AMS ELV Option to ISS

Presented by

Trent Martin/EA2

Cheryl Malloy/LSP

Compiled by

Trent Martin/EA2

NASA AMS Deputy Project Manager

Presentation Contributors

Charles Young/Shuttle Integration

Ross Abotteen/Shuttle Integration

John Steils/Shuttle Safety

Matthew Schuetz/ISS Integration

Cheryl Malloy/LSP

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Purpose of Presentation

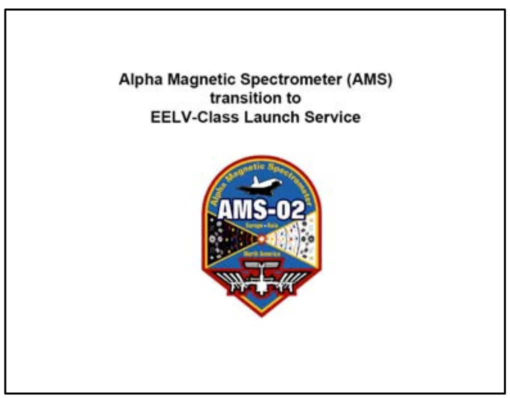
- In Sept. 2005, Prof. Ting met with NASA Administrator
  - Prof. Ting requested continued support of AMS on Shuttle
  - Dr. Griffin said that he would do what he could to support AMS, but AMS should assume that the elimination of a Shuttle ride to ISS for AMS was a serious possibility
  - JSC AMS Project Office (APO) agreed to work with KSC to develop AMS ELV options
- KSC LSP Office and AMS met with Mr. Gerstenmaier on Nov. 18, 2005
  - Proposed combined Shuttle/EELV mission to essentially get more payloads to ISS on one Shuttle flight
  - Mr. Gerstenmaier requested that AMS go to Shuttle and ISS for further study
- Since the November meeting, a team at JSC has been looking at this option
  - Goal was to investigate the feasibility of launching the AMS on an EELV with a spacecraft bus, delivering it to ISS using a Shuttle after an on-orbit transfer from the spacecraft bus
    - Identify any preliminary technical show stoppers
    - Highlight key issues that require further investigation
  - Report findings back to NASA HQ
    - Mr. Sistilli – Jan. 19, 2006
    - Mr. Gerstenmaier – Feb. 7, 2006
    - Dr. Griffin – Feb. 16, 2006

Feasibility Study Team

- **AMS Project Office (JSC/EA)**
    - Steve Porter
    - Trent Martin
- **ISS**
  - Safety and Mission Assurance (JSC/OE)
    - Saroj Patel
  - Program Integration Office (JSC/OM)
    - Matthew Schuetz
    - Neil Lemmons
    - Nancy Wilks
    - Joe LaRochelle
- **Shuttle**
  - Flight Operations and Integration Office (JSC/MO)
    - Charles Young
    - Ross Abotteen
    - Ken Bollweg
    - Steve Kunkel
- **Flight Crew Operations (JSC/CB)**
    - Dom Gorie
- **Mission Operations Directorate**
  - Systems Division (JSC/DF)
    - Dean Lenort
  - Flight Design (JSC/DM)
    - Mark Schrock
    - Brian Yarbrough
    - Dick Theis
    - Bill Tracy
    - Megan Sip
    - Steve Staas
  - Operations (JSC/DO)
    - James Medford
- **Safety and Mission Assurance**
  - ISS & Space Shuttle S&MA (JSC/NE)
    - John Steils
    - Hesham Hussein
- **Launch Services Program (KSC/VA)**
    - Cheryl Malloy
    - Norm Beck
    - Emilio Cruz
    - Tim Bulk
    - Brian Pitchford

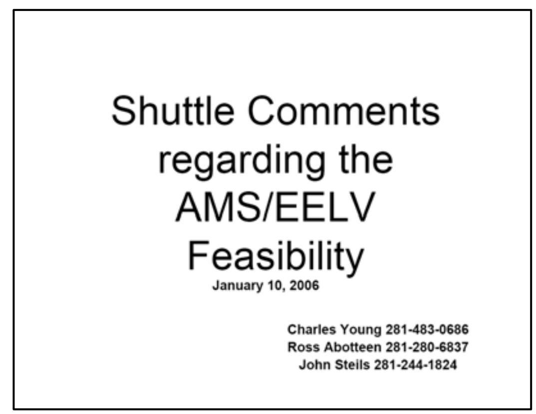
Presentation Inputs

- This presentation is a compilation of the Shuttle, ISS, and LSP presentations
- This presentation has been reviewed by the entire study team
  - Mark Sistilli (AMS Program Manager), Skip Hatfield (ISS), Don McCormick and Robert Galvez (STS), and Ray Lugo (LSP) have reviewed this concept

