Essential Elements of Successful Missions

"Managing Resources within the Mission Cost Cap"

Presented by Joe Vellinga, (Ret.)

Lockheed Martin Stardust Program Mgr

From the paper:

"How to Plan and Manage Reserves Effectively"

By

Ken Atkins, Development & Launch Project Manager

Jet Propulsion Laboratory

Paper #1292

IEEE 04 Aerospace Conference

Big Sky, Montana

March 2004

Science Requirements
(NASA Stardust Project)

Primary Requirement:

Collect 1000 comet particles >15µm at encounter velocity <6.5 km/s and return to Earth

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Secondary Requirements:

Collect interstellar particles for 150 days minimum and return to Earth.

Provide >65 images of Wild 2, having a resolution of at least 67 µrad/pixel, taken within 2000 km of the comet nucleus

Provide in-situ particle analysis for comet coma flythrough

Tertiary Requirements:

Provide in-situ particle analysis for interstellar and interplanetary dust;

Collect comet coma molecules and return to Earth;

Measure dust mass fluence, large particles and comet mass upper limit;

Provide dust flux measurement of $>10^{-9}$g to 1g particles

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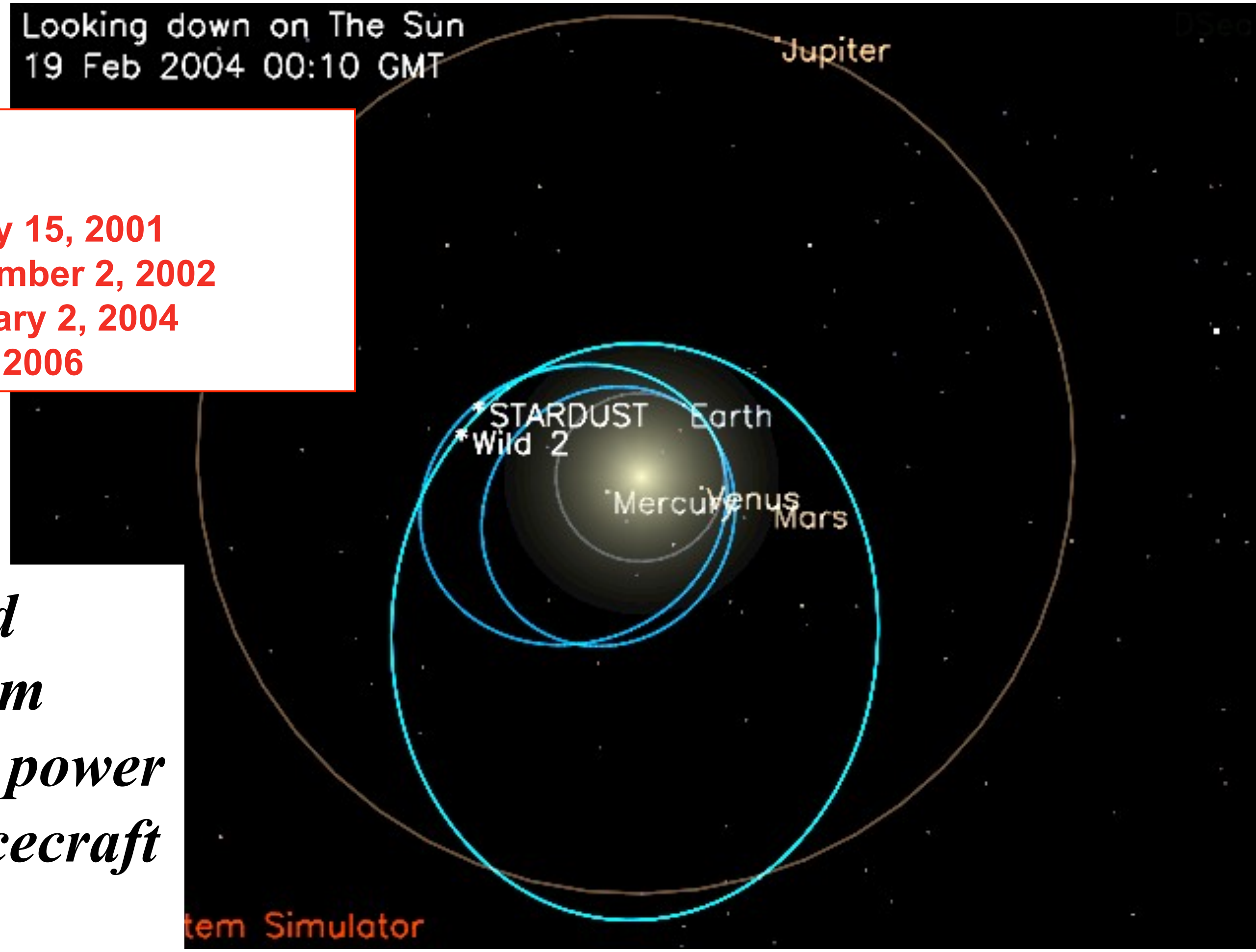
Stardust
"Bringing Back Cosmic History"



Mission Timeline:
- **Launched: February 7, 1999**
- **Earth Gravity Assist: January 15, 2001**
- **AnneFrank Encounter: November 2, 2002**
- **Encounter with Wild 2: January 2, 2004**
- **Return to Earth: January 15, 2006**

Fact: ***Stardust had traveled further from the sun using solar power than any other spacecraft at the time***

Stardust Program Summary

Cost Cap: **$200 M including Launch Vehicle**
Cost Commitment: **$199.6 M including Launch Vehicle**
Cost Commitment: **$164.6 M without Launch Vehicle**

Launch: **February 7, 1999**

Mass: **385 kilograms (848 pounds) total,**
254 kilogram (560-pound) spacecraft
46 kilogram (101-pound) sample return capsule (SRC)
85 kilograms (187 pounds) fuel

Science-related subsystems:

Aerogel dust collectors (cometary & interstellar)
Sample Return Capsule (SRC)
Comet and Interstellar Dust Analyzer (CIDA)
Dust Flux Monitor (DFM)
Navigation Camera (Nav Cam)

