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Progress Report on Mars Pathfinder Project Approach

Anthony J. Spear
Mars Pathfinder Project Manager
Jet Propulsion Laboratory
California Institute Technology
4800 Oak Grove Drive, M/S 230-235
Pasadena, California 91109-8099
Tel: 818-393-7868 Fax: 393-1227
E-Mail: anthony.j.spear@jpl.nasa.gov

ABSTRACT

Mars Pathfinder, launching on December 2, 1996 and landing on Mars on July 4, 1997, will demonstrate a low-cost delivery system to the surface of Mars. Historically, spacecraft that orbit or land on a distant body carry massive amounts of fuel for braking at the planet. Pathfinder requires fuel only to navigate to Mars; the spacecraft aerobrakes into the Mars atmosphere directly from Earth-Mars transfer trajectory, deploys a parachute at 10 km above the surface and, within 100 m of the surface, fires solid rockets for final braking prior to deployment of airbags that cushion touch down. After landing, petals open to upright the lander, followed by deployment of a small rover and several science instruments.

A major objective of Pathfinder— acquisition and return of engineering data on entry, descent, and landing (EDL) and lander performance— will be completed within the first few hours after safe landing. in addition, the lander will transmit images of the Martian surface the first day. Next, a rover will be deployed, as early as the first day, to perform mobility tests, image its surroundings, including the lander, and place an Alpha Proton X-Ray Spectrometer (APXS) against a rock or soil to make elemental composition measurements. The primary mission durations for the rover and lander are one week and one month, respectively. However, there is nothing to preclude longer operations up to a year.

Pathfinder will also accomplish a focused, exciting set of science investigations with a stereo, multi-color lander imager on a pop-up mast; atmospheric instrumentation for measuring a pressure, temperature and density profile during entry and descent and for monitoring martian weather after landing; and the rover with its forward and aft cameras and the APXS. The APXS and the visible to near infrared filters on the lander imaging system will determine the elemental composition and constrain the mineralogy of rocks and other surface materials, which can be used to address first order questions concerning the composition of the crust, its differentiation and the development of weathering products. Regular tracking of the lander will allow determination of the martian pole of rotation, its precession since Viking era measurements, and the moment of inertia, which should allow discrimination between interior models that include a metallic core and those that do not.

The Pathfinder Landing Site selected is Ares Vallis (19.5°N, 32.8°W), which is near the

sub-solar latitude (15°N) for maximum solar power at landing on July 4, 1997 and is at 2 km below the datum for comet operation of the parachute. The site is in Chryse Planitia a lowland where a number of catastrophic floods from the highlands to the north debouch. It is a "grab bag" site with the potential for sampling a wide variety of different martian crustal materials, such as ancient crustal materials, intermediate age ridged plains and a variety of reworked channel materials. liven though the exact provenance of the samples would riot be known, data from subsequent orbital remote sensing missions could be used to infer the provenance for the "ground truth" samples studied by Pathfinder. Available data suggest the site is about as rocky as the Viking sites, but perhaps a bit less dusty. This site has streamlined islands (carved by the flood) nearby and a very smooth depositional surface at Viking resolution, except for small hills and secondary craters.

MARS PATHFINDER IMPLEMENTATION STRATEGY

Pathfinder is in a special "cheaper, better, faster" project operating mode, accomplishing a challenging mission at low cost and fixed price, using a "Kelly Johnson''-like skunkworks approach, focusing on a limited set of objectives, streamlining project approaches and attempting to minimize bureaucratic interference. NASA's Office of Space Science is developing Pathfinder. The Advanced Concepts and Technology office teamed with the Space Science office is developing the Pathfinder rover. Pathfinder is being performed at JPL in its in-house, subsystem mode.

Currently Pathfinder's Flight System is being, assembled and tested for launch on December 2, 1996.

Some of the major elements of Pathfinder's project implementation strategy which will be addressed in this paper as to importance and impact, arc the following:

- formation of a project team comprised of bright, energetic youth and scarred old-timers, extracted from the standard institutional organization, formed into a skunkworks
- co- location around a Test Bed
- necessary up-front planning and design, but emphasis on early deliveries to provide for a long test pcl ioct for intensive testing
- earl y proof-of-concept testing
- earl y interface and functional testing in the Test Bed
- start of Flight System Assembly and Test on June 1, 1995, 18 months prior to launch
- concurrent engineering among mission, science, instrument, rover, flight system, ground data system, mission operations, procurement, and product assurance elements of the project
- emphasis on Work Breakdown Structure, Project Integrated Schedules, and cost estimating, monitoring and control.

MARS PATHFINDER MISSION DESCRIPTION

A single Mars Pathfinder flight system will be launched to Mars in the period December 2,1996 to December 25, 1996 from a Delta 11, landing on July 4, 1997. The flight system is spin stabilized during cruise, spinning at 2 rpm, with the spin axis and medium gain antenna pointed to earth except for the first 20 days after launch, when the spin axis is pointed closer to the sun line. After the first 20 days, the sun line remains within 40 degrees of Earth, and the earth point attitude is maintained until Mars atmosphere entry, including cruise trajectory maneuvers which are performed in a turn to the thrust vector and burn mode 0 1 in the vector mode: thrusting along or perpendicular to the spin axis. All cruise critical events are telemetered in real time to earth.

Twenty four hours before Mars arrival, the flight system will turn approximately 7 degrees to its entry attitude and, keeping in touch with Earth, will jettison its cruise stage and enter directly into the Mars atmosphere, braking with an aeroshell, parachute, small solid retrorockets and landing on airbags.

The entry velocity is 7.6 km/sec (17,100 mph) compared with Viking at 4.6 km/see which entered from orbit. Mars Pathfinder's entry angle is 14.2 degrees from the local horizon (90 degrees would be straight down) and peak atmospheric shock of less than 20 g's is encountered at 30 km above the surface. The parachute is deployed at Mach 1.8(900 mph) at 10 km, 100 seconds after atmospheric entry. Next, the heatshield is released and the lander is separated from the backshell cm the bridle. The chute slows the lander down to 60 m/see (134 mph) and a few seconds from impact the airbags are inflated and the RAD rockets fire to slow the lander at impact to less than 20 m/see (45 mph), a combination of vertical and horizontal velocities.

Ames Research Center, supporting Mars Pathfinder's aeroshell design, has arc-jet tested the Viking SLA561 ablative material planned for use on Mars Pathfinder, to insure it can withstand the extra heat pulse due to the larger entry velocity, Lockheed Martin developed and space qualified the aeroshell.