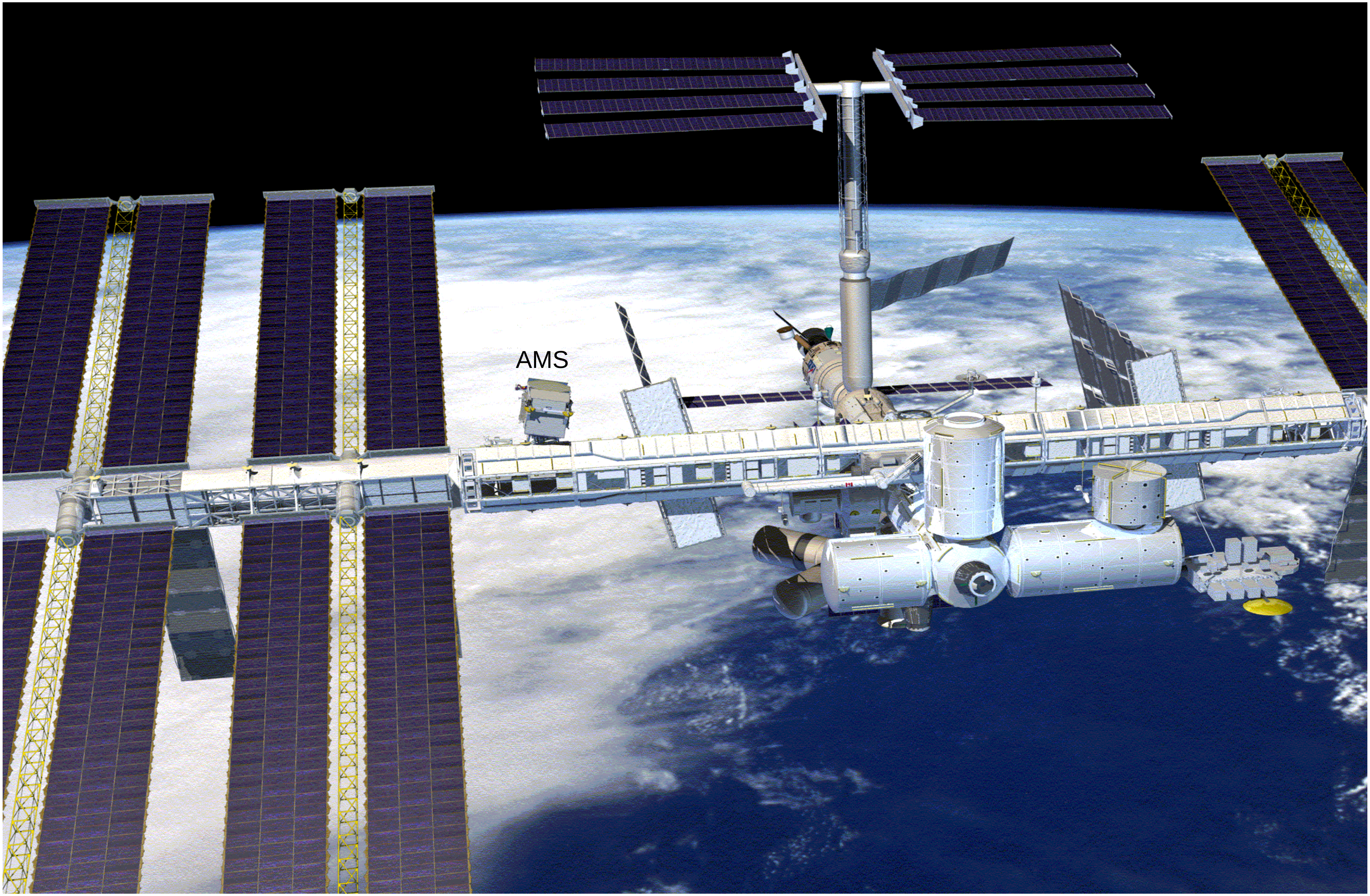


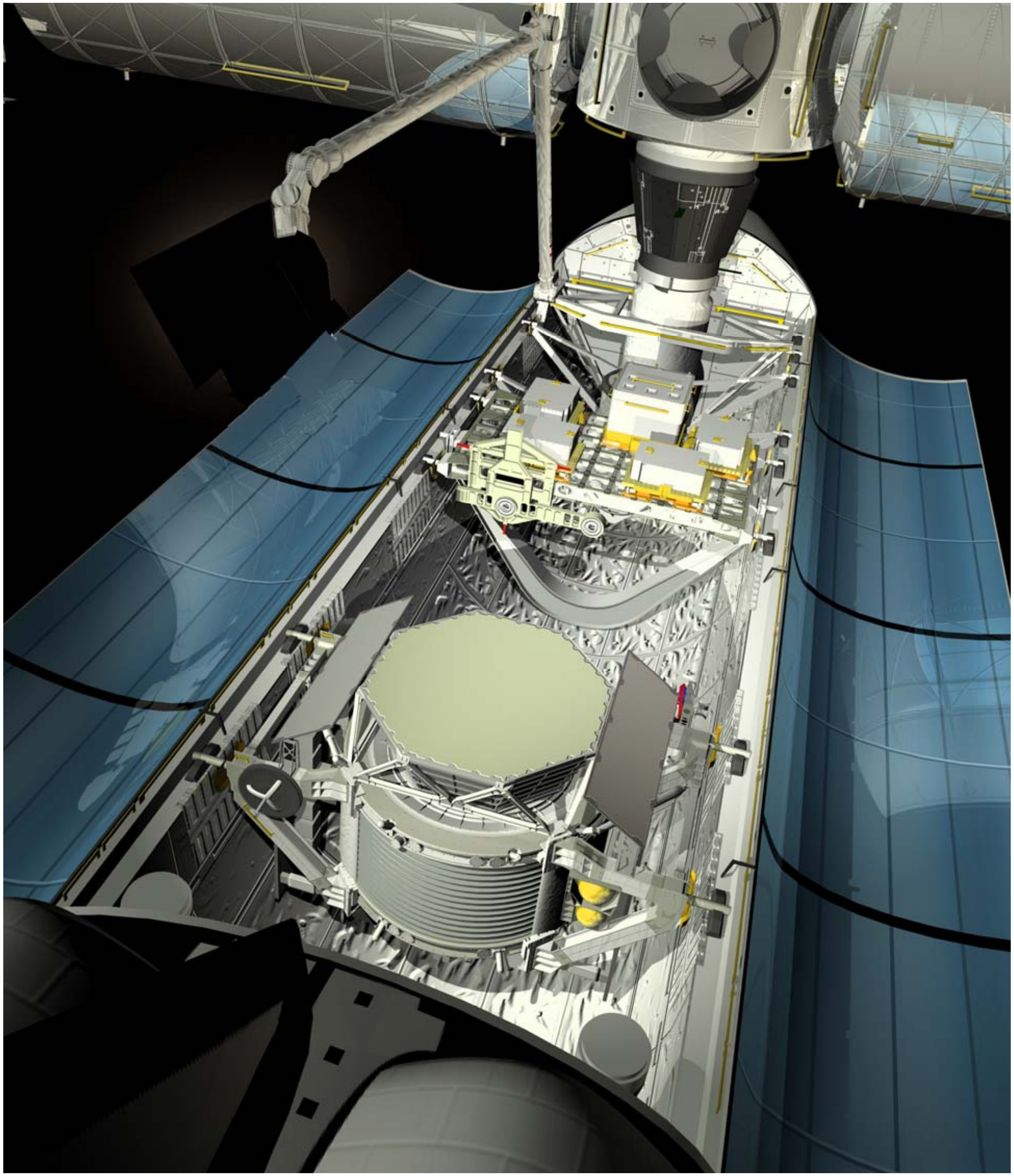
KSC Presentation

ISS Presentation



STS Presentation


AMS

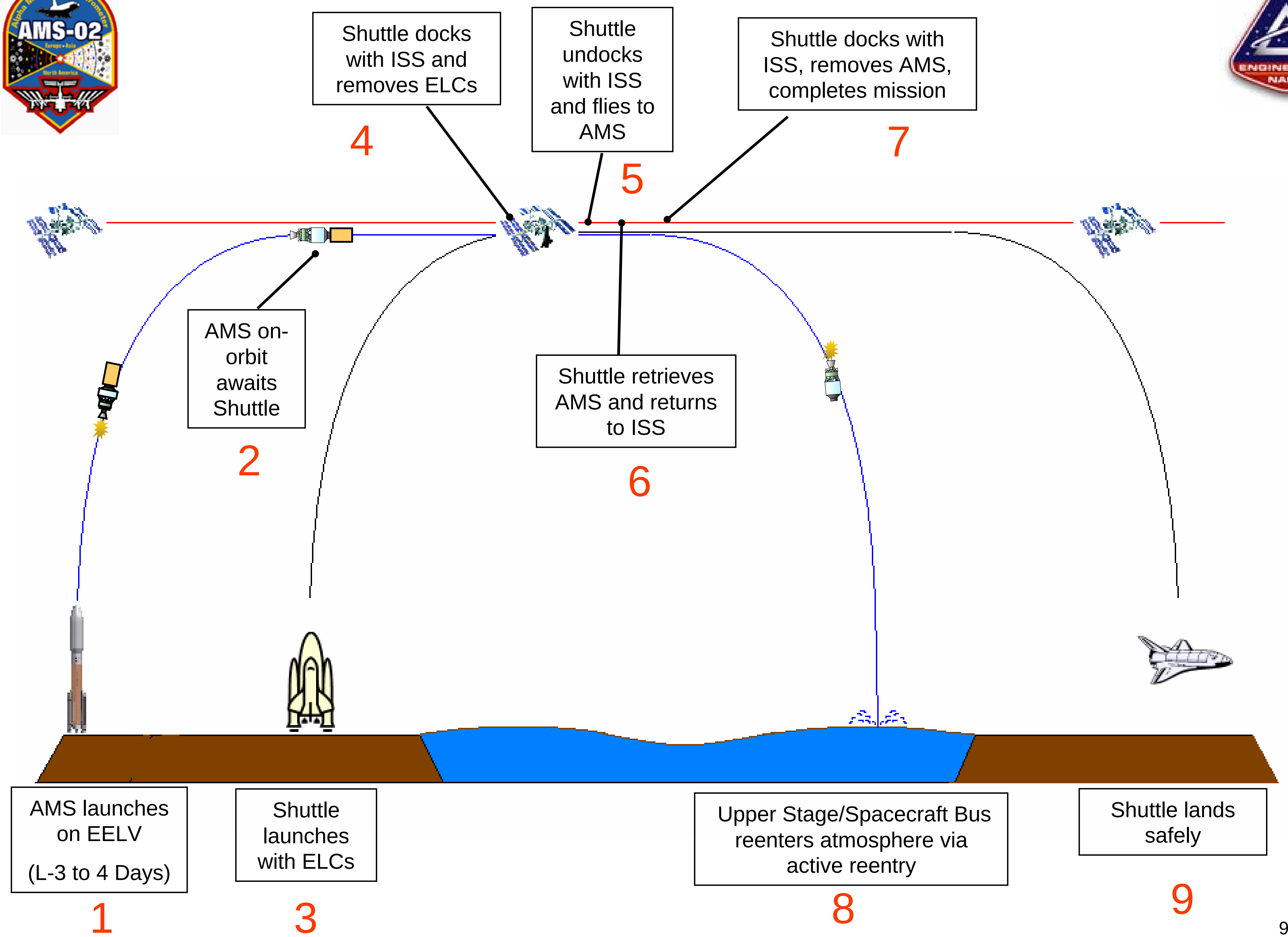


AMS Top Level Specifications

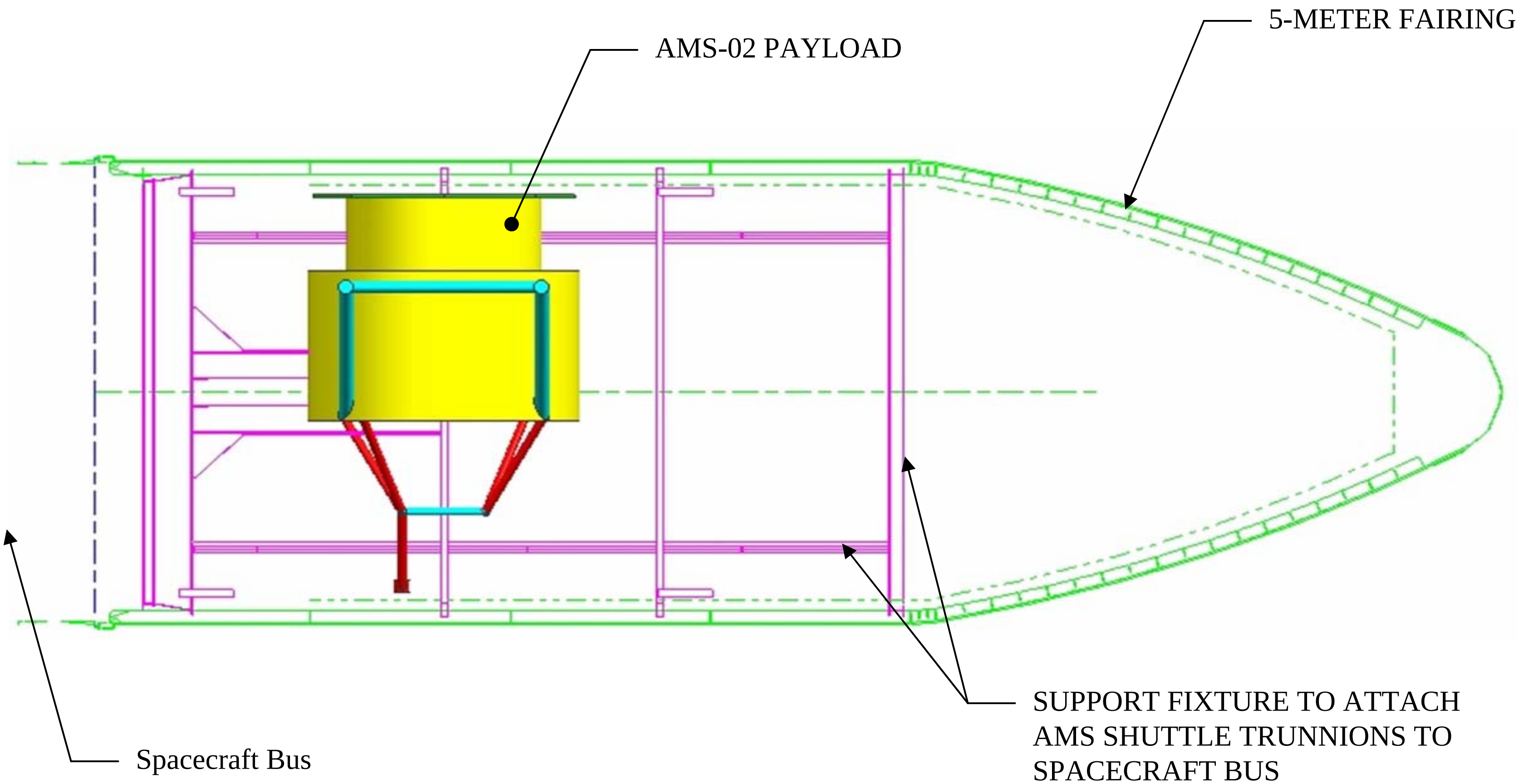
	AMS Unpress
Upmass	15,100 lbs
Volume	¼ Bay Payload
Power	2,400 W Cont. (ISS & STS)
	2,800 W Peak (ISS)
High-rate Data	2 Mbps (can burst up to 20 Mbps)
Crew Time	Robotic only during install
Magnetic Field	8500 G Center of Magnet, 2000 G Max Fringe Field at VC
	(1400 G Center of Magnet on AMS-01)

Options Considered

- Option 1: AMS launches on ELV with upgraded Upper Stage. AMS retrieved by Shuttle and delivered to ISS.
