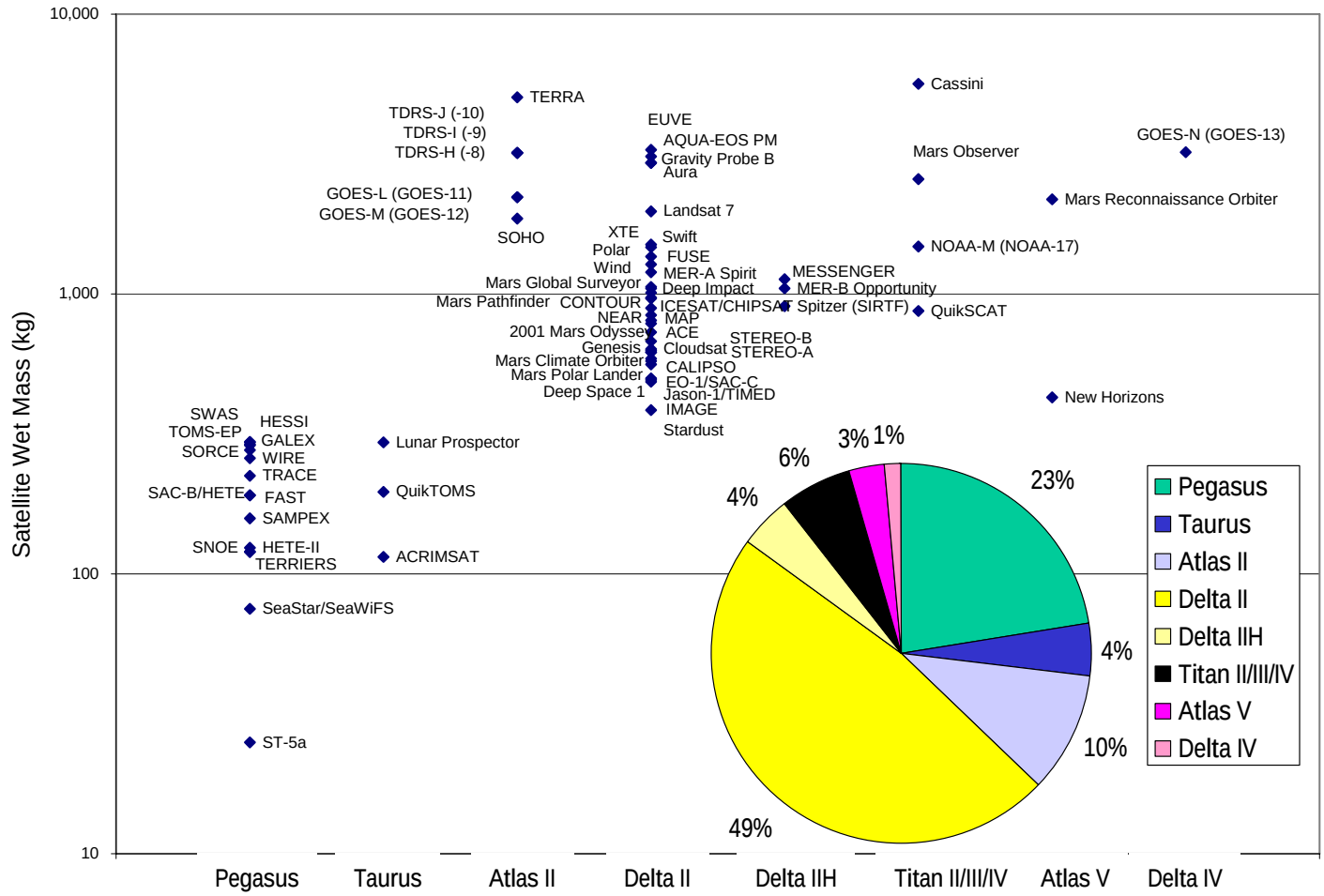
Historical NASA Missions Launched 1990-2006*



Delta II has been Predominant Launch Vehicle with Half of All NASA Launches

*Note: As taken from "Major NASA ELV Launches, Volume 2 (1990 to Present)", IS-2006-02-007-KSC