Langley Research Center is performing the aerodynamic stability analysis for entry and descent. Early proof of concept airbag tests were accomplished at Sandia in the spring of 1992 and follow up tests were conducted in the summer of 1994. The parachute, a Viking derivative disk-gap. band, is being developed by the Pioneer Aerospace Company. The airbags are being developed by ILC Dover and final development and space qualification testing is being accomplished at the NASA Lewis Research Center, Plum Brook facility. The RAD rockets are being developed by Thiokol, and JPL is developing the bridle.

EDL engineering telemetry will be transmitted to Earth in real time. to the extent possible. Before chute deployment, earth remains near the spin axis behind the craft and communication to earth is through a low gain antenna. After chute deployment, the Earth moves to approximately 90 degrees from the spin axis including chute swing, making communications more difficult. At this time, we will switch to carrier presence detection[1] only. EDL, lasting for 5 minutes, will be supported with the DSN 70 m antennas. On the surface, the vehicle will right itself by deploying petals which expose solar panels to the Sun for powering surface operations.

After landing, the lander will transmit stored EDL data and real time lander and rover engineering telemetry first. Panoramic images of the surface will be also transmitted to Earth the first day. The rover will be deployed as early, as the first day, for start of its surface operations. The rover conducts surface mobility experiments, images rocks and soil and deploys the APXS on soil and against rocks. While 30 day and 7 day primary surface missions are planned for the lander and rover, respectively, close to 100% of all lander and rover engineering and science objectives are achieved nominally in the first few days of

[1] The carrier will be amplitude modulated at this time to communicate critical events only such as aeroshell, and chute deployments, RAD firing and airbag deployment

Surface operations. However, nothing precludes operations of the lander 01 the rover past their primary mission requirements.

The Pathfinder scientific payload includes instrumentation for measuring atmospheric and landing deceleration; pressure and temperature during entry and while on the surface; a 12, spectral channel, stereo lander camera for surface and atmospheric imaging, inducting imaging magnetic properties targets, a wind sock and support of rover navigation; and the rover-deployed APXS for elemental composition measurements of rocks and soil. The rover carries aft and forward cameras for demonstrating autonomous hazard avoidance and imaging its local surroundings, soil and rocks. and the lander.

MARS PATHFINDER PRIMARY MISSION OBJECTIVES

- Demonstrate a low-cost delivery system to the surface of Mars
- Transport a rover to Mars, deploying it onto the surface
- Transmit to Earth cruise, EDL, Lander and rover engineering performance data
- Transmit to Earth a panoramic image of the landing silt
- Transmit 101 Earth atmospheric and surface science data

MARS PATHFINDER EXTENDED MISSION OBJECTIVES

- Transmit to 1 Earth long-term lander and rover engineering performance data
- Transmit to Earth]ong-term science data including weather and seasonal atmospheric and surface changes

THE US ENVIRONMENT IN WHICH PATHFINDER WAS INITIATED AND IMPLEMENTED CONTRASTED WITH VIKING'S

The conditions in this country were markedly different the last and only time wc landed on Mars in 1976 with two Viking landers serviced by two orbiters.

First, the Cold War was still raging and while Apollo landings on the Moon did much to quench the impact of early Soviet space feats on our national pride and security, we remained competitive with the Soviets in space, this being a major driver to space program funding up to the end of the Cold War.

Second I y, whi lc the. space program was now already into its second decade, deep space robotic missions were confined to fly-bys and orbiters. Previous to Viking, only Ranger, Surveyor and Apollo lander missions to the Moon were attempted by the US in the 1960s. The Viking lander mission to a distant planet, Mars, represented a significant technology challenge and was an exploration largel y of the unknown: the Mars atmosphere was not understood and its surface was not mapped as well as it is today, flight electronics, while evolving rapidly at the time, were not as compact, reliable or less costly as today 's--- Viking's compute], for inst ance, represented a major development, almost costing as much as the complete Pathfinder flight system development at $ 130M. Wc got ours, a powerful 32-bit, 20 MIPS radiation hardened version of the IBM commercial RS6000, for less than $7.0M, developed by Loral.

In addition, the Viking landers carried complex life-seeking instrumentation requiring significant development and cost.

At the same time the Cold War was closing, the US began seriously to face into the realities of its large deficit. The large expenditures for a powerful military force that helped end the Cold War and for a major space program that brought this country esteem and confidence caught up with us, caused the US to over-extend its credit cards - an experience many of its citizens are only too familiar with.

So Pathfinder was conceived in 1992 at a time when NASA is being scaled back and large deep space robotic missions are no longer possible- the Cassini mission to Saturn being the last.

Wes Huntress, then manager of the Planetary Division of NASA's Office of Space Science, now manager of this office, accurately sensed this need to scale back relatively early and initiated a series of small mission studies for what he termed the "Discovery Program". He was ready when Dan Goldin became NASA's Administrator challenging NASA project implementors with his "cheaper, better, faster" slogan.

The Discovery Program has a number of radically innovative features, but the most significant in terms of signaling the departure from NASA's old way of doing business and its trend to larger and more expensive missions, many experiencing significant overruns, was the stipulation that Discovery projects were to be accomplished at a fixed price, development complete in 3 years, with development capped at $150M in FY92 dollars. NASA drew a line in the sand: project termination Review Boards will be initiated if expected project cost-to- complete development estimates exceed the cap plus 20%.

in March 1992, when Pathfinder study was initiated, everything except the $ 150M cap was up for grabs.

The mission had to be worth doing, but mission objectives were cost driven. The Pathfinder study team was then challenged to determine in its 18 month pre-project phase, prior to schedule start in October 1993, if a worthwhile lander mission could be in fact accomplished under the cost cap. in addition, Wes asked that we define a new way of doing business at JPL: a quick-reaction, low-cost, fixed price project implementation approach.

So in a nutshell, that's the conditions under which Pathfinder was conceived, contrasted with Viking's era 20 years ago.

A bottom line statement on the scope of Pathfinder's lander mission relative to Viking's is dramatically illustrated in Figure 1, a comparison of workforce used as a function of time for each Project.