- Option 2: AMS launches on ELV with Spacecraft Bus. AMS retrieved by Shuttle and delivered to ISS.
- Option 3: AMS launches on ELV with upgraded Spacecraft Bus that is capable of rendezvous and docking/berthing with ISS.
  - COTS Capability A, External Hardware, concepts reviewed
    - RFP does not include capability to lift payload the size of AMS
    - The COTS demonstration phase did not intend for NASA to provide hardware. AMS interfaces would raise complexity and cost of this demonstration.
    - The demonstration flight is not required to go to the ISS test bed.
      - Both ATV and HTV can attest to the difficultly of satisfying ISS visiting vehicle requirements, escpecially Automated Rendezvous and Proximity Operations. Implementation of ISS visiting vehicle requirements would likely delay the expected demonstration timeframe of 2008 - 2010.
    - COTS requirements as written in the RFP do NOT meet the AMS requirements.
      - External cargo is limited to 5000 kgs/yr.
      - 100 W average, 120 Vdc power to cargo, per payload attachment site
  - This option rejected because it would take longer than 3 years to develop and would cost considerably more than Options 1 or 2
    - The Alternate Access to Station study several years ago showed that the cost to develop this technology was $421M-$594M (2003 dollars) not including the launch vehicle and assuming recurring flights to ISS


