MER: Stealing success from the Jaws of Failure

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are needed to see this picture.

The Gentry Challenge

- Should ALL System Engineers have Gentry Lee's "Ten attributes of a good systems engineer"??
  - Intellectually curious, likes big picture, makes connections, comfortable with change, comfortable with uncertainty, has proper paranoia, loves margins, strong communication skills, self-confident and energetic, appreciation for the SE process.
- No, please no!
  - Some of them must actually do the work and run the process!
    - Manage people, tasks lists, schedule tests, write reports, close Problem Reports, make more lists, trade analysis …
- Team DIVERSITY is key to success.
- We need all sorts for people and personalities to succeed.

Terror in Trailer 1723 (and other cubicles)

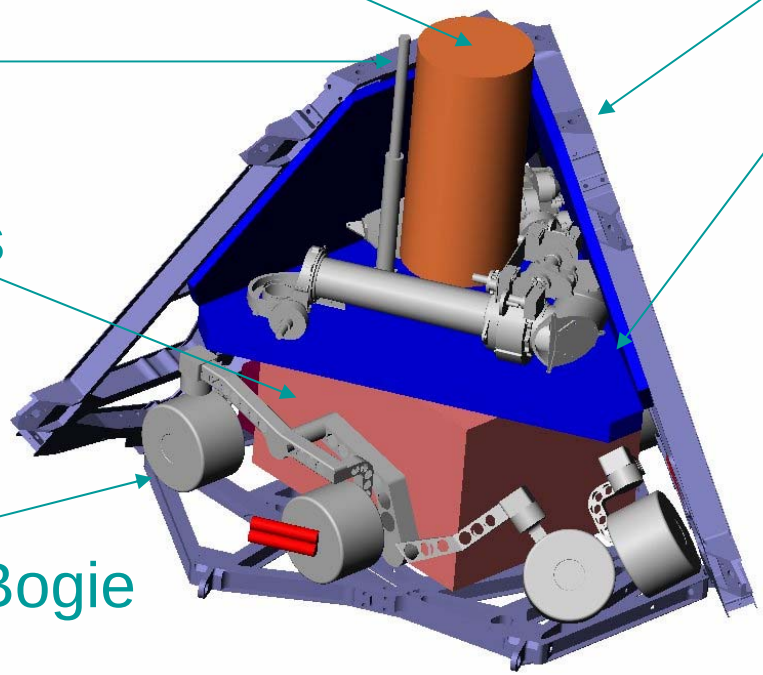
- Build to print? What prints?
- Volumetrically challenged
- Mass delusion
- Complexity gone wild
- Late start?
- Soft goods: Tear-a-chutes, squidders & bladders
- $1M for a Dime on a Windy day
- Pyros and fuses and cutters! Oh my!
- Late testing: Field Prohibitive Gut Aches.
- Luck?

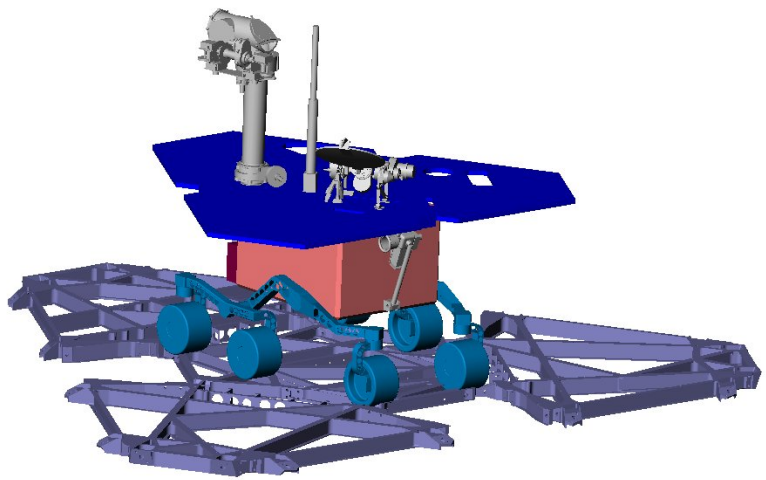
Lesson:

There is no such thing as “build-to-print” spacecraft.

(unless it is planned for)

Build-to-print proposal by Adler, Manning et al, April 2000





We estimated that about 50% of the launched dry mass would be inherited detailed design.

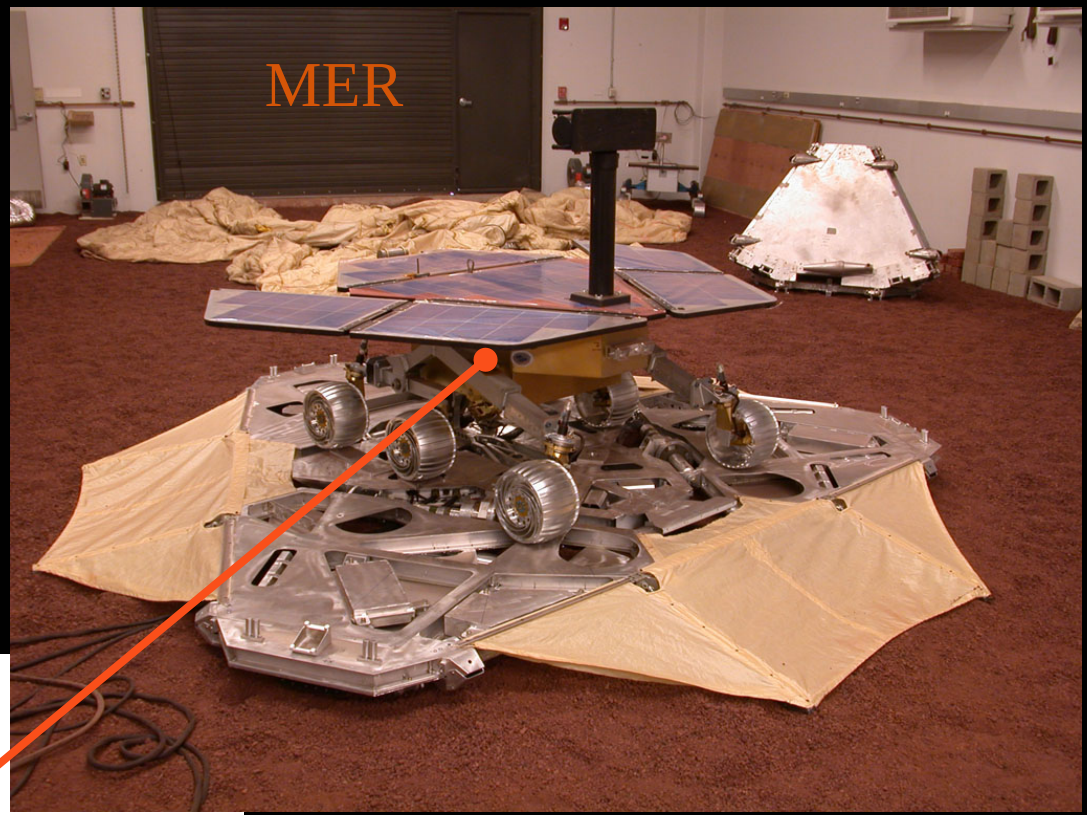
The Painful Truth

- Nobody (including MER team) believed that a NEW design could be launched in only 3 years.
- Slowly and frustratingly, detailed engineering studies showed we could not use the old design as-is.
  - Extra mass margins were required on new designs (30%)
- 6 months & $100 M later, we found out that we had only 30 months to get a new design to the pad!
- Ultimately, less