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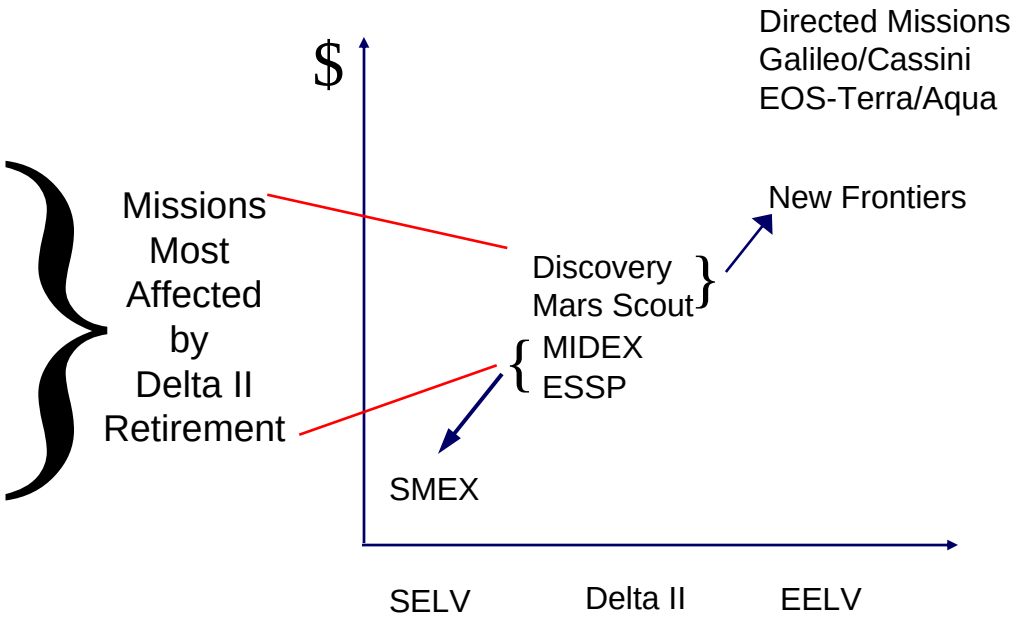
Current Launch Vehicles Available for Missions Competed through Announcements of Opportunity (AO)

Mission*	Mission Cost Cap (FY07$M)	Range of Available Launch Vehicles	% LV Cost	AO Date
SMEX	$138	Pegasus	23%	2003
		Taurus	35%	
ESSP	$193	Pegasus	17%	2001
		Taurus	28%	
		Shared Delta 2	28%	
MIDEX	$214	Taurus	23%	2002
		Delta II 2420	33%	
		Delta II 2925H	42%	
Discovery	$439	Taurus	15%	2006
		Delta II 2920-10	22%	
		Atlas V (401) or Delta IV 4040-12	31%	
Mars Scout	$490	Delta II 2925	19%	2006
		Atlas V (521) or Delta IV 4450-14	33%	
New Frontiers	$803	Delta II 2925	9%	2003
		Delta IV Heavy	28%	