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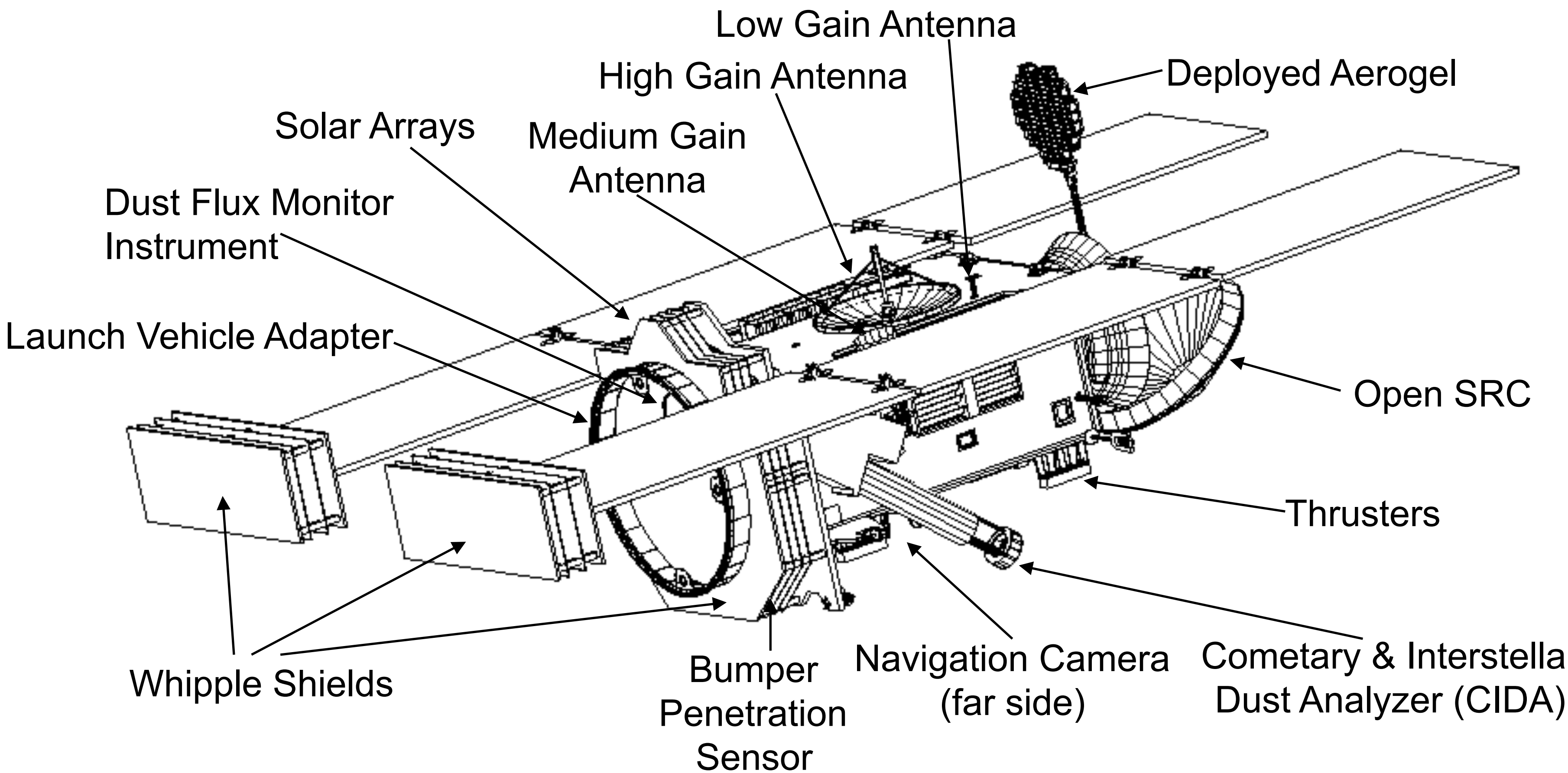
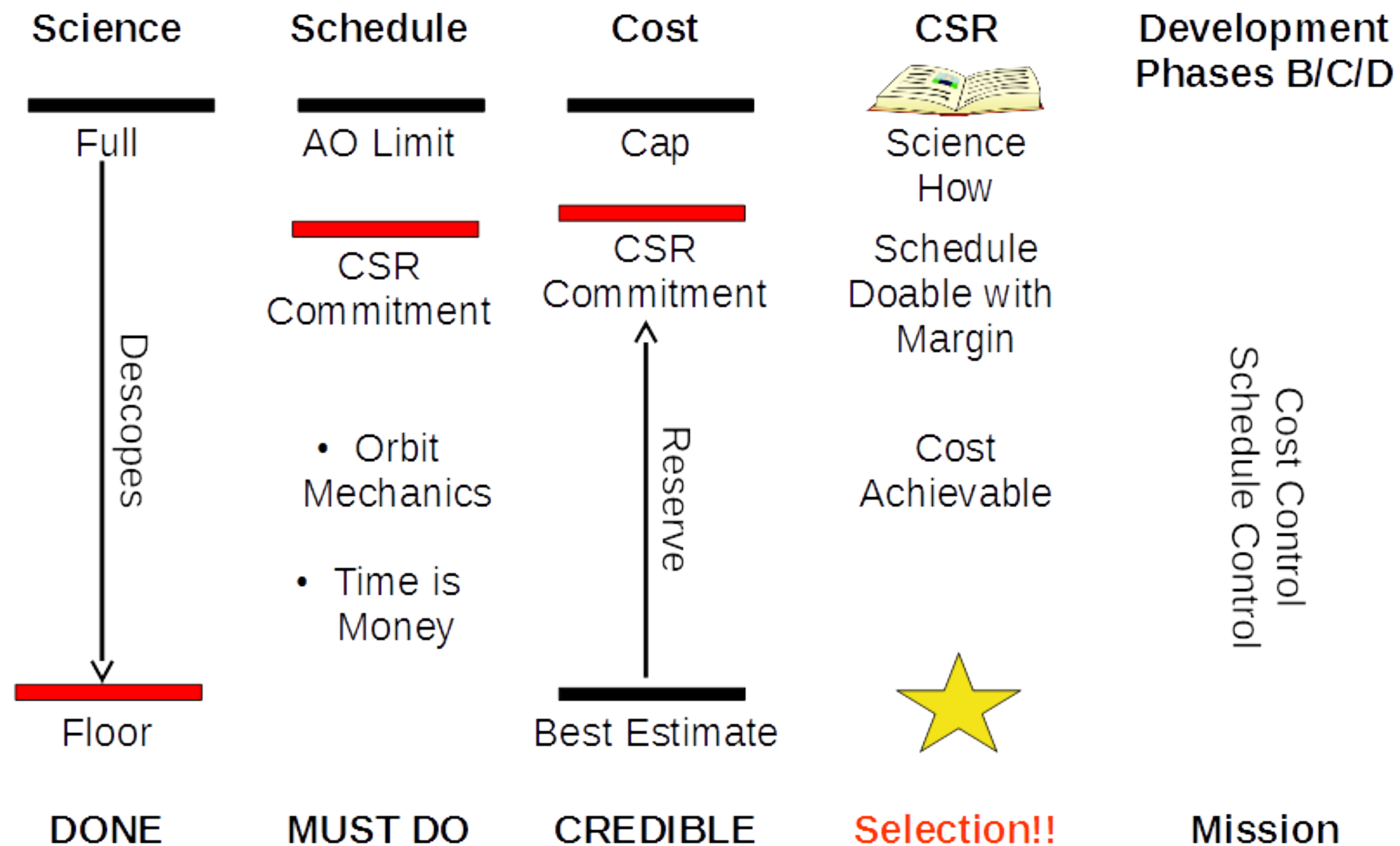
Stardust at Wild 2 Encounter