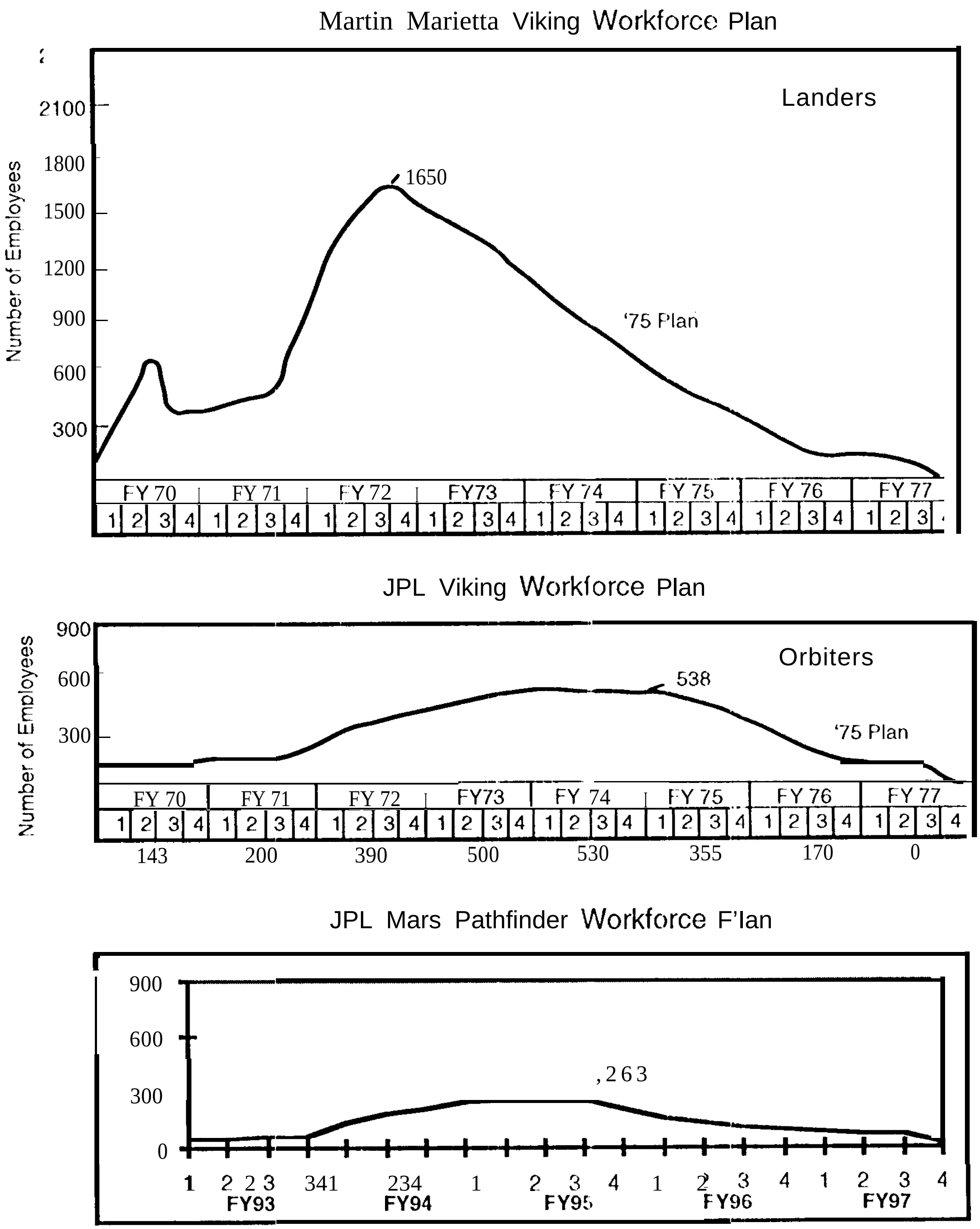

Figure 1. Viking vs. Mars Pathfinder Work force

WITH VIKING COSTING OVER $3.0B IN TODAY'S DOLLARS, HOW ON EARTH CAN PATHFINDER LAND ON MAIM CAPPED AT $150M (FY92 DOLLARS) OR $171M REAL YEAR DOLLARS?

That was the million dollar question wc faced at the start of Pathfinder's pre-project study and here's what wc did to define a mission that was sufficiently salable to justify its project start:

First wc assembled an excellent, motivated team. Now that may sound like "Motherhood and Apple Pie", but far and away this is the most important ingredient to Pathfinder's successful approach (o date. Pulling high-spirited individuals together, inside and outside J]'],, to make up the Pathfinder team was not a trivial task. With JPL institutional support, key team members were extracted from their home divisions and co-located with the Project in what is called a "soft projectization mode" where team members remain administratively tied to their home divisions. The team is a mix of bright, ambitious youth anti scarred old-timers, all sensitized not only to the technical chai lenge but very importantl y to the need to do this job at a fixed price. Al l were empowered to produce their product according to their plan.

Not fully appreciated at the start was the degree to which wc would need to expand the Pathfinder team outside of JPL in order to bring in the necessary expertise for development of our entry, descent anti landing approach.

We knew wc had to go outside of JPL for this, but never appreciated how much. You could not go to the J]'], phone book and look up the names for the planetary entry, descent and landing division. Wc have not had this development expertise at JPL in place since the Surveyor Moon mission in the 1960s- -as a matter of fact, no complete planetary landing development technology base was available anywhere in the US.

At Pathfinder start, just bits and pieces of related expertise were scattered about. We scoured the count ryside anti found very importantly this support:

1. Major test facilities anti test expertise for earl y proof-of-concept airbag testing at Sandia National I laboratories
2. Key aged, but contributing Viking engineers and managers and their lessons learned
3. Excellent, cosl-effective atmospheric entry support from NASA's Ames and Langley Research Centers
4. Aeroshell design, fabrication and test expert ise at Lockheed Martin adapt ing the Viking design including usc of the Viking heatshield ablative material
5. Parachute experience at Pioneer Aerospace adapting mainly their Earth parachute expertise, but starting with the Viking disk-gap-band parachute design and importantly relying on Viking's extensive parachute test experience, especially at high altitudes
6. Extensive expertise at ILC Dover for Pathfinder's major development of the airbags
7. Major test facilities and test expertise at the China Lake Naval Weapons Center for rocket drop tests, altimeter tests and cruise stage-backshel 1- lander separations tests
8. Major test facilities and test expertise at NASA's Lewis Research Center Plum Brook Station chamber for airbag drop tests at simul ated Mars at mosphere

9. Very importantly, the infusion into the Pathfinder team of a clcsigt~-test-dcsigll some more-lcs[--- culture for items like the parachute, the bridle, solid rocket system and the airbags by Sandia, Pioneer, China 1 .ake and ILC Dover

10. Design and test consulting and critique from within JPL, Sandia National Laboratories, Space Industries, NASA's Ames and Langley Research Centers, Lockheed Martin and from numerous consultants (wc also interacted with the Russians anti the European Space Agency [ESA])

JPL is putting the whole Jill. system together: performing the system design, orchestrating the EDL tests and simulations, assessing mission risk mitigation, and building the backshell, bridle and lander including its uprighting petals (as well as the cruise stage which is jettisoned prior to entry). The full EDL team is listed in Figure 2. All contractors arc listed in Figure 3. To a contractor, smal 1 to large, each got with the spirit of Pathfinder, doing more for less. Most contracts were fixed price.