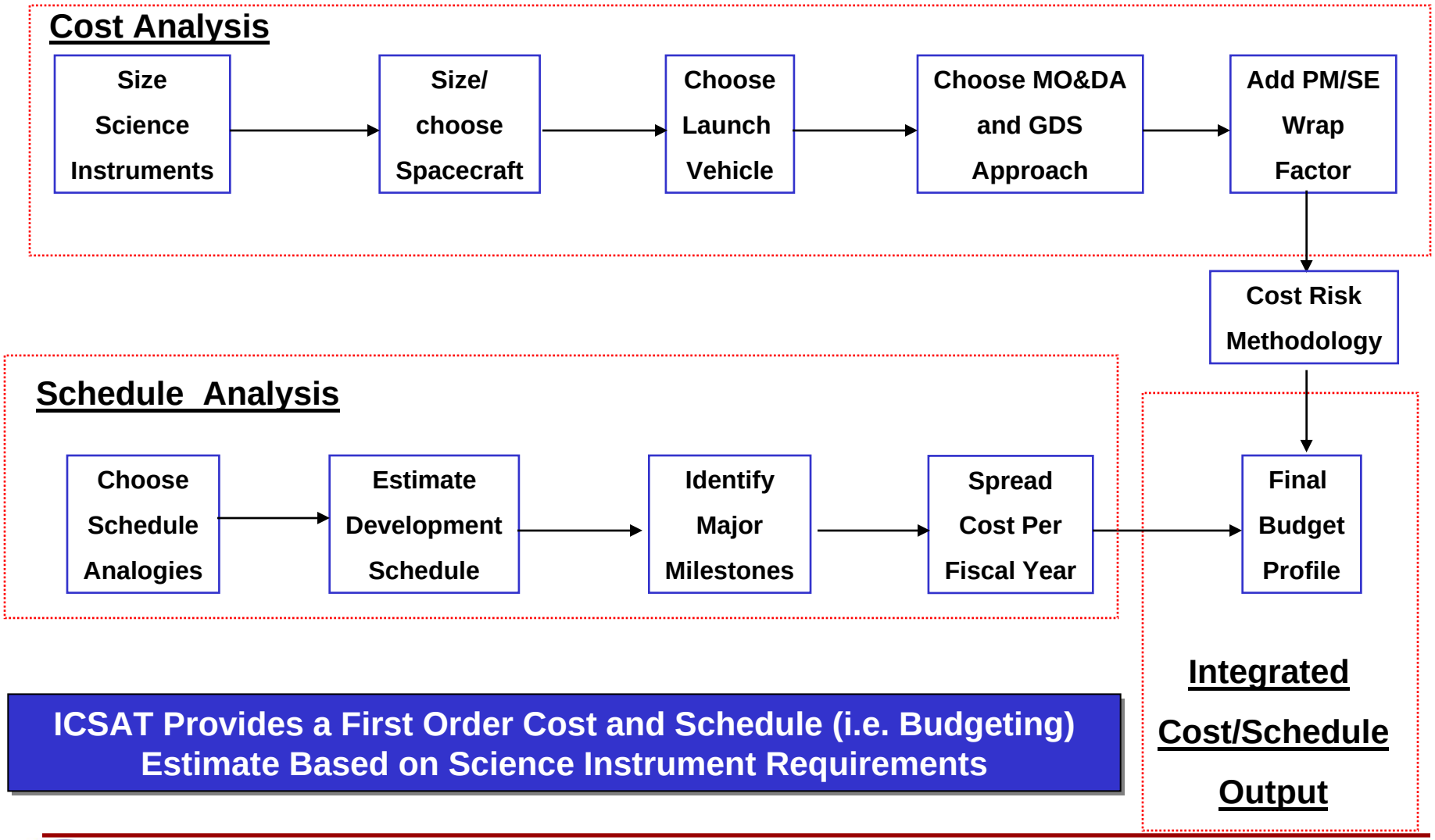


Migration of Missions to SELV or EELV Class

Most Affected Missions will be ESSP, MIDEX, Discovery & Mars Scout; Missions will Migrate to Smaller LVs, Larger LVs or Dual Manifesting

* SMEX = Small Explorer, ESSP = Earth System Science Pathfinder, MIDEX = Medium Explorer
Launch vehicle cost information taken from NASA provided public data for AOs

Integrated Cost and Schedule Analysis Tool (ICSAT) Used for Estimating Cost & Schedule of Example Missions



Case 1 Definition:

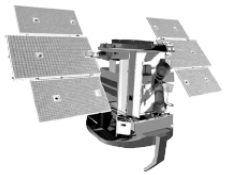
Two Small Spacecraft on Two Separate SELVs

Spacecraft 1

CloudSat-like Instrument*

Instrument	Mass (kg)	Power (W)
CPR	260	270
Total	260	270

+



Satellite	Mass (kg)
Instrument	260
Spacecraft	454
Propellant	134
Total	848

+

SELV
Maximum Performance
to Sun-synch, 700 km
= 955 kg

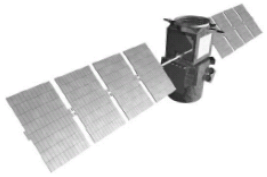
Image Courtesy of
Orbital Sciences Corporation

Spacecraft 2

Calipso-like Instruments*

Instrument	Mass (kg)	Power (W)
CALOP	156	207
IIR	21	27
WFC	2.6	8
Total	179.6	242

+



Satellite	Mass (kg)
Instruments	180
Spacecraft	326
Propellant	94
Total	600

+

SELV
Maximum Performance
to Sun-synch, 700 km
= 955 kg

Image Courtesy of
Orbital Sciences Corporation

* Source: Earth Science 2006 Reference Handbook

Case 2 Definition:

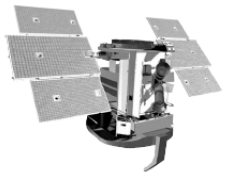
Two Small Spacecraft Co-Manifested on Single EELV

Spacecraft 1

CloudSat-like Instrument*

Instrument	Mass (kg)	Power (W)
CPR	260	270
Total	260	270

+



Satellite	Mass (kg)
Instrument	260
Spacecraft	454
Propellant	134
Total	848

+

Dual Payload Attachment Fitting (DPAF)

Mass = 325 kg

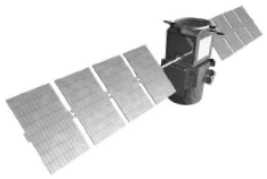
Illustration reprinted courtesy of NASA

Spacecraft 2

Calipso-like Instruments*

Instrument	Mass (kg)	Power (W)
CALOP	156	207
IIR	21	27
WFC	2.6	8
Total	179.6	242

+



Satellite	Mass (kg)
Instruments	180
Spacecraft	326
Propellant	94
Total	600

+

EELV

Maximum Performance to Sun-synch, 700 km = 6015 kg

Photograph reprinted courtesy of the US Air Force

* Source: Earth Science 2006 Reference Handbook
Picture of Atlas V taken from http://www.aero.org/publications/crosslink/winter2004/07.html

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Case 3 Definition:
Single Large Spacecraft on Single EELV

Instrument Set 1

CloudSat-like Instrument*

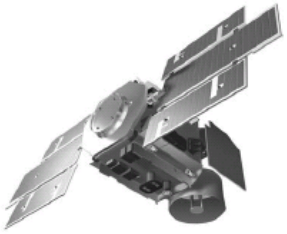
Instrument	Mass (kg)	Power (W)
CPR	260	270
Total	260	270