Rotating - 1 Solar Array 1st Motion

Phase A


Science
Schedule
Cost
CSR
Development Phases B/C/D
Full
AO Limit
Cap
Science How
CSR Commitment
CSR Commitment
Schedule Doable with Margin
Descopes
Reserve
• Orbit Mechanics
• Time is Money
Cost Achievable
Cost Control
Schedule Control
Floor
Best Estimate
DONE
MUST DO
CREDIBLE
Selection!!
Mission

Cost Control Starts with Design-to-Cost Process

REQUIREMENT-DRIVEN

REQUIREMENTS

DRIVE

DESIGN

DRIVES

COST

CAPABILITY-DRIVEN

(Requirements compared against existing designs)

EXISTING DESIGNS

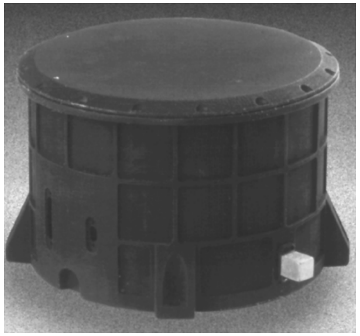
PROVIDE

CAPABILITY

DETERMINES

COST

Attitude Control Capability vs. Requirements Matrix

Component	*Existing Hardware (CDR -Level)*	*In Development* (PDR -Level)	*New/Unique (Reqmts-Level)*
STAR CAMERA ***- OCA Star Tracker Camera*** ***- CDR 2/96*** ***- EDU 7/96***			
IMU ***- Honeywell MIMU YG9666B*** ***- Qualification In Progress***			
ACS Algorithms		• **RCS 3-Axis Control** • **Sensor Processing** • **Attitude Determination** • **TCM Control** • **Ephemeris Generation**	• ***Encounter ACS*** • ***NAVCAM Point***

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Elements of the Significant Risk List (SRL)

- Description of each risk item
- The area (e.g., system/ subsystem) that would deal with this risk
- Estimated cost to recover from the risk if no mitigation occurs (optionally - a description of what would need to be done to recover after the risk event takes place)
- Estimated probability of the risk occurring if no mitigation action occurs
- Any mitigation decision made (accept risk, mitigate now, or mitigate if some criteria is met)
- Any decision dates, if the mitigation decision is deferred
- Any mitigation costs
- Residual risk after mitigation, in terms of probability and cost of the risk occurring despite mitigation
- Whether the risk has been retired

-- Risk Management Handbook for JPL Projects, D-15951, October 1998

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Significant Risk List (SRL) from January 1997

MISSION RISK LIST

Risk Item No.	Name	Description/Justification	Affected S/Ss	Impact	Severity of Occurrence /Failure (note 1)	Prob. of occurr-ence (note 2)	Fix	Mitigating Circumstances
2	Late ATLO deliveries	Once the S/C is 'buttoned up', it will be difficult to remove and replace parts.	ATLO	Reduced ATLO test time decreases reliability	Minor	Medium	Aggressively work late deliveries. Have enough slack in ATLO schedule to support late remove and replace operations.	Thorough env test program on assemblies. All assemblies require 100 hours of operation prior to ATLO
4	Parachute Deploy	Drogue parachute G switch and timer. 7 year life for switch.	SRC	Single point mission failure	Total		Use redundant G switch and timer	Analysis of switches
5	Thruster/ Valve Drive Failure	Thruster or drive valve fails. This may require use of non-optimal thrusters to maintain Attitude control and expending excess propellant.	ACS, Prop.	Reduced attitude control capability during encounter reduces reliability	Minor	Unlikely	Redundancy (non-optimal) and mission planning flexibility	
9	Occultation Period	Long autonomous operation required due to ground Ops unable to command S/C for up to 100 days.	All	Possible loss of mission	Total	Low	Extensive fault protection design and test	
12	Nav Cam Failure	Nav Cam fails and must rely on Star Camera to navigate to comet and earth return	AACS, Ops	Loss of imaging data.	Minor	Medium	Add redundant Nav Cam	Primary mission not threatened
14	SRC Separation Dynamics	Separation of SRC exceeds RPM and tip-off envelopes, resulting in exceeding entry angle errors	SRC	Possible loss of mission	Major to Total	Low	No feasible fix	Margined, analyzed, and well tested design

Notes:	1) Severity of Occurrence/Failure		2) Probability of occurrence choose one:	
	Total	Mission loss—loss of particle samples	10%	Low—In all likelihood will not occur
	Major	Major impact—significant loss of data	40%	Medium —may occur despite norma[illegible]
	[illegible]or	Minor impa[illegible]ptable	60%	High—may occur even with special
			90%	Very high—nearly certain to occur