Shuttle docks with ISS and removes ELCs
4
Shuttle undocks with ISS and flies to AMS
5
Shuttle docks with ISS, removes AMS, completes mission
7
AMS on-orbit awaits Shuttle
2
Shuttle retrieves AMS and returns to ISS
6
AMS launches on EELV
(L-3 to 4 Days)
1
Shuttle launches with ELCs
3
Upper Stage/Spacecraft Bus reenters atmosphere via active reentry
8
Shuttle lands safely
9

AMS on ELV


AMS-02 PAYLOAD
5-METER FAIRING
Spacecraft Bus
SUPPORT FIXTURE TO ATTACH AMS SHUTTLE TRUNNIONS TO SPACECRAFT BUS

Operational Concept

- Assumptions
  - Shuttle has 5 cryo tanks and SSPTS
  - Conservative timeline with margin for contingencies
- Overview of Activities
  - AMS is launched on an ELV and placed in a parking orbit behind the ISS, in the ISS orbit, and at ISS altitude
  - Shuttle docks to ISS with 2 unpressurized carriers in the payload bay
  - Cargo carriers are removed from Shuttle and placed on ISS
  - Shuttle separates from ISS and rendezvous with the AMS/Spacecraft Bus
  - Shuttle crew grapples the AMS
  - Spacecraft Bus and AMS are separated
  - AMS is placed in the Shuttle payload bay
  - Shuttle rendezvous with ISS and places the AMS on the truss
  - Shuttle separates and returns to Earth.

	Potential Planning	***Nominal Planning***
L-3	**AMS launch on EELV**	
L-2		
L-1		
FD1	**Shuttle Launch**	**Shuttle Launch**
FD2	Shuttle Phasing Burns	Shuttle Phasing Burns
FD3	Shuttle Docks to ISS.	Shuttle Docks to ISS.
FD4	ULC1 deployed to attach site	EVA1
FD5	ULC5 deployed to attach site	ULC1 deployed to attach site
FD6	**Shuttle undock and phasing**	EVA2
FD7	**Rendezvous with AMS**	ULC5 deployed to attach site
FD8	**Phasing and Shuttle re-dock**	EVA3
FD9	*Shuttle Rest Day*	Off-duty and MLE Transfer
FD10	AMS deploy activities *	EVA4
FD11		MLE transfer
FD12	Shuttle undocks from ISS	EVA5
FD13	Day before landing	MLE transfer
FD14	**Shuttle Landing**	Shuttle undocks from ISS
FD15	*ISS contingency day*	Day before landing
FD16	*Shuttle contingency day*	**Shuttle Landing**
FD17	*Shuttle contingency day*	*Shuttle contingency day*
FD18		*Shuttle contingency day*
FD19		*ISS contingency day*

**** May possibly require putting an ELC back into the Shuttle bay or relocating an external carrier***

Expendable Launch Vehicle Configuration

- Vehicle Configuration
  - Both Delta IV and Atlas V have launch vehicles that can perform this mission
- Launch Site: CCAFS
- Launch Date: TBD, mid-2009
- Mission Requirements:
  - Orbit Requirements: LEO-200 n. mi. altitude, trailing ISS by 100 n. mi., with minimal planar dispersions
  - LV Performance: 11,500kg / Performance Margin: 33%
  - LV launch window: TBD, ~ 7 days
  - Extended Mission Duration Package: TBD, ~ 30 – 45 days
- Environments
  - A full evaluation of AMS requirements must be performed, however EELV throttling may be able to reduce coupled loads concerns
    - Orbital Space Plane studies determined EELV environments are comparable to Shuttle

Assumptions

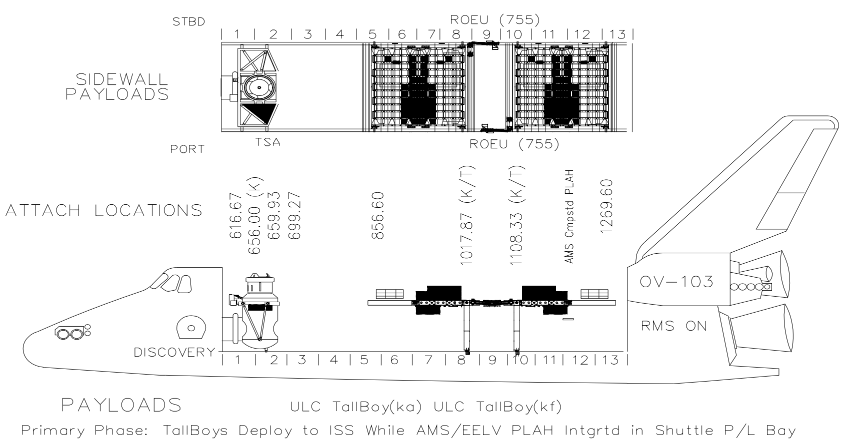
- AMS uses spacecraft bus thruster system to maintain an orbit 100 nmi from ISS on the V-bar
  - Current projections assume the Station will be at an altitude of 200 nmi
- AMS spacecraft bus has attitude control stability
  - Active attitude control will need to be shut down when the Shuttle is in proximity to avoid plume impingement
    - Utilize non-propulsive attitude control
- AMS does not require power while in the Shuttle payload bay
  - Currently AMS requires 2000 W while in the Shuttle.
  - This study assumes no power connection in the Shuttle payload bay because of the difficulty of launching AMS with a PDA or placing the active PDA in the Shuttle bay
- Contingencies in the mission before AMS will probably cause the AMS retrieval to be scrubbed
- AMS will return to Earth for some contingency situations while it is in the Shuttle