System	JPL
Red Hat Team[2]	J}' I., USC, Space Industries, UCLA, CIT, Other consultants
Analysis, Consulting, Review	Space Industries
Entry Dynamics Sim	Langley Research ('enter
Backshell Structure	Lockheed Martin
Backshell Interface Plate (BIP)	JPL
Aeroshell and Heatshield Analysis	Lockheed Martin
Heatshield Analysis Support	Ames Research Ccr,tcr/Applied Research Associates/Langley Research Ctr.
Backshell '1'1'S	Lockheed Martin
BIP Insulation	Ames Research Center
Multi-Body Descent Sim	J] 'I.
Parachute	Pioneer Aerospace
Bridle Drop Tests	China Lake Naval Air Weapons Center
Bridle	JPL
RAD System	JPL
RAD Rockets	Thiokol
Airbag Impact Analysis	Sandia National Lab, Rockwell
Airbags	ILC Dover
Airbag Gas Generators	Thiokol
Separations	JPL
Sequence	JPL
Communications	JPL
RAD Drop Tests	China Lake Naval Air Weapons Center
Initial Airbag Drop Test	Sandia National Lab
lilll-Scale Airbag Drop Tests	Lewis Plum Brook Research Center
Parachute Drop Tests	Yuma and Boise Orchard Training Range

Figure 2. EDL Support Team

[2] Red Hat = Devil's advocates which challenge and question EDL design and test approaches

Contractor	Description (item)	Contract ##	Contractor Status	Contractor Location	Contract Type	Contract Value $K
\aron-Ross Corp	mgm't in formation sys. support	959908	SwOB '^	CA, Glendora	CPFF	20
\dcolc Corp	digital sun sensors	959905	SB	MA, Marlborough	FP	423
\F Machine	metal fab	66991 ?	SDB	CA, Santa Monica	PO	4
\llied Signal	accelerometers, eng units	668914	LB	WA, Redmond	PO	23
\llied Signal	accelerometers, f-light units	674500	LB	WA, Redmond	P()	66
\llied Signal	accelerometers, EDL test units	684974	LB	WA, Redmond	1'0	27
\merican Electronics, Inc AEI)	petal motor/gearhead	661752	SB	CA, Fullerton	PO	72
\merican Technology Consortium	airbag retraction actuators	960186	SB	CA, Camarillo	FP	i47
\merican Technology Consortium	1 Mi' Gearbox	960418	SB	('A, Camarillo	FP	51
Ames Research Center	AS I SAT member-Haberle		G	CA, Moffett Field	506	10
Ames Research Center	windsock/ASI wind tunnel tests		G	CA, Moffett Field	506	96
Applied Research Associates	heatshield analysis	959983	SB	Nh4, Albuquerque	CPFF	49
Applied Solar Energy Corp	solar arrays	9599"13	SB	CA, City of Industry	FP	i 777
Arizona State University	educational outreach	960112	U	AZ, Tempe	SFRC	10
Artecon	GDS workstations	645516	SB	CA, Carlsbad	IDC	495
Astro Aerospace Corp	Rover deployment ramps	960156	LB	CA, Carpenteria	FP	242
Avantek	RF power modules	664724	.B	CA, Van Nuys	PO	188
Ball Aerospace Systems Group	high gain antenna	959988	.B	CO, Broomfield	FP	504
Ball Corp-Electo-Optics/Cyrogenics	star scanner study	959561	.B	CO, Boulder	FP	24
Ball Technology Services Corp	star tracker data list	958942	LB	CA, San Diego	CWO	22
Barr Associates	Rover bandpass filters	673723	SB	MA, Westford	PO	7
Black Box	cables & junction box- ATLO	691935	SB	PA, Lawrence	PO	11
BST Systems, Inc	silver-zinc batteries	960161	SDB	CT, Plainfield	FP	329
Central State Univ	educational outreach	960113	HBCU	0}1, Wilberforce	SFRC	10
China Lake Naval Air Warfare Center	RAD testing	WO-8997	G	CA, China Lake	G-Req	200
Coherent Optics, inc	Rove] camera optics window	673091	LB	CA. Auburn	PO	13
Computervision	CAD/CAM training support	683154	1.13	h4A, Bedford	1'0	100
DOE/Sandia National Laboratory	airbag proof-of concept	WO-8964	G	NM, Albuquerque	G-Req	45i
IX)] :/Sandia National Laboratory	airbag and load analysis	WO-8995	G	Nh4, Albuquerque	GReq	50

)OE/Sandia National .aboratory	1 IAC airbag impact test program	WO-9004	G	NM, Albuquerque	G-Req	208
)ow-Key Microwave Corp	RF switch evaluation	6419?1	SB	CA, Ventura	PO	1
)ynatech Microwave Technology	RF switch evaluation	641279	SB	CA, Calabasas	PO	i
Eagle Picher	thermal battery	668578	LB	MO, Joplin	PO	5
Eagle Picher	AgZn test cells	642173	LB	MO, Joplin	1'0	21
Eagle Picher	thermal batteries	675147	LB	MO, Joplin	1'0	74
Eaton Corp	latch valves	960008	LB	CA, El Segundo	FP	130
Elmwood Sensors	thermostats	685902	LB	RI, Nan agansett	PO	36
Falcon Design	drawing design	662041	SDB	CA, Duarte	PO	4
Falcon Design	drawing design	664736	SDB	CA, Duarte	1'0	4
Falcon Design	drawing design	667726	SDB	CA, Duarte	1'0	17
Falcon Design	(ll-awing design	667915	SDB	CA, Duarte	PO	2
Falcon Design	di awing design	668013	SDB	CA, Duarte	Po	2
Falcon Design	drawing design	668121	SDB	CA, Duarte	1'0	2
Falcon Design	(lt-awing design	668403	SDB	CA, Duarte	1'0	2
Falcon Design	drawing design	66869X	SDB	CA, Duarte	PO	2
Falcon Design	drawing design	6691 28	SDB	CA, Duarte	1'0	2
Falcon Design	drawing design	6715X?	SDB	CA, Duarte	IDC	35
Georgia Tech	educational outreach	959910	U	GA, Atlanta	SFRC	10
GW Spencer	tile machining	690553	SB	CA, Santa Ana	Po	14
GW Spencer	tile machining-EDU & Flt	695272	SB	CA, Santa Ana	PO	35
Hi-Shear Technology Corp	NSI booster modules	960171	SB	CA, Torrance	FP	59
Hi-Shear Technology Corp	5/8" cable cutters	960192	SB	CA, Torrance	FP	119
Hi-Shear Technology Corp	separation nuts	960222	SB	CA, Torrance	FP	224
Hewlett-Packard	GDS workstations	645527	LB	CA, Fullerton	IDC	35
Holometrix	testing, insulation material	643283	LB	MA, Bedford	PO	20
Honeywell Inc	radar altimeters	664996	LB	MN, St Louis Park	1'0	69
Honeywell Space & Strategic System	star scanner study	959552	LB	FL, Clearwater	FP	23
Howden Fluid Systems	integrated pump assembly	960165	LB	CA, Santa Barbara	FP	619
IJ Research	hermetic packages	959963	SDB	Ca, Santa Ana	FP	27
ILC Dover, Inc	prototype airbag	959839	LB	DE, Frederica	FP	109
ILC Dover sub: Fabric Development	uncoated kevlar fabric	na	SDB	PA, Warminster		29
ILC Dover, Inc	airbag proof-of-concept studies	959927	LB	DE, Frederica	FP	25
ILC Dover, Inc	airbags	960076	LB	DE, Frederica	FP	4746
ILC Dover sub: Thiokol	gas generators		LB	MD, Elkton	CPFF	1458
ILC Dover sub : Rockwell Aerospace.	airbag analysis		LB	CA, Downey	CPFF	73
ILogix, Inc	Statemate analyzer & S/W spt	667701	LB	CA, Santa Clara	PO	67