Significant Risk List (SRL) to Budget Change

BUDGET CHANGE LOG				EST .SOFT LIENS		
	Reason	Date	Date	FY98	FY99	TOTAL
PROBABILITY FACTORS:						
HIGH = 100%						
MED = 60%						
LOW = 30%						
SOFT LIENS		**Probability**	**Originator**	FY98	FY99	C/D
Sim Software Resources		High	JPL	150		150
FSW Development Risk		High	JPL	300		300
Nav Cam Sleep Mode Will Not Work		High	JPL	10		10
Open NavCam ICD issues & misunderstandings		High	JPL	10		10
Nav Cam Late Delivery (incl MDI Supplies)		High	JPL	250		250
IMU Leakage Problem		High	JPL	200		200
Aerogel ICD / Contam Requirements		High	JPL	300		300
CIDA Ground Loop		High	JPL	75		75
CIDA - PACI I/F Issues		High	JPL	250		250
Flight Spares Operating Time		High	JPL	75		75
Analysis/Verifications (act or paperwork delay)		High	JPL	200		200
OCA Star CAM Development		High	JPL	75		75
Fuse Rel Questions		Med	JPL	300		300
PACI Board Issues		Med	JPL	200		200
C&DH Backplane Failure		Med	JPL	100		100
Nav Cam Rework/Repair Contingency		Low	JPL	55		55
TOTAL SOFT LIENS				2718	0	2718
TOTAL HIGH PROBABILITY				2020	0	2020
TOTAL MEDIUM PROBABILITY				384	0	384
TOTAL LOW PROBABILITY				18	0	18
TOTAL WITH PROB. APPLIED + Proc O/H				2421	0	2421

Reserve/Lien List - Mar. 30,1998

BUDGET CHANGE LOG				ESTIMATED LIENS				DEFINITIZED LIENS				
	Reason	Date	Account	FY 97	FY98	FY99	TOTAL	FY 97	FY98	FY99	TOTAL	STATUS
TOTAL PHASE C/D RESERVES					12753	0	12753		12753	0	12753	
JPL Project (P)					8947	0	8947		8947	0	8947	
LMA Flight System (FS)					3806	0	3806		3806	0	3806	
LIENS												
EPS Test	R/R	Aug-97	LMA Contract		-150		-150		-150		-150	In Dec MPM Plan
LMA ETC	O/R	Oct-97	LMA Internal		-3806	0	-3806		-3806	0	-3806	In 98 Plan
JPL ETC	O/R	Oct-97	JPL Internal		-626		-626		-626		-626	In 98 Plan
Nav Cam Radiator, etc	C/S	Nov-97	LMA Contract		-37		-37		-37		-37	No Cost Change
SRC Avionics Shock Isolation	O/R	Nov-97	LMA Internal		0		0		0		0	In ETC Plan
Picture Frame for ATLO	R/R	Nov-97	LMA Internal		0		0		0		0	In ETC Plan
Solar Array Diode Addition for Shadowing	C/S	Nov-97	LMA Contract		-213		-213					
Aerogel Recovery	O/R	Nov-97	JPL 51100		-432		-432		-432		-432	In 98 Plan
CIDA Parts	R/R	Dec-97	JPL 60006		-32		-32		-32		-32	Incurred Dec-97
CIDA Mass/Thermal Simulator	C/S	Dec-97	LMA Contract		-85		-85		-85		-85	Negotiated
Breakout Boxes	R/R	Dec-97	LMA Contract		-83		-83		-83		-83	In Feb MPM Plan
Aerogel Spectrometer	C/S	Feb-98	JPL 51200		-177		-177		-177		-177	In Feb MPM Plan
Feb LMA Cost Over Reserve (541K)	O/R	Feb-98	LMA Contract		-577		-577					Noted
HARD LIENS FY98					-6218	0	-6218		-5429	0	-5429	
Reserves - Hard Liens					6535	0	6535		7324	0	7324	
JPL Project (P)					6535	0	6535		7324	0	7324	
LMA Flight System (FS)					0	0	0		0	0	0	
ATLO H/W Delivery Soft Lien ($2M H/W to ATLO less spent)					-1555							
ATLO RESERVES (Less Hardware Delivery Soft Lien)				0	4980	0	4980	0	7324	0	7324	
TOTAL SOFT LIENS (From Soft Lien List)				0	-2421	0	-2421	0	-2421	0	-2421	
TOTAL UNENCUMBERED RESERVES (w/Soft Lien List)				0	4114	0	4114	0	4903	0	4903	

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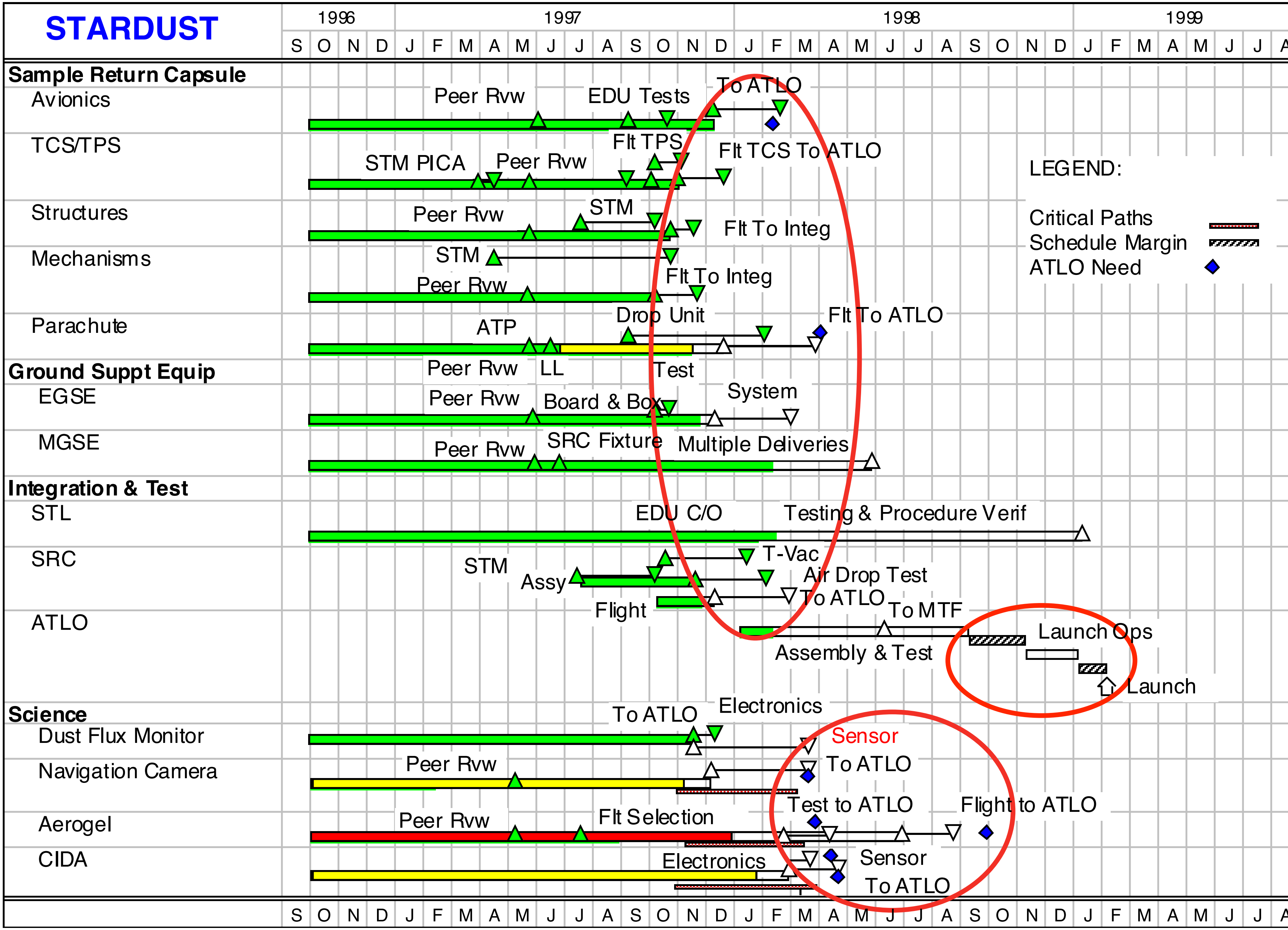
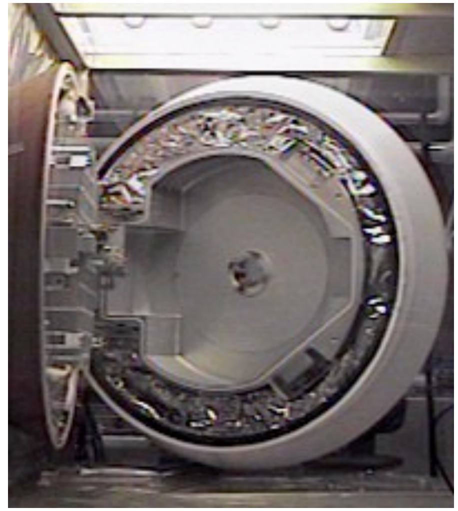