Instrument Set 2

Calipso-like Instruments*

Instrument	Mass (kg)	Power (W)
CALOP	156	207
IIR	21	27
WFC	2.6	8
Total	179.6	242

+



Satellite	Mass (kg)
Instruments	440
Spacecraft	633
Propellant	216
Total	1289

+

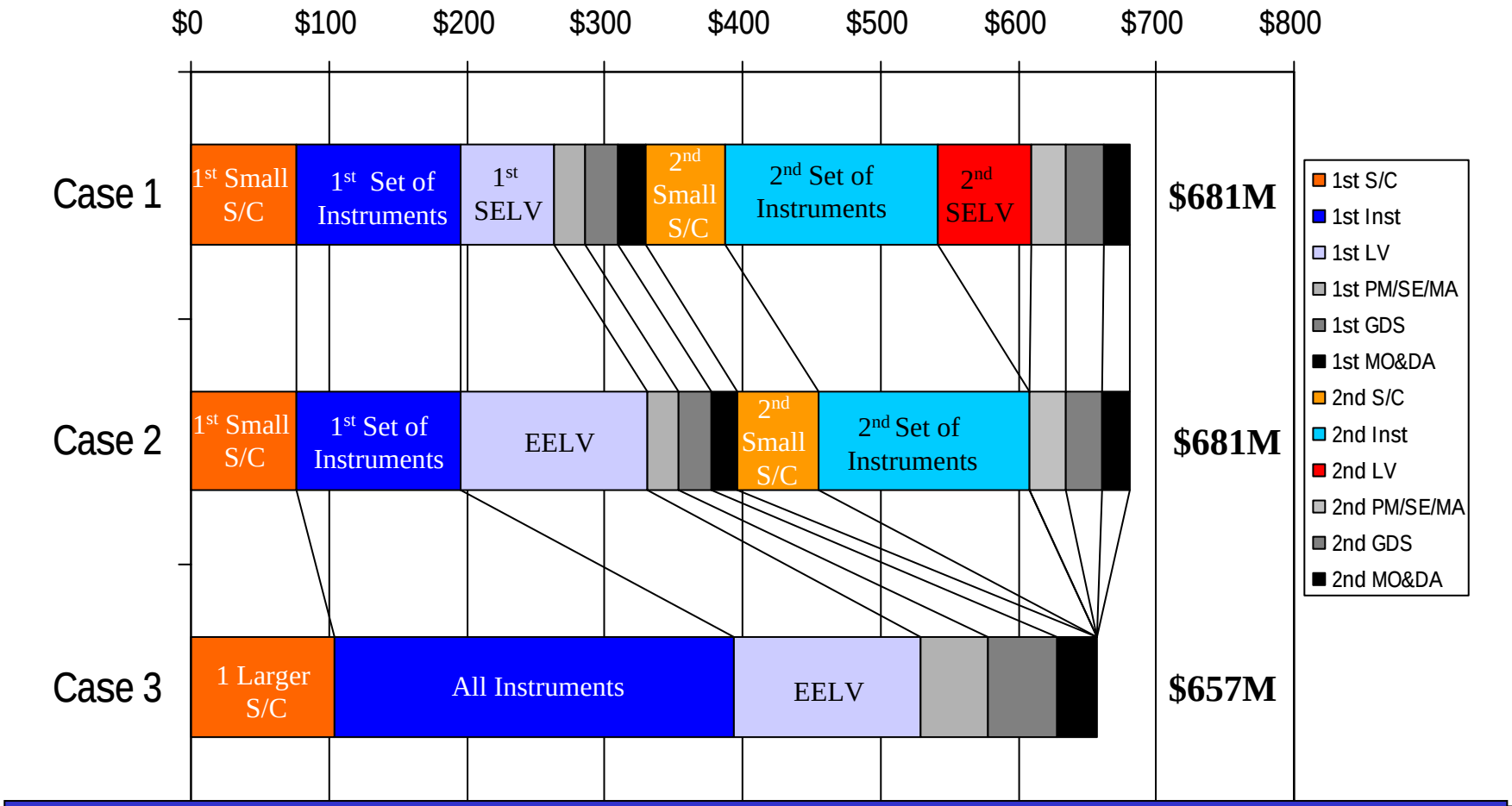
EELV

Maximum Performance to Sun-synch, 700 km = 6015 kg

Photograph reprinted courtesy of the US Air Force

* Source: Earth Science 2006 Reference Handbook
Picture of Atlas V taken from http://www.aero.org/publications/crosslink/winter2004/07.html

Earth Orbiting Scenario Cost Analysis Results Comparison



While Total Mission Cost of Case 1 (2 SELV Launches), is similar cost to Case 2 (Co-Manifesting), the Single Larger Mission, Case 3, is the Least Cost Alternative

* Development time for Case 1 and Case 2 were estimated to be 4.7-years vs. 5.5-years for Case 3