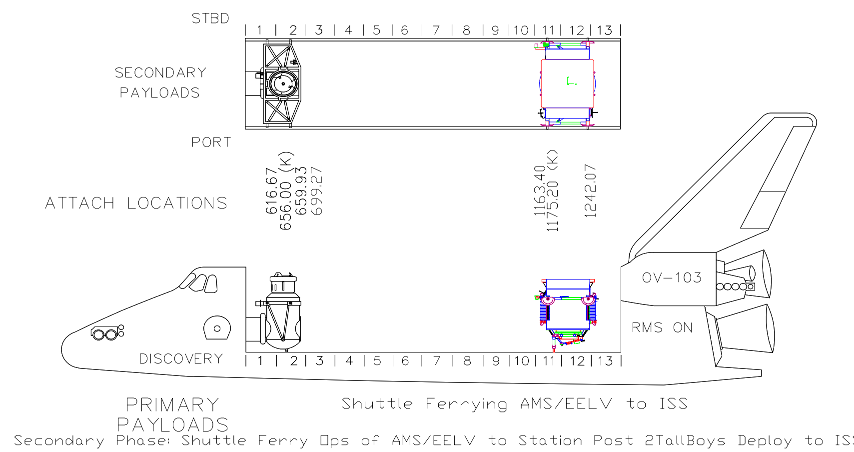
Shuttle Performance Impact

- Total reduction in delivery capability of 2,895 lbs (1,314 kg) for cargo and associated flight support equipment
  - Rendezvous Propellant - 1,869 lbs (848 kg)
    - 534 lbs to fill the Forward RCS *(354 lbs usage +180 lbs dispersions)*
    - 1335 lbs more OMS prop to orbit by reducing the OMS Assist during ascent *(1110 lbs usage + 225 lbs dispersions)*
  - AMS attach hardware – 1,026 lbs (466 kg)
  - The reduction equates to approximately 2-3 ORUs, of the 24 currently planned, or external payloads being removed
- Reboost propellant for Station may not be available
  - Typically reboost propellant is not budgeted since it is accomplished with buy-back propellant when events are nominal
  - Higher demands on Forward RCS and the addition of 2 rendezvous reduces the chance of reboost

Payload Bay Configuration/Issues

- Adding the AMS retrieval to this Unpressurized carrier flight requires 21 Latch Control Functions
  - Shuttle's LCF capability is only 19
  - Possible solution is to change the ELC trunnion spacing and move the AMS to share longeron latches – must resolve the ELC design change and structural loads capability
  - Another solution is to gang both ROEUs together - must resolve removing power/data from one of the ELCs a day early





ISS/Shuttle Safety Impacts

- Significant technical challenges to address all of the Payload Safety hazards
- Most of these are potentially catastrophic hazards and will fall under the heading of Collision with the Orbiter
  - The transfer involves,
    - Shuttle RMS captures AMS grapple fixture
    - Upper stage opens the retention latches
    - Shuttle RMS pulls the AMS from the upper stage
  - Contact between the spacecraft bus latches and AMS during RMS operations can impart momentum to the bus
  - Spacecraft bus can not counteract any induced moment because the bus must remain in free-drift with all safety inhibits
  - Potential hazard of spacecraft bus contact with the Orbiter

- Hazard concerns will need to be reviewed in the ongoing Payload Safety Review Panel (PSRP) that is reviewing the nominal AMS mission
  - Spacecraft Bus must meet all payload safety requirements

Station Crew Time Impact

- Middeck transfer does not appear to be an issue
  - Transfer must occur immediately instead of over the entire flight but crew time is available
- 5 Shuttle docked EVAs for maintenance actions must be performed by the increment crew in the stage
  - This is a significant crew time requirement added to increment (~17 hrs/wk over the course of a year)
    - 5 Shuttle docked EVAs translates to ~8 stage EVAs by increment crew due to EVA inefficiencies and training proficiency
    - Shuttle EVAs require 85 hrs/EVA
    - ISS stage EVAs require 110 hrs/EVA or 160 hrs/double EVA
  - Additional EVAs consume the stage EVA capability
    - Increment crew can perform a limited number of EVAs per stage

Open Issues and Concerns

- Reassess Assembly Sequence and on-orbit stowage with AMS
  - May need to bring back an additional external carrier
    - Less external stowage for pre-positioned spares and utilization payloads
    - EVA activities to prepare a carrier for return must be performed
      - ELC4 on flight ULF4 could be a potential carrier for return
      - Currently ELC4 is manifested with the MMOD wings and corrective maintenance ORUs
  - Or look into options where ESP-3 is removed (i.e. jettison)

- Develop AMS spacecraft bus design requirements including:
  - AMS attitude control capability including plume impingement issues
  - AMS range and location from Station
  - 3 inhibits to safe the upper stage/spacecraft bus thruster systems during Shuttle proximity operations
  - Contact dynamics when pulling AMS away from the upper stage (now in free drift)

Technical Review Summary

- This preliminary assessment shows that there are significant technical hurdles to overcome, but no technical show-stoppers have been identified
- Majority of the issues will be driven to ground in the normal course of design and development of the AMS Spacecraft Bus
- Must begin technical assessments by the end of January 2006 or this will not be feasible by mid-2009

Spacecraft Bus Package

- The highest risk (cost, schedule and technical) element of this proposal, from the LSP perspective, is the Spacecraft Bus Package. The LSP is strategizing on the best approach to mitigate risk and meet the mid-2009 launch schedule.