STARDUST
1996
1997
1998
1999
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A
Sample Return Capsule
Avionics
Peer Rvw
EDU Tests
To ATLO
TCS/TPS
STM PICA
Peer Rvw
Flt TPS
Flt TCS To ATLO
Structures
Peer Rvw
STM
Flt To Integ
Mechanisms
STM
Peer Rvw
Flt To Integ
Parachute
ATP
Drop Unit
Flt To ATLO
Ground Suppt Equip
Peer Rvw
LL
Test
EGSE
Peer Rvw
Board & Box
System
MGSE
Peer Rvw
SRC Fixture
Multiple Deliveries
Integration & Test
STL
EDU C/O
Testing & Procedure Verif
SRC
STM
T-Vac
Assy
Air Drop Test
To ATLO
Flight
ATLO
To MTF
Launch Ops
Assembly & Test
Launch
Science
Dust Flux Monitor
To ATLO
Electronics
Sensor
Navigation Camera
Peer Rvw
To ATLO
Aerogel
Peer Rvw
Flt Selection
Test to ATLO
Flight to ATLO
CIDA
Electronics
Sensor
To ATLO
LEGEND:
Critical Paths
Schedule Margin
ATLO Need
S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A

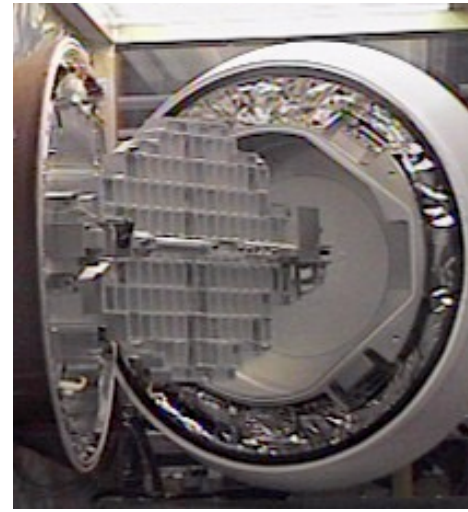
Flight Aerogel Installed at KSC

Latched

Unlatched

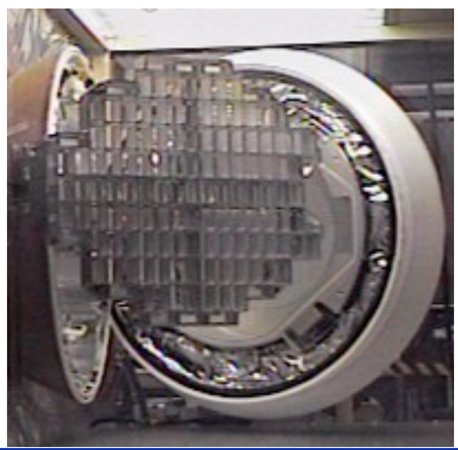


Hinge Open

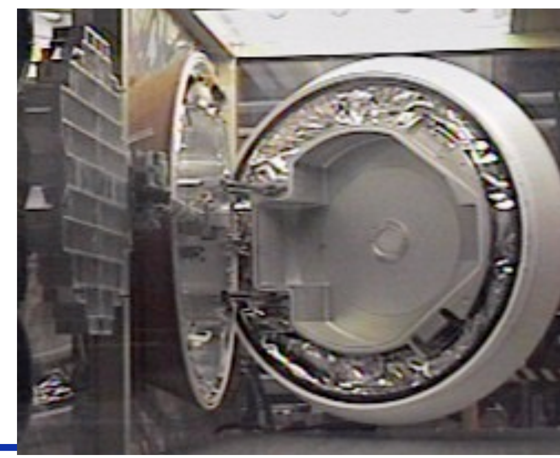


Shoulder Opening

Shoulder Deployed



Wrist Deploying



Fully Deployed

NASA

JPL
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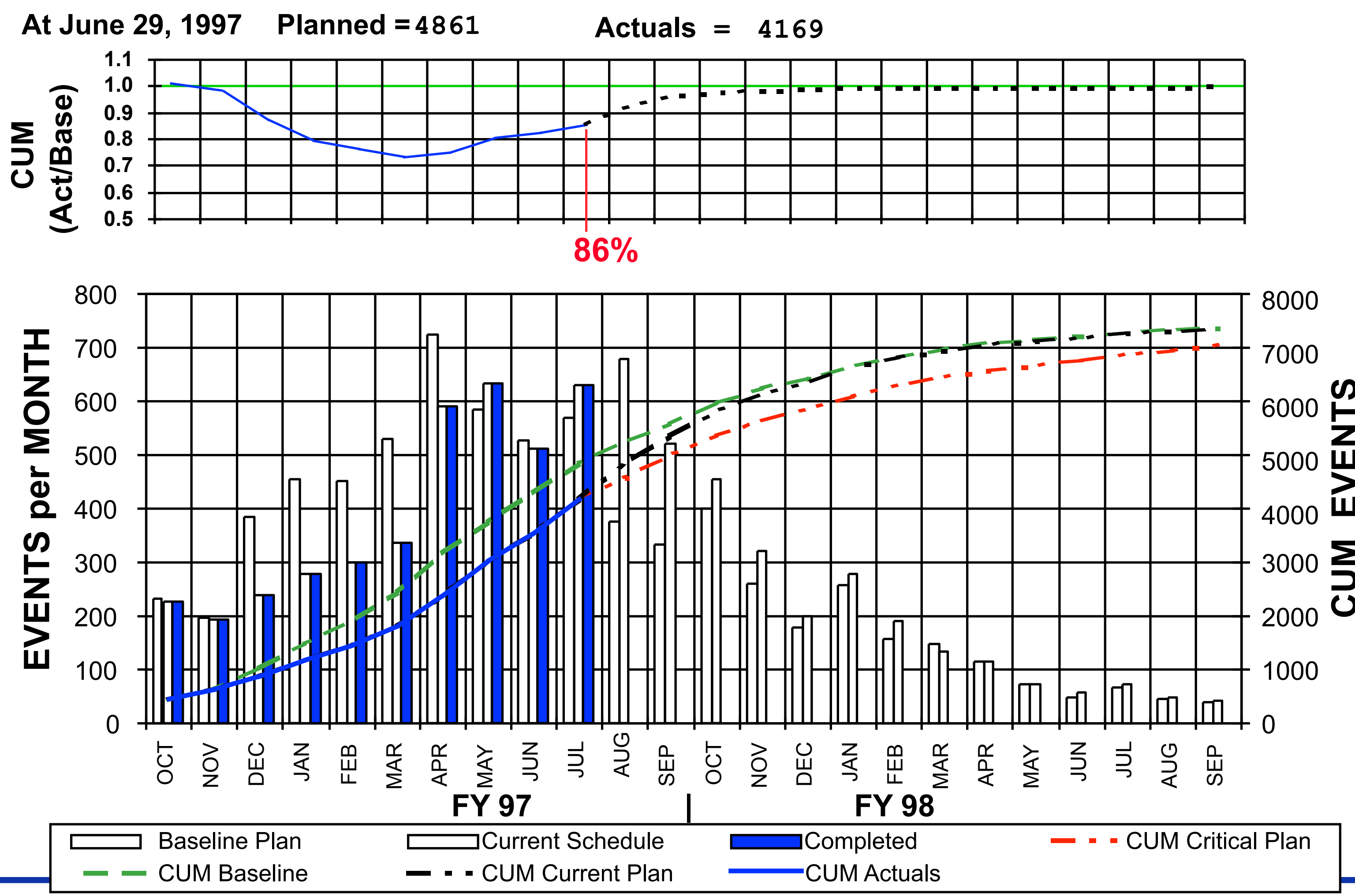
University of Washington