Irvin Industries	airbag proof-of-concept studies	959928	LB	CA, Santa Ana	FP R&D	25
Ketema Programmed Composites	lander solar array substrate	960180	LB	CA, Brea	FP	143
Ketema Programmed Composites	cruise solar array substrate	960181	LB	CA, Brea	FP	85
Kevlin Corp	rotary joint assembly	959953	SB	MA, Wilmington	FP	47
Landscape Rock Sales	EDL artificial rocks	688437	SB	CA, Yorba Linda	1'0	12
I oral	flight computer	959763	LB	VA, Manassas	FP	2209
1 oral EOS	power system study	958484	LB	CA, Pasadena	CWO	50
LoralEOS	power subsystem	9584x4	LB	CA, Pasadena	C w o	3310
Loral EOS sub: orstan Electronics	relays		SB	CA, Santa Ana		28
1 oral EOS	AIM support equipment	958484	LB	CA, Pasadena	CWO	1094
1 oral EOS	AIM IEM vibration	959890	LB	CA, Pasadena	CWO	25
I oral EOS	SSPA vibration	959890	LB	CA, Pasadena	CWO	10
I oral 1 :OS	TMU vibration	959890	LB	CA, Pasadena	CWO	10
Martin Marietta Astronautics Group	aeroshell	959950	LB	CO, Denver	FP	7018
MMC sub:Performance Plastics	layup tools		SB	CA, San Ysidro	FP	144
MMC sub: Kamp Systems	tools for aeroshell		SDB	CA, Ontario	FP	42
MMC sub:Bryte Technologies	tape & EDU pre-preg cloth		SB	CA, Milpitas	PO	52
MMC sub: Bryte Technologies	tape & Flt unit pre-preg cloth		SB	CA, Milpitas	PO	31
Metal Crafters	metal fab	667331	SB	CA, Simi Valley	PO	2
Metal Crafters	metal fab	669362	SB	CA, Simi Valley	1'0	1
Metal Crafters	metal fab	669373	SB	CA, Simi Valley	1'0	1
Metal Crafters	metal fab	670234	SB	CA, Simi Valley	P o	1
Metal Crafters	metal fab	670235	SB	CA, Simi Valley	PO	1
Metal Crafters	metal fab	671747	SB	CA, Simi Valley	P o	4
Metal Crafters	metal fab	672737	SB	CA, Simi Valley	PO	1'
Metal Crafters	metal fab	673356	SB	CA, Simi Valley	1'0	3
Microwave Communications Corp	diplexer/WG adapter	959857	SB	CA. Valencia	FP	58
Modular Devices, Inc	DC-DC converters	671498	SB	NY, Shirley	PO	84
Modular Devices, Inc	XSSPA power- converter	959912	SB	NY, Shirley	FP	431
Modular Devices, Inc	AXT power converter	960246	SB	NY, Shirley	'P	28
Motorola, Government Systems Grp	Deep Space Transponder	559891	LB	AZ, Scottsdale	'P	2300
National Technical	centrifuge test for ldr DTM	960282	SB	CA, Saugus	'P	7s

ɜı Vices						
)lin Aerospace :ompany	thrusters, I .0 lb	**960106**	1.11	WA, Redmond	FP	550
)regon **Stale** Jniversity	ASISAT **member-** Barnes	959819	U	OR, Corvallis	CREI	70
'acific Scientific	1/8" cable cutters	960179	1.11	AZ, Chandler	FP	44
'ioneer Aerospace :orp	parachute	**9600'?8**	I .B	CT, South Windsor	FP	2846
'ioneer sub-Nat'l 'echnical Systems	parachute testing		1.B	MA, Boxborough		65
'ioneer sub:Idaho Ielicopter CO ____	aircraft for parachute tests __ –.		1.11	ID, Boise		263
Pioneer sub-Olin Acrospace	mortar ass'y & testing --.1 ------ ------		1.B	WA, Seattle		500
'ressure Systems, nc	propulsion tanks	667015	SB	CA, City of Commerce	PO	241
ƐC Kavaya Eng.	drawing design	664735	SDB	CA, Alta Loma	PO	2
ƐC Kavaya Eng.	drawing design	664737	SDB	CA, Alta Loma	PO	2
ƐC Kavaya Eng.	drawing design	668197	SDB	CA, Alta Loma	1'0	2
ƐC Kavaya Eng.	drawing design	671278	SDB	CA, Alta Loma	PO	2
ƐC Kavaya Eng.	drawing design	671604	SDB	CA, Alta Loma	IDC	40
Ɛoberts Research	kevlar cutters	696543	SB	CA, Torrance	PO	25
Ɛosemount \erospace	temperature sensors	680853	LB	MN, Eagan	PO	**no**
Ɛosemount \erospace	temperature sensors	682732	1.B	MN, Eagan	PO	6
;aft America	Rover battery	960154	LB	MI), Cockeysville	FP	120
;age Laboratories, nc	coax switches	692295	SB	MA, Nantick	1'0	31
;ector Microwave ndustries	waveguide transfer switches	959896	SB	NY, Deerfield	FP	92
;ierra Microwave	isolators	**959987**	SB	TX, Georgetown	FP	18
;iller Brothers	helicopter service for 1 :I)1. tests	**960347**	SB	CA, Nevada City	IDC	2s
;MTEK, Inc	electronic assembly	**960203**	SB	CA, Newbury **Park**	CPFF	71
;outhwest 'roducts	spherical bearings for bridle	687353	SB	CA, Irwindale	PO	3
;ystem Design ;ervices	ADP plan support	628377	SWOB	CA, Pasadena	IDC	22
l'alley 1)efense System	airbag proof-of-concept studies	9S9929	LB	AZ, Mesa	FP R&D	25
l'avis Corp	pressure transducer	672987	SB	CA, Mariposa	1'0	10
l'ayco	**tank beaters**	658842	SB	CA, Cerritos	PO	7
l'exas Instruments	MMICs and HFETs	665445	LB	'l'X, Dallas	PO	95
l'hiokol Corp, :lkton Div	solid **propellant motors**	959906	LB	MD, Elkton	FP	1293
'hiokol Corp, :lkton Div	solid propellant motors	671498	LB	MD, Elkton	FP	123
'RW	hybrid assembly	**960042**	LB	CA, Redondo Beach	CPFF	318
1.S. Geological ;ur**vcy**	rover scientist- Moore	WO-8998	G	CA, Menlo **Park**	G-Req	30