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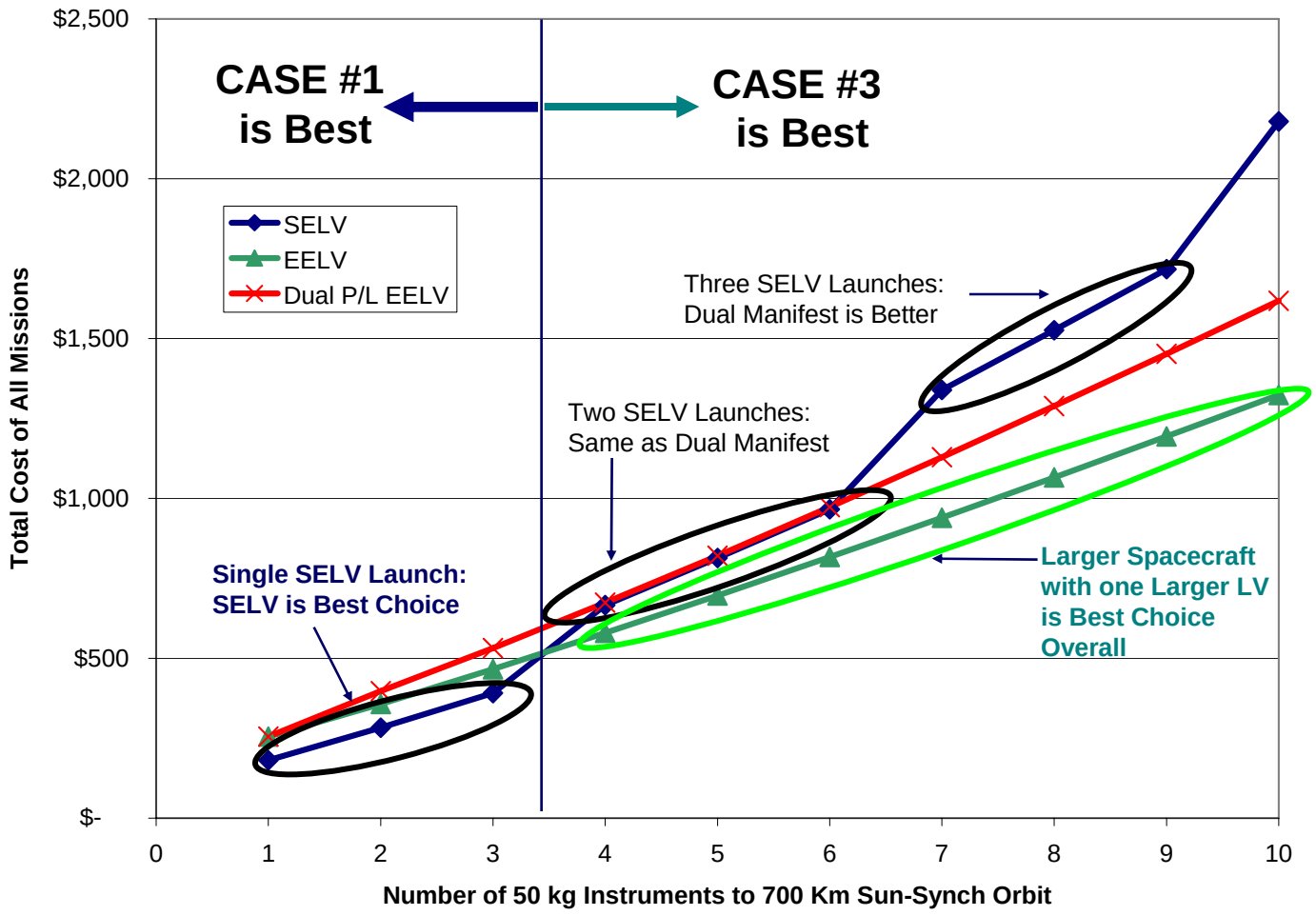
Pros & Cons of Each Approach

- Case 1: Smaller Missions with Multiple SELV Launches
  - Pros
    - More frequent launches
    - More funding and program flexibility
  - Cons
    - Smaller science payloads
    - Less efficient overall usage of funding
- Case 2: Multiple Missions with Co-Manifesting on Larger LV
  - Pros
    - Allows for larger payloads than single launches
    - Unconstrained mass allows adding significant propellant to allow for minor plane change, or significant orbit altitude change, following separation from Launch Vehicle
  - Cons
    - Potential for greater cost and schedule growth due to dependency on another satellite
    - Requires dual manifested satellites go to similar orbits
- Case 3: Larger Single Mission on Larger LV
  - Pros
    - More “bang for the buck”
  - Cons
    - Potentially fewer missions