Lockheed Martin

STARDUST

Schedule Performance Assessment Metric



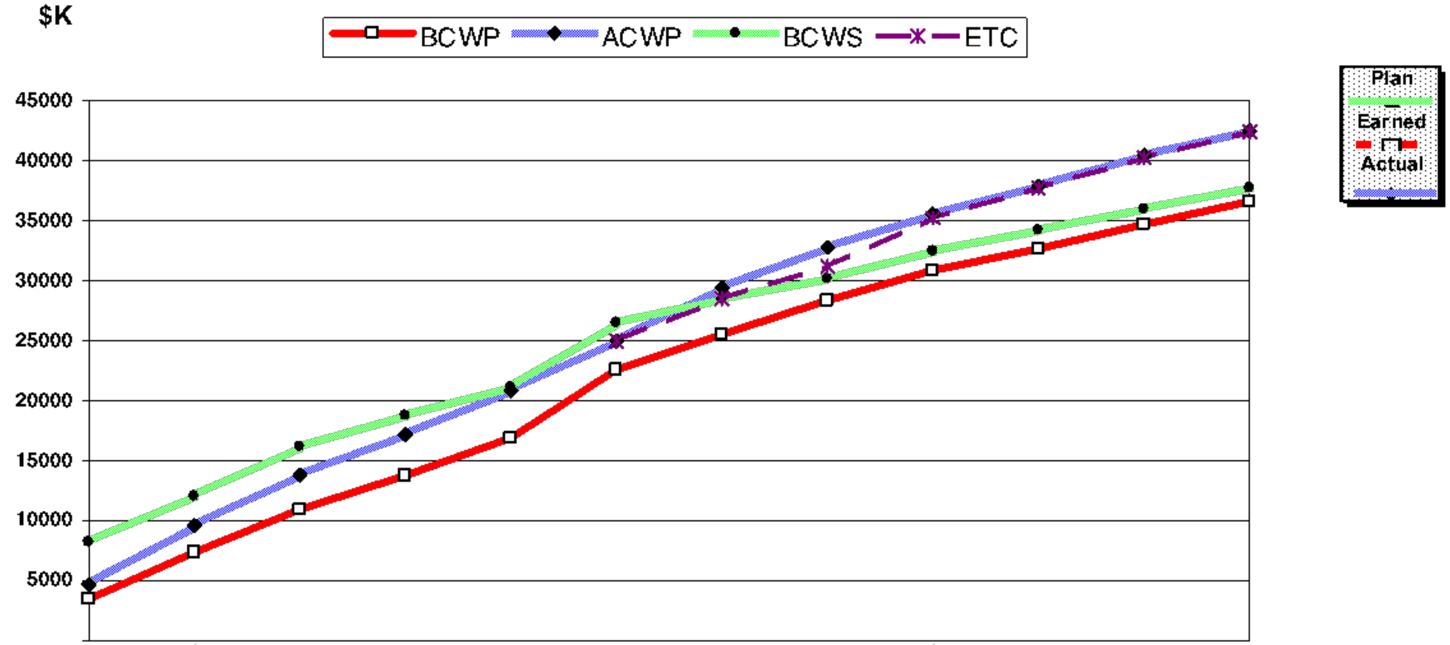
JPL

COST PERFORMANCE MANAGEMENT

September 1998

Program Earned Value

FISCAL YEAR '98



		Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
	ETC						25013	28527	31205	35251	37725	40235	42419
C	Plan	8235	12071	16163	18762	21098	26485	28457	30199	32452	34214	35970	37741
U	Earned	3469	7373	10954	13750	16893	22613	25548	28352	30865	32690	34693	36646