U.S. Geological survey	IMP co-investigator-Soderblom	WO-8999	G	AZ, Flagstaff	G-Req	11
United Tech. Microelectronic Center	TMU ASICs	959974	111	(.X), Colorado Springs	FP	209
University of Arizona	lander imager	959647	U	AZ, Tucson	CREI	5278
U Of AZ sub: Martin Marietta	Imager for Mars Pathfinder		LB	Cc), Denver		2462
Vacco Industries	propulsion filters	681662	LB	CA, S. El Monte	Po	34
Vacco Industries	propulsion service valves	679880	LB	CA, S. El Monte	PO	49
University of Alaska	educational outreach	960206	OMI	AK, Fairbanks	SFRC	10
University of Chicago	APXS instrument	959825	u	IL, Chicago	CREI	1499
University of Hawaii	educational outreach	959907	OMI	)11, 11 onOILuLu	SFRC	11
University of So. Colorado	educational outreach	960205	HBCU	CO, Pueblo	SFRC	10
University of Washington	ASI SAT member-Tillman	959986	U	WA, Seattle	CREI	92
Wheeling Jesuit	educational outreach	959961	U	WV, Wheeling	SFRC	10
Wind River Systems	VxWorks	960075	SB	CA, Alameda	FP	408
Wyle Labs	centrifuge test for ldr shelf elec	960372	LB	CA. El Segundo	FP	29
Yardney Technical Products Inc	AgZn battery cells	673673	SB	CT, Pawcatuck	Po	6

CPFF= cost plus fixed fee
CREI= cost reimbursable educational institution
FP= fixed price
G-req= government requisition
G= government agency
HBCU= Historically Black College or University
IDC= indefinite delivery contract
LB= large business
OMI= Other Minority Institutions
PO= purchase order
SB= small business
SDB= small disadvantaged business
SFRC= short form research contract
SWOB= small women owned business
U= university/college

8% goal= SDB+SWOB+HBCU+OMI

Figure 3. Mars Pathfinder Contractors

WHAT MAKES A GOOD PROJECT TEAM

A good project team relies on fundamentals: achieving a thorough understanding of the work scope, breaking this work scope into its individual pieces, assigning individual team members responsibility for these pieces, giving them a clear understanding of their responsibility and constraints, doing the system engineering up front to ensure compatibility of the pieces.

A good project team is dynamic and flexible. It carries an up-to-date, thorough cost anti schedule plan in front of it at all times, changing the plan as necessary, when necessary, to reflect better understanding of the job as it unfolds, work-arounds to problems and changes in scope or direction—which in this day of fixed price projects can't be tolerated to any significant degree. Key to success is achieving and maintaining a clearly understood project objective up front with the customer.

On Pathfinder, for Project performance tracking and control, we adapted the hair-raising, at times frustrating, two-minute drill "bend but don't break" defensive tactic NFL teams use to protect a lead: give up yardage but don't let them score. You start the project, this defensive drill, with sufficient dollars and schedule reserves: our available yardage. On Pathfinder, we started with $50M of the $150M as reserves and laid out a schedule which had deliveries of the major flight subsystems starting as early as 21 months after Project start to provide ample time, 18 months for Flight System Assembl y, Test and launch Operations (AT] .0).

Proceeding throughout Project development, monthly technical schedule and cost performance measurements are made--- actuals compared against plan. Plans are updated with both schedule and cost reserves passed out if necessary for recovery against problems-bending but not breaking each month as we proceed to launch, using wisely our reserves but not exceeding the caps. Important to this is a thorough job of pre-project planning in defining project scope and achieving a thorough Work Breakdown Structure (WBS) and cost estimates.

Emphasis is placed on looking forward towards completion of development, keeping a thorough cost-to-complete estimate for all development items:

Cost-To-Complete = Actuals $ Expended to Date +
Reserves Required to Finish Delayed Work (if any) +
Reserves for Problems, "Forgots", Etc. +
An Estimate of the Expected Reserves Required for Future Problems ("Things That Could Go Wrong").

This is in contrast to management's tendency to look backward in measuring a project's performance: measuring actual accomplishments against the original baseline plan, but this too is important. This is where computer aided project metrics are handy: producing quickly, modified plans and forward looking cost- to-complete estimates for the Project, at the same. time comparing Project performance against the original baseline plan for its management.

But computer aided metrics, schedules, tables of cost in every format are only as good as the input, never ever will they be a substitute for a good team---which if necessary can still do a project on the back of an envelope.

On Pathfinder we have an excellent team!

HOW WE DEFINED MISSION SCOPE FOR THE DOLLARS IN THE PRE-PROJECT PHASE

The following technical trades were made:

- Cruise-EDL-Lander system architecture
- EDL approach
- Relay link vs. direct link communications
- Battery only vs. solar power and battery for the lander power source
- Tethered vs. untethered rover

We quickly adopted the NASA Ames Research Center's direct entry approach to avoid the need of carrying a large supply of fuel to the planet for braking, aerobraking in the atmosphere instead. Our entry velocity is 7.6 km/sec, compared with 4.6 km/sec for Viking 1 anders, significantly higher, but within design limits. Ames has conducted arcjet testing of the Viking SLA-561 ablator material to show that a Viking derivative aeroshell using this ablator material can be used for Pathfinder's direct entry approach.