Parametric Trade of Mission Costs vs. Payload Size*



Given Retirement of Delta II, Case #2 Dual Manifesting is not Cost Effective

* Note: Thirty percent payload mass fraction assumed in all cases

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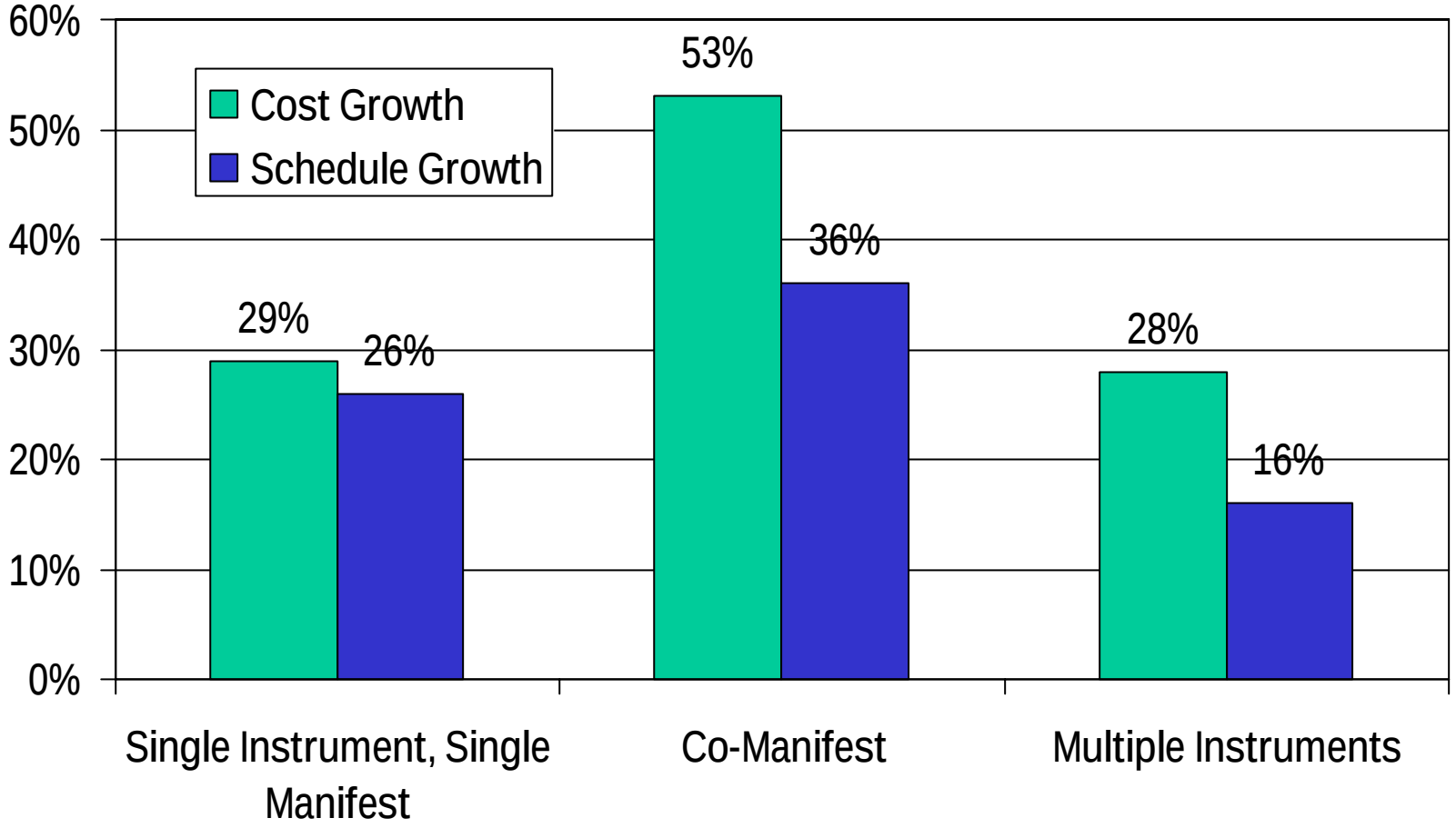
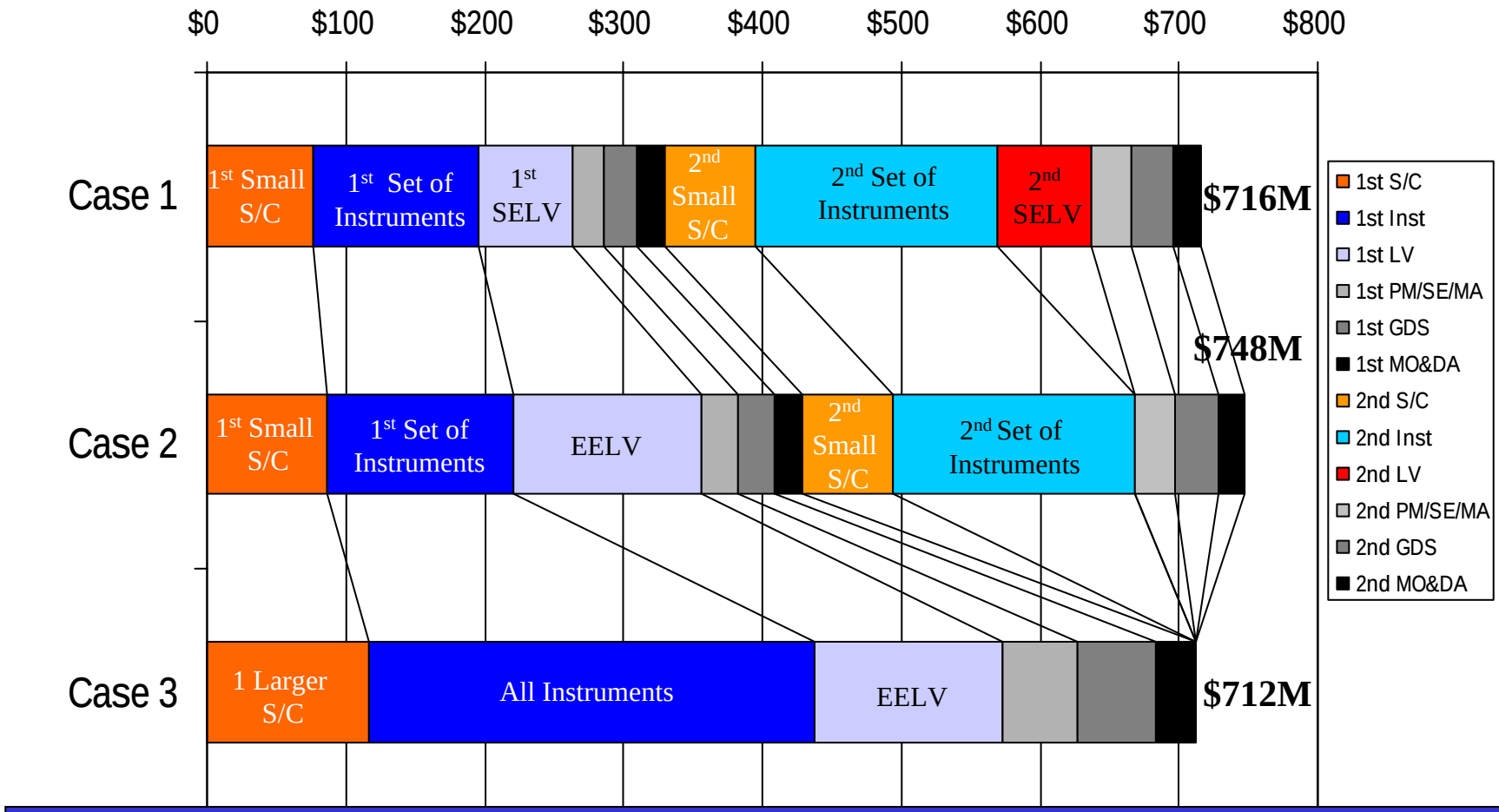
Other Considerations: Cost/Schedule Growth Histories – Based on 40 NASA Mission Data Set