M	Actual	4668	9610	13797	17152	20848	25013	29447	32768	35575	37925	40492	42476

Sched Var	-4766	-4698	-5209	-5012	-4205	-3872	-2909	-1847	-1587	-1524	-1277	-1095
Cost Var	-1199	-2237	-2843	-3402	-3955	-2400	-3899	-4416	-4710	-5235	-5799	-5830
Plan- Act	3567	2461	2366	1610	250	1472	-990	-2569	-3123	-3711	-4522	-4735

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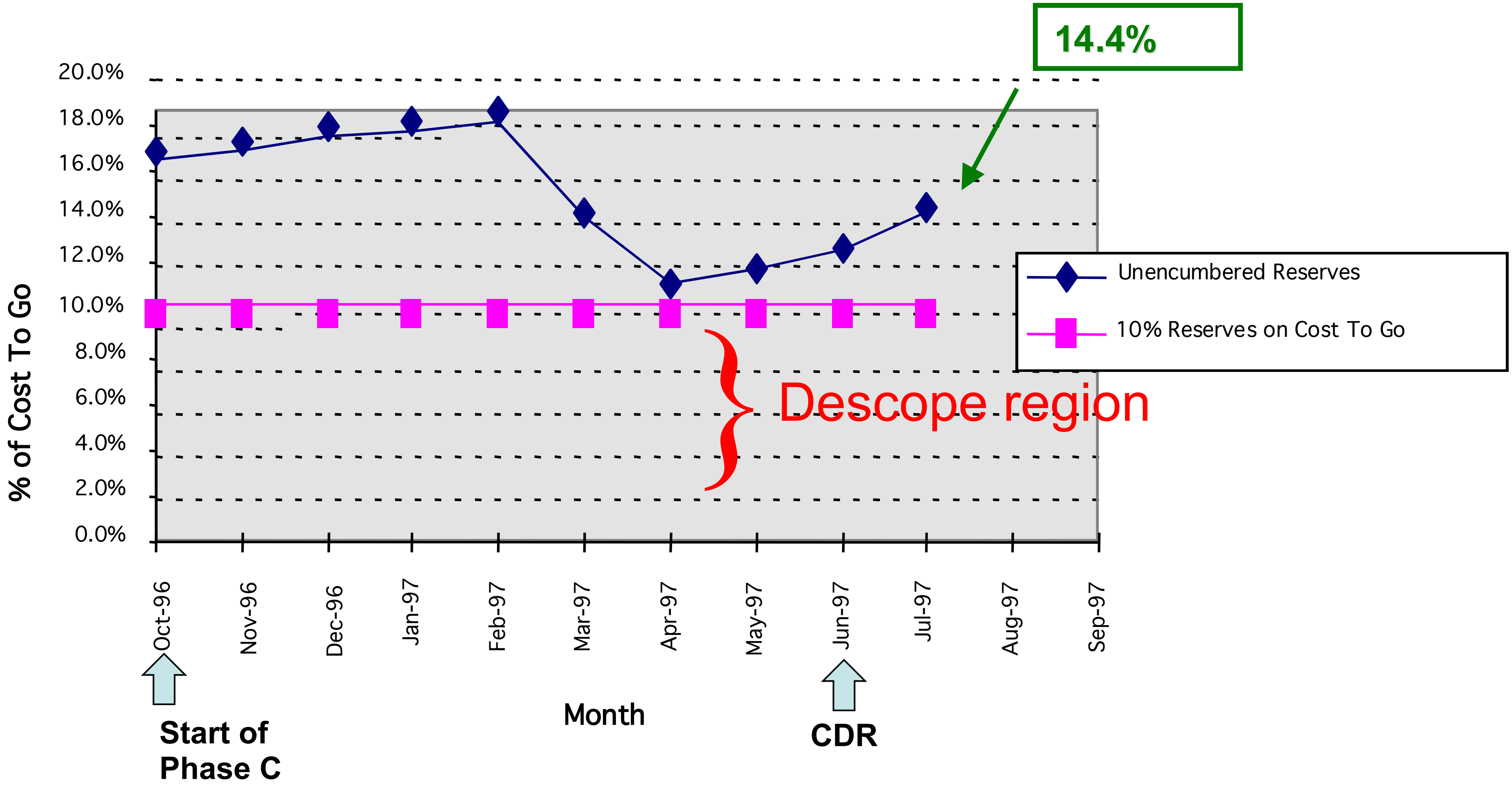
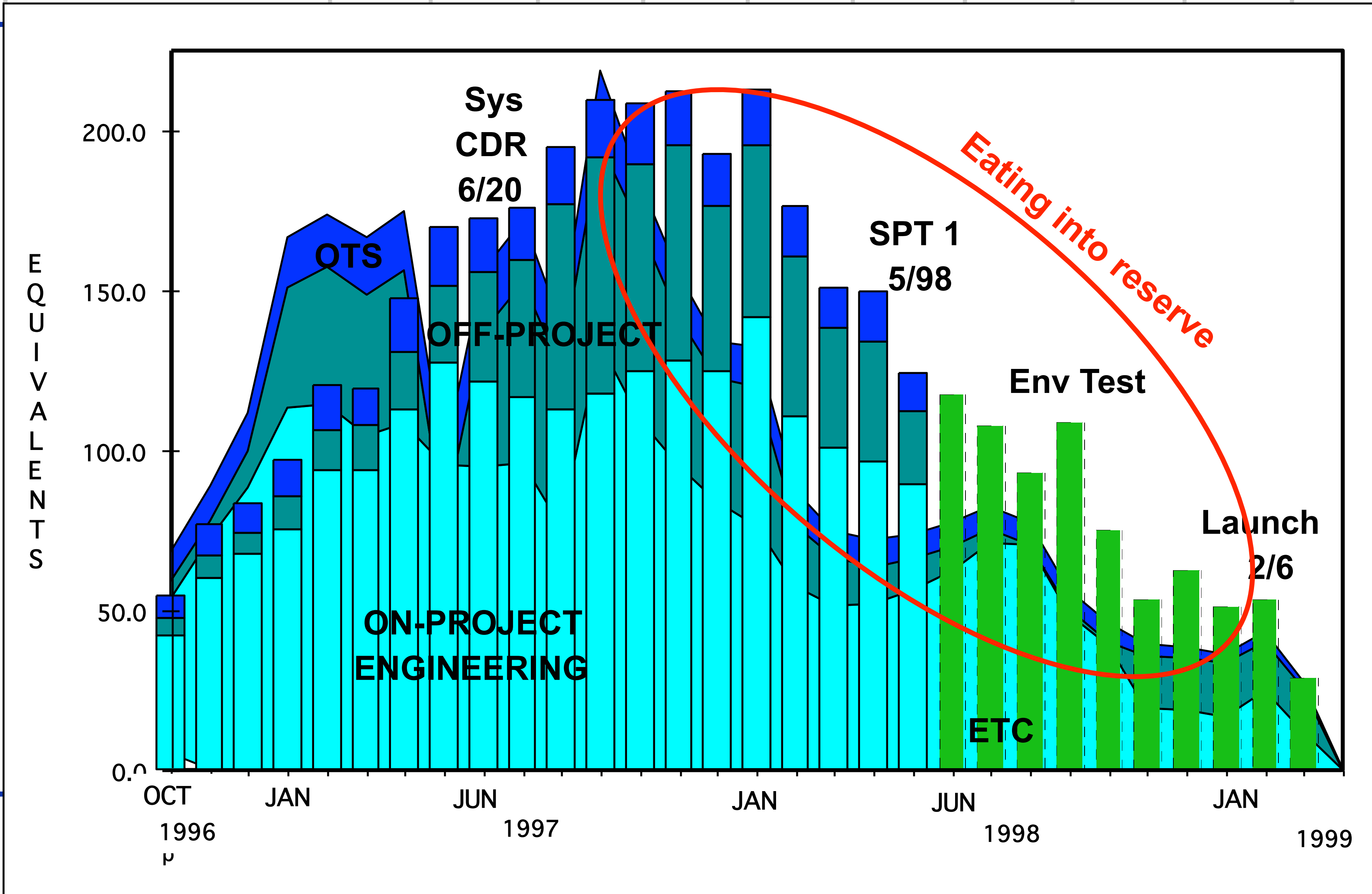
Unencumbered Reserves vs. Cost-to-Go