- This package would include: Power, Attitude Control System, Communications, Thermal System, Safety implementation for docked phase with Shuttle and a collision avoidance and/or deorbit burn after Shuttle departs for ISS. Strategies include:
  - Compete and manage a simplified spacecraft bus design (non cryogenic) through the Rapid Spacecraft Development Office at GSFC
    - The LSP would be responsible for integration of this bus to AMS and EELV

EELV Development Plan

- Early Feasibility Studies are utilized prior to a competitive procurement to allow evaluation of possible high risk development items and optimize design solutions. The results of these studies also provide fidelity to the Interface Requirements Document utilized in the procurement phase.

Pre-Mission Planning → Mission Planning → Baseline Mission & Procure Launch Services → L/V & S/C Engin'g & Manfact'g → Launch Site Ops & camp-aign → Post Launch

February – May 2006 : Feasibility Studies

March 2006 : Release RFI for Spacecraft Bus

- June – December 2006: Launch Service/Spacecraft Bus Competition
  - ATP December 2006

January 2007 to Launch: Mission Integration

Launch Service Program Contracts/Budget

- Full Mission Budget and profile:
  - All costs are established in real-year dollars (order year = L-30) based on current NLS contract information.
  - Launch service cost includes all services provided by the Launch Services Program including Payload Processing Facilities

- AMS with Spacecraft Bus
  - Mission Budget $303M - $323M
  - Budget Profile: FY06 1%, FY07 56%, FY08 25%, FY09 18%
    - Spacecraft on-orbit service module provides all operational requirements for power, extended mission duration, two-way communication, attitude control
    - Including STS redundancy and non-propulsive attitude control

Budget and Phasing

- LSP requires $303M over 4 years (Assumes Option 2)
- New integration effort for APO requires $12M over 4 years
- Includes Program Management Contingency

FY/$M	2006	2007	2008	2009	Total
LSP	3.0	169.7	75.8	54.5	303.0
APO	4.0	3.0	3.0	2.0	12.0
Subtotal	*7.0*	*172.7*	*78.8*	*56.5*	*315.0*
% Contingency	25	25	20	10	N/A
Contingency	1.8	43.2	15.8	5.7	66.5
Total	8.8	215.9	94.6	62.2	381.5

Proposal

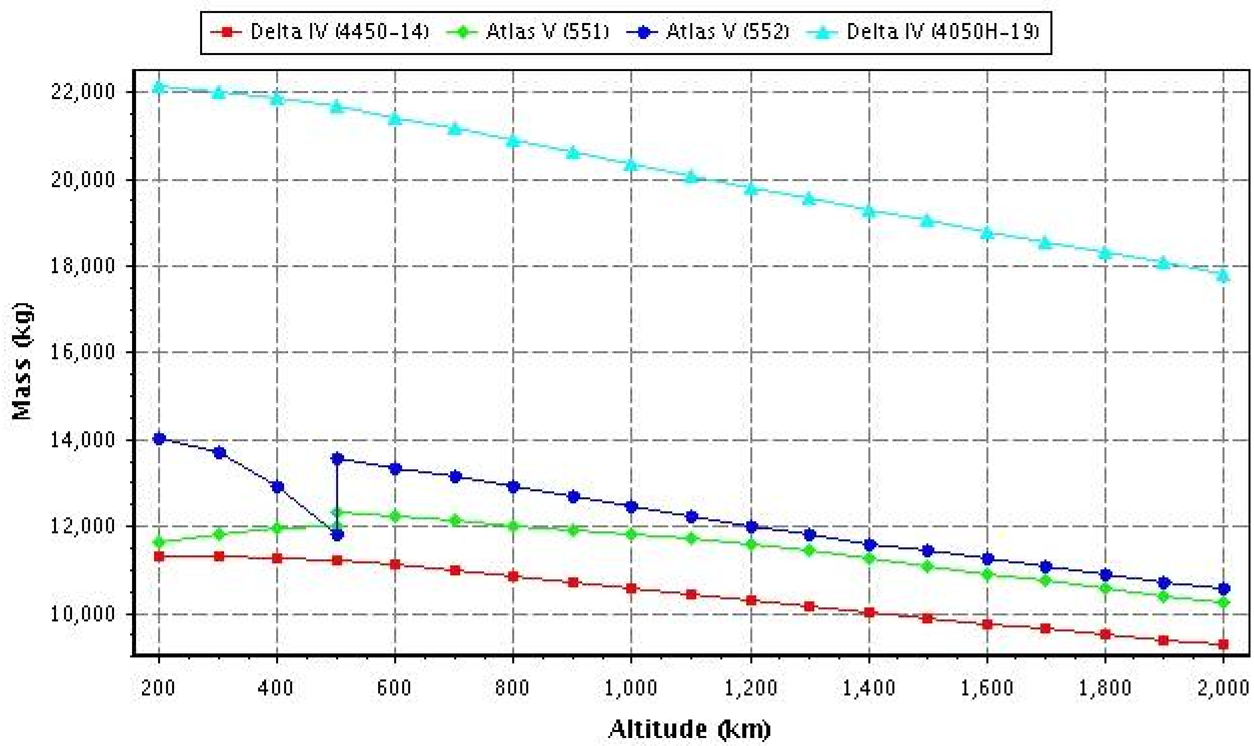
- If a Shuttle ride to ISS can not be identified for AMS, implement this approach, implement spacecraft bus approach minimizing safety risks with Shuttle
  – Since this requires 30-36 months to implement, feasibility assessments must begin immediately and the EELV procurement process must be started no later than June 2006 to make a mid-2009 launch date

Backup Material

Important Note: The data contained in these curves are based on ground rules and assumptions located below the plot. Please read this information carefully. This information is intended for NASA customers only.