Co-Manifesting has had historically greater cost and schedule growth due to dependency on other satellite

Adding Schedule and Cost Growth to Earth Orbiting Scenario Separates Approaches Even Further*



Realistic Instrument Delay of 6-months makes Case 1 (2 SELV Launches) similar cost to Case 3 (Single Large Mission), while Co-Manifesting Case 2 is the Most Costly

* Note: Assumes that only one instrument is delayed such that only one mission is affected in Case 1 while both missions are affected in Case 2 and the whole mission is affected in Case 3

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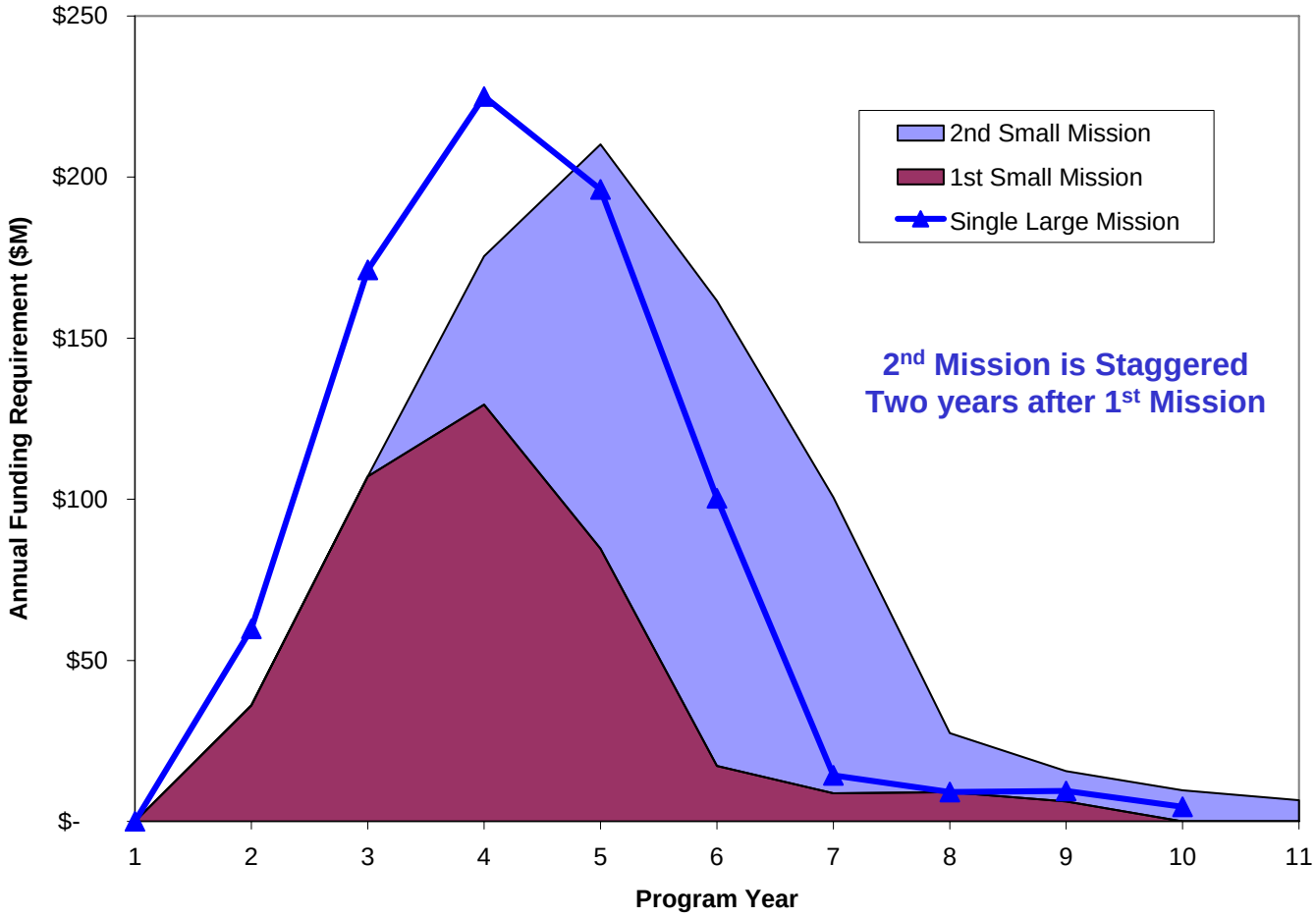
Other Considerations: Earth Orbiter Program Funding Comparison - 2 Smaller SELV Missions (Case 1) vs. a Single EELV Mission (Case 3)*