The next step dealt with designing a cost effective flight system architecture to carry the lander to Mars. One approach studied was the design of a separate cruise spacecraft to carry the lander to Mars. The lander, housed inside the EDL capsule, would be attached to the cruise spacecraft anti release.cl for EDL at the proper time. To reduce equipment and cost, the decision was made instead to build an integrated flight system around a central computer which conducted cruise, EDL and surface operations functions.

This approach is made possible with the selected flight computer which accomplishes the following functions:

- Fault detection and safing
- Lander anti rover command and telemetry
- Cruise attitude control and maneuvers
- EDL sequencing control
- Science data processing
- Lander image compression

For EDL, we studied both active vs. passive approaches, i.e. a Viking like, 3 axis control, rocket deceleration vs. a Russian like, semi hard impact using air bags and uprighting petals. And, as mentioned earlier, we interacted with all available areas of expertise in this technology and after much deliberation in an August 1992 peer review, we selected the following EDL approach:

- Viking derivative aeroshell
- Viking derivative disk-gap-band parachute
- Russian/auto industry/military like air bags
- Russian like uprighting petals

Two important EDL design refinements occurred over the next year which were thoroughly peer reviewed:

- addition of a surface height detector, first a plumb bob, later replaced by a DOD derived altimeter
- addition of DOD derivative small solid rockets for a short burst of deceleration just before impact

Surface detection became necessary to delay air bag opening until the last second to prevent air bag gas cooling and depressurization. The addition of the small solid rockets reduced the parachute size, solved the parachute drape abatement problem and simplified air bag design.

in the Pathfinder trade study, no EDL approach was, singled out as the ultimate. Each has its set of advantages and disadvantages. The Pathfinder approach, robust, promising low recurring cost and adaptable to a large set of missions, is a unique compilation of subsystems with significant design heritage, except that the space qualification of air bags represents a significant development. It is affordable under the cost cap and represents the culmination of a thorough, but not exhaustive trade study that had to end quickly to maintain the fast track schedule.

Landing site accuracy is on the order of 200 km x 100 km 3 sigma worst case - good for deployment of geoscience, meteorology and seismic stations, and adequate for a first regional reconnaissance mission. For future missions, additional accuracy will be achieved through improved navigation, reduced ballistic coefficient, active propulsive control for aeromaneuvering and terminal descent trajectory control. For instance, Mars sample return landers may adjust their final approach, not only to avoid hazards, but to actively seek out a more desirable landing site to accomplish its mission.

Under the cost caps, an orbiter in support of the Mars Pathfinder lander was clearly not affordable. The decision was made to build into Pathfinder a significant direct link capability so that it could stand alone, not reliant on orbiters that may be at Mars for relay communications.

The expense and time associated with the implement at ion of a Radioisotope Thermoelectric Generator (RTG) was judged not compatible with Mars Pathfinder's low cost, 3 year development approach. Instead, battery only and sol ar panels/battery approaches were studied as lander power options. The solar pane] with battery approach was selected primarily for the following two reasons:

- a battery only option could not guarantee sufficient lander surface ops lifetime for support of the rover

- in the spirit of Pathfinder's engineering mission, demonstrating solar pane] performance on the surface of Mars was deemed an important engineering objective

NASA's Lewis Research Center provides support on solar panel performance in the Martian surface environment.

We studied both tethered and untethered rover approaches. Tethered, the rover would remain connected to the lander through a wire ant] would rely on the lander for power and computer processing, and the need for a lander-rover RF link is eliminated. However, a tether restricts rover mobility and would require a more interactive ro~'er-lander development. in the spirit to push to do more for less, a decision was reached to implement a fully autonomous, non-tethered rover. The rover is self-powered using a solar panel and a primary battery, has its own computer for data processing and surface navigation and communicates with the lander over a UHF link, adapting a commercial modem for space use. It employs a 6 wheel "rocker- bogie" mobility approach which provides for a steady platform while navigating a rocky surface If the rover was the size of an automobile, then the rover would be able to move over objects the of a dining room table.

OUR COST ESTIMATING PROCESS

It was a combination of JPL and SAIC cost modeling and supporting analysis anti "grassroots" estimates.

Since the Project was cost-capped, we in turn cost-capped all key elements of our WBS. We ran our cost modeling program at JPL to derive the first estimate for these cost caps for all key elements of our WBS and then asked each responsible WBS clement manager to see what could be done for this amount. Project management took control of cost at the outset: taking the initiative to set the individual WBS clement costs first instead of waiting for the element managers to come in with their estimate.

A rather emotional cost cap negotiation ensued where some cost caps, pretty much out of line, were increased. Some WBS elements were descoped to fit the caps and in many places very innovative methods surfaced in order to stay within the caps-— rarely was a cap too large and dollars given back.

With this modified "capped/grassroots" process wc developed the original cost estimate of $100M for project development, leaving $50M for reserves.

To determine if $50M was enough reserves, wc had SAIC interview each WBS clement manager as to what could go wrong in development and added up all these reserves needs to generate somewhat of a worst case number which happened to fit within the $50M.

Cost estimation, tracking and control never stopped from this original estimate. Monthly updates occurred using our aforementioned "bend but not break" approach and at least twice a year major grassroots update exercises were conducted, again with emphasis on descoping and replanning if necessary, always looking forward to cost-to-complete.

AND FINALLY, AS TO WHY PATHFINDER CAN BE DEVELOPED FOR $150M

WHILE SUBJECT TO A LOW COST CAP, PATHFINDER ENJOYS MAJOR TECHNICAL ADVANTAGES OVER VIKING WHICH MAKES PATHFINDER POSSIBLE:

1. The Viking database augmented with ground radar and Hubble observation provides Pathfinder a much better understanding of Mars atmosphere and its selected landing site

2. A significant deep space ground infrastructure coupled with the availability of high-performance, reliable flight electronics has materialized since Viking providing for a low-cost but powerful ground data and tracking system matched to an equally powerful flight electronic system. Normally big ticket items such as radios, flight computers, and the lander camera have been acquired cheaply by Pathfinder.

3. Pathfinder's powerful surface direct link radio coupled with its cruise stage and its direct aero-braking entry obviates the need for an orbiter to carry the lander to Mars and support it with relay link communication- this has a ripple effect in reducing overall mission by reducing the size of the launch vehicle required for Pathfinder.