NASA ELV Performance Estimation Curve(s)

LEO Circular with inclination 60
Please note ground rules and assumptions below.



Assumptions:

Delta IV (4450-14)
- 3-sigma probability of Stage 2 commanded shutdown, plus additional reserves as determined by the LSP.
- 1194-5 payload adapter.
- Launch from SLC-6 at VAFB (Vandenberg Air Force Base).
- 185 km (100 nmi) park orbit perigee.

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Atlas V (551)
- 3-sigma mission required margin, plus additional reserves as determined by the LSP.
- Launch from SLC-41 at CCAFS (Cape Canaveral Air Force Station).
- Performance values assume harness, logo, reradiating antenna, 3 payload fairing doors.
- Payload mass greater than 9000 kg (19,841 lbs) may require mission unique accommodations.
- Type B2 payload adapter plus type C2 spacer.
- 5-meter Short Payload Fairing.
- 185 km (100 nmi) minimum park orbit perigee altitude.

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Atlas V (552)
- 3-sigma mission required margin, plus additional reserves as determined by the LSP.
- Launch from SLC-41 at CCAFS (Cape Canaveral Air Force Station).
- Performance values assume harness, logo, reradiating antenna, 3 payload fairing doors.
- Payload mass greater than 9000 kg (19,841 lbs) may require mission unique accommodations.
- Type B2 payload adapter plus type C2 spacer.
- 5-meter Short Payload Fairing.
- 185 km (100 nmi) minimum park orbit perigee altitude.

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Delta IV (4050H-19)
- 3-sigma probability of Stage 2 commanded shutdown, plus additional reserves as determined by the LSP.
- 1194-5 payload adapter.
- Launch from SLC-6 at VAFB (Vandenberg Air Force Base).
- 185 km (100 nmi) park orbit perigee.

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Payload Safety

Orbiter Collision Hazard

• The following points are not a complete listing of safety requirements for this type of mission.

- Total thrust of the system will be used to establish a "safe distance" from the Orbiter, which will probably be on the order of thousands of feet
- Before the Orbiter can approach the AMS within this safe distance, all hazardous systems must be safed to the proper fault tolerance, and the fault tolerance must be substantiated directly or indirectly by the Crew or the ground
- Additionally, the AMS/upper stage combination must be certified "safe" by the Payload Organization based on a hazard analysis that considers anything that may have happened during ascent and orbital insertion before Orbiter approach can begin

Orbiter Collision Hazard Requirements Examples

- **Safety features of liquid propulsion systems designed to be safe for the Orbiter are different from those usually found on ELVs. In fact, the redundant inhibits required for safety are often at odds with ELV requirements for reliability because they add single point failures to desired functions.**

  - A liquid propulsion system must have three mechanically independent flow control devices in series to prevent delivery of propellant. A bi-propellant system must have them in both the fuel and oxidizer subsystems.
  - One of these devices must isolate the prop tank from the rest of the system.
  - At least one must be fail-safe (i.e.-return to the closed position in the absence of an opening signal)
  - There must be at least three independent electrical inhibits controlling the opening of the flow control devices.
  - The failure of any one cannot open more than one of the flow control devices.
  - The status of at least two must be monitored by Crew or the ground.

Orbiter Collision Hazard Requirements Examples

- Any command that can remove an inhibit or activate and unpowered hazardous system is considered a hazardous command - This will require a safety assessment of failure modes associated with command center hardware, software and procedures

- Non-propulsive attitude control systems (momentum wheels, magnetic torque rods, etc.) must be assessed for hazards associated with their failure

- At all times, in order to facilitate rapid safing for emergency return, the payload must be able to be released, jettisoned, or be safe for return and landing in the Orbiter

Space Shuttle Program Conclusions

- **Significant technical challenges to address all of the Payload Safety hazards**
  - Introduces crew safety critical hazards for both the Station and Shuttle
  - Unresolved operational contact hazards (tip off rates) with the current concept
  - ELV upper stage must meet all payload safety requirements
- **Retrieving the AMS from an ELV upper stage is a significant impact to this logistics mission**
  - Costs 46% of the scheduled docked time **(6 of 13 docked days lost)**
  - Costs 13% of the cargo bay un-pressurized up mass **(3 of 23.4 Klbs lost)**

Other Launch Vehicle Risks

- Launch Operations CONOP
  - STS and EELV must launch within close proximity
    - Range must agree to priority launch dates and window
    - LSC's must protect their manifest to delays
    - Launch window is very short
  - Launch preparations and reviews for Shuttle and LSP will occur in parallel
    - Heightened level of contingency planning including AMS cryogenic servicing at the pad during possible scrub scenarios
- Late notification of PLF modification requirements to accommodate AMS
  - Schedule and ROM have not been validated by contactors should this modification become necessary
- New flight software for guided burns and deorbit after Shuttle rendezvous
  - Similar software under evaluation for Solar Dynamics Observatory (SDO) mission
- Delta IV launch vehicle certification, if required
  - Certification of the Atlas V 551 vehicle will be completed for the Pluto mission in January 2006 (February 2007 backup)
- Payload Attach Fitting development schedule and cost are not validated by contractors