Human Resources – LM Staffing



Summary/Conclusion

1. Document Scope Hierarchy; Have good Descope List
2. Perform a C vs. R Review (CRR)
3. Populate the WBS -- Adjusted for Risk
4. Integrate & Link the Schedule. Determine the CP and Slack.
5. Load the Rates, etc., to get the Time-Phased Budget & EV Structure. Size tasks to be meaningful earned value
6. Update the SRL -- Carefully
7. Keep the Budget Change Log…It's your Controller.
8. Implement EV -- Crisply Focused for Effectiveness Feedback
9. Sweep for Threats -- Regularly
10. Release Reserve to Mitigate and Preempt with Cost-to-Go as "Governor."

NO!!! Requirements Creep

- **Mantra: "Do Not Allow Requirements Creep Camel to get his Nose Under the Tent"**
  - **PI, Don Brownlee, Gave Ken Atkins, Development Project Manager, Toy Camel at Ken's Retirement in Commemoration**
- **Turned Down Improvement 'Opportunities'**
  - **Addition of Volatiles Capture Mechanism Pushed by Science Team**
    - **Concept Study Done**
    - **Unknown Risks if Development Approved**
  - **TPS Instrumentation**
    - **Pushed by ARC Up Through NASA HQ**
    - **Unknown Additional Risk in New Heatshield that was Already Highest Risk in Program**
- **One Improvement Incorporated: Variable Density Aerogel @ No Additional Cost**

When Cost is Committed, Requirements ARE FROZEN

Stardust was a Successful PI Led Mission

- Schedule: Phase B 9 months; Phase C/D 28 months to launch – Ready to Launch of 1st Day of Window
- Launched On Budget
- How
  - No Creep (Requirements, Processes, Team)
    - Science Team Wanted Volatiles Added – NO
    - ARC wanted Heatshield Instrumentation – NO (twice)
  - Very Little Iteration
  - Adequate but Lean Staff (Project Office & LM)
  - Bounding Analyses
  - Adequate – Design, Analyses, Tests
  - Offloaded People
  - EVM Straight forward & Integrated at LM & JPL

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Mission Success

- **Science**
  - Wild 2 is a collection of materials that probably came from all regions of the young solar system; an odd mix of low and high temperature components
  - "Calcium Aluminum Inclusions" or CAI's minerals that form at extremely high temperature; comet's rocks were predominantly formed close to the Sun
  - Glycine, an amino acid used by living organisms to make proteins; suggests that all Earth-like planets obtain important pre-biotic molecules from space
  - Pre-solar "stardust" grains, identified by their unusual isotopic composition
  - Samples will be analyzed by hundreds of scientists for decades to come
  - Wild 2 is very different; kilometer-sized deep holes bounded by vertical and even overhanging cliffs; flat topped hills surrounded by cliffs; spiky pinnacles hundreds of meters tall, no impact craters
  - Comet Particle Impact rate changed in spurts, probably caused by entering and exiting "jets"
- **Recognition**
  - Popular Mechanics Breakthrough Award, Stardust, October 2006
  - Aviation Week Program Excellence Award, Stardust, November 2006
  - National Space Club Nelson P. Jackson Aerospace Award, Stardust, March 2007
  - Aviation Week Laureate Award, Stardust, March 2007
  - Rotary Stellar Award, Stardust Flight and Recovery Team, May 2007
  - Smithsonian National Air & Space Museum Current Achievement Award, Stardust Comet Sample Return Mission Team, April 3, 2008

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