Staggered Multiple Launches have similar profile as Large mission while providing added flexibility

* Development time for Smaller missions estimated to be 4.7-years vs. 5.5-years for Larger mission

Other Considerations: Potential Additional Benefit of Use of Larger Launch Vehicle

- There is potential for substantial cost savings on multi-instrument spacecraft if a large enough launch vehicle is chosen early on to allow unconstrained mass growth
- Some potential areas of savings:
  - Build it out of “cast iron” - design so that expensive dynamic modeling and structural tests are not needed
  - No need for lighter weight, more expensive material such as titanium
  - Easier to get rid of waste heat, as volume is not constrained so avionics could be dispersed/located away from instruments
- This approach would be a major paradigm shift from previous design philosophy that lighter is better given historical restrictions based on constrained launch vehicle performance
- Using the Small Satellite Cost Model structural cost estimating relationship as a guide, an aluminum structure can be 227% heavier than a composite structure for the equivalent cost*

* Reference: Small Satellite Cost Model Version 98DP User's Guide, June 15, 1998

Planetary Launch Vehicle Considerations

- Impact on available funding
  - Atlas V and Delta IV are larger percentage of mission cost
  - Overall cost cap would have to be increased to afford EELV
- Requirements creep to "fill up" EELV
  - Unused capacity means that full value is not realized
    - Example: Each Mars Exploration Rover (MER) had a launch mass of 1,062 kg vs. Atlas V 401 performance of 2,880 kg for the required injection energy (C_3) needed for MER-A of 9.3 km^2/s^2 and 2,500 kg needed for a C3 of 16.3 km^2/s^2 for MER-B
  - Could push new Discovery missions to New Frontiers boundaries
- Potential Mars Scout & Mars Exploration Program (MEP) co-manifest
  - Example: A small Mars Scout orbiter plus a larger MEP lander

Dual Manifest for Planetary Missions Unlikely Unless Going to Same Destination; Discovery may migrate to New Frontiers-like program to "Fill Up" LV

* Note: MER launch mass taken from Mars Exploration Rover Launches Press Kit June 2003, Atlas V 401 Launch Vehicle Performance for required C_3 taken from http://elvperf.ksc.nasa.gov

Considerations for New Mission AOs

- May consider two-tiered Announcement of Opportunity
  - ESSP
    - Traditional ESSP for launch on Taurus
    - ESSP+ for launch on Atlas V or Delta IV
    - Selection could consist of two staggered, traditional ESSP or one ESSP+ mission
  - Explorer
    - Compete both SMEX and MIDEX together although expand MIDEX for launch on Atlas V or Delta IV
    - Selection could consist of two staggered SMEX or one MIDEX+ mission
  - Discovery
    - Consideration should be given to combine Discovery and New Frontiers into one mission to use full capability of launch vehicle
    - May require narrower scope of science objectives
  - Mars Scout
    - Consideration should be given for co-manifesting with primary Mars Exploration Program mission if volume constraints allow

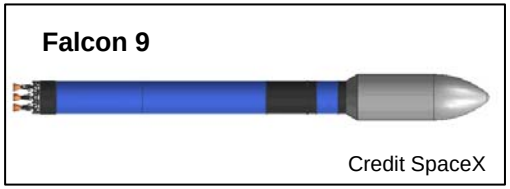
Emerging Launch Vehicles May Decrease Cost but Proven Performance for NASA hasn't Been Realized Yet

- Minotaur
  - Provides similar capability to Taurus for substantially less cost
  - Would increase push for smaller missions
  - Potential problem as it is a USAF, non-commercial launch vehicle
- Falcon
  - Falcon 9 would provide similar capability to Delta II at significantly less cost
  - Initial Falcon 1 launch failed
  - 2nd launch failed to reach orbital velocity but was otherwise successful*
  - Would need to provide reliable performance before consideration
- Kistler
  - Has not yet launched
- Others
  - Launch vehicles on drawing board would not affect near term AOs

Image Courtesy of Orbital Sciences Corporation

Image Courtesy of Orbital Sciences Corporation

Credit SpaceX



Credit SpaceX

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* Reference: http://www.spacex.com/updates.php

Summary Highlights

- Delta II retirement leaves significant cost and capability gaps in NASA's launch fleet
- In most cases, dual manifesting on a single launch vehicle is not the preferred option from a cost or performance perspective
- Retirement of Delta II may lead to stratification of NASA missions into two groups that could be competed within same Announcement of Opportunity
- Emerging launchers could reduce launch cost and subsequent mission cost if made available to NASA after providing proven, reliable performance

BACK-UP

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