4. Pathfinder's direct acre-braking entry also eliminated the need for an expensive, heavy propulsion system.

FOR MISSION RISK MITIGATION PATHFINDER'S APPROACH IS SYNONYMOUS WITH TEST, TEST, TEST

A major clement of Pathfinder's new way of doing business was achieving necessary up-front planning, analysis and design, but placing emphasis on early fright subsystem deliveries to allow for thorough testing prior to launch. in parallel with planning, analysis and design, wc conducted early proof-of-concept testing, starting in the pre-project study phase for our major developments: airbags, rover mobility on simulated martian surfaces, X-band solid state amplifier.

Wc co-located the Project around our Test Bed where end-to-end flight-ground functional and interface tests were conducted, incrementally, starting with breadboards and engineering models and partial I y developed software packages and proceeding to finished flight-ground Subsystems and software packages prior to delivery to ATLO.

in AT] .0, wc will conduct system integration and test over an 18 month period before launcl~----twicc as long as the primary mission duration of **8** months. Here wc will extensively qual if y our three-in-onc spacecraft for its EDL and surface operations environments as well as for the standard launch and cruise environments normally accomplished on deep space cruiser, orbiter and rendezvous spacecraft.

In parallel with ATI .0, EDL subsystem and system simulations and tests arc being conducted all over the map: airbag drop tests outside Cleveland in Ohio; multi-body parachute-backshel l-bridle-lander separat ion tests at China Lake in the Mojave desert outside of Los Angeles; altimeter and rocket drop tests, again at China Lake, airbag retraction and lander uprighting tests in Pasadena, CA; and computer and water tank (yes, water tank) multi-body flow simulations in Pasadena.

Another important Pathfinder process is concurrent engineering. Wc had the whole team up and running together at the start: mission operations, flight system, instrument, rover, ground data system, mission operat ions, product assurance and procurement members.

The first time I heard of concurrent engineering, but with a different slant, was When the Mariner-Venus-Mercury Project Manager in the early 1970s would say often: "WC need to get all the liars around the table" in response to an issue.

Here's the first payoff on our **concurrent engineering approach:** at a retreat wc conducted at Pathfinder's start, while emphasis was on the then staggering flight system challenge that lay before us, the ground data system manager pointed out that if the flight system team could usc data protocols and formats already resident in the Magellan Venus mission ground data system, wc could adapt that data system quickly anti cheaply, substantially reducing ground data system costs from that normally experienced on past JPL missions. The. flight system in its early design phase could accommodate this---so a substantial amount of dol lars were freed up to app] y to the larger chal lenges of the flight system.

Another important concurrent engineering impact has been development of the surface operat i ons scenario after landing in parallel with flight system cicsigtl—ensuring what wc design will work once on the surface.

Our Project Engineering Team (PET), with membership from al 1 Project elements, is our major concurrent engineering vehicle. PET coordinated Project document development includi ng the Project Plan and lower level require ments stemming from the Project Plan's Level 1 requirements. PET is responsible for tracking compliance to requirements, for planning incremental hardware and software deliveries to the J]'], Test Bed for early phased test in:, as capabilities evolve, and for coordinating the Engineering Configuration Control and Problem/Failure processes. PET also acts as the Project referee in working "PET PEEVES": problems that impact requirements or have an impact to other elements of the Project.

with application of critical redundancy and extensive flight system testing prior to launch,

OUR COMPLETE RISK ASSESSMENT AND MITIGATION APPROACH

Scaling back from billion dollar class missions to mission costing a few hundred million dollars is not an excuse for taking undo risk or mission failure, and significant effort is being expended on Pathfinder to mitigate mission risk.

Similar to our costing estimating process, we broke down the flight system into its key functional elements for each mission phase, a functional Work Breakdown Structure, and, as we interacted with each element team member in our cost exercise to derive dollar reserves needs, we did the same for determining an estimate, primarily an engineering judgment on the part of the expert, for the functional reliability on each element in the mission. The most important product of this exercise was identification of the weak links in the system which were then beefed up with application of redundancy or an increased test program to ensure its performance.

Here's an example: in our interaction with the airbag cognizant engineer on functional reliability of airbag inflation, impact and retraction we soon realized that we needed to expend additional reserves for more testing than originally planned to ensure the airbag performance in flight. As with our cost estimating process, we are continually updating our mission risk assessments, activating additional risk mitigation steps as necessary.

The bottom line for mission risk mitigation for Pathfinder is a short mission lifetime of 8 months coupled

THERE IS NO MAGIC IN THE PATHFINDER PROJECT APPROACH

It's back to basics augmented with modern, computer aided project tracking/control and design methods: attention to detail, personal commitment, lots of hard work, follow through, a tightly connected team that communicates verbally around the table, eyeball to eyeball, making thoroughly aired decisions quickly, instead of communicating through the use of interoffice memos, meeting minutes and circulation of reports for review. Documentation is limited to that which is essential: mission and design requirements; streamlined project plans, interface agreements, compliance metrics; procurement, key item delivery, and key test milestone metrics; cost performance metrics; integrated schedule; problem/failure disposition reports; as-built documentation, test results, etc. We eliminated the use of mechanical drawings for the cruise stage entry and lander structures, moving instead to a "**computer art to part**" process.

With respect to the external world around the Project, we "gently" alert NASA and JPL management to unnecessary bureaucratic interference— a major accomplishment here was the combination of numerous JPL institutional and NASA reviews into one formal review occurring just once per year.

AND HOW ARE WE DOING SO FAR?

ATLO was started on June 1, 1995 as planned in the pre-project phase a number of years ago. We have completed early integration tests, and in January 1996, eleven months before launch, the full flight spacecraft will be assembled ancl functionally tested as a flight system with more than 90% of its flight software checked out and with RF compatibility tests with the Deep Space Network Test Bed completed.

Also, in January 1996 more than 90% of the planned EDL test and simulations will have been Completed.

What is remaining to accomplish before launch is these final space flight environmental tests and launch preparations: weight/center of gravity (CG), spin balance, acoustic, thermal/vacuum, thermal/Mars atmosphere, Electro-Magnetic Compatibility y/Radio Frequency Interference (EMC/RFI), pyro shock, system tests in between, ship to the Eastern Test Range (ETR) launch site, final assembly and system test, launch preparations and launch.

We start FY96, the final third year of development, with $9M of reserves remaining for approximately $30M of work scope to go to launch— we have no major problems at this time, **we have an excellent chance of completing development and launching successfully under the cost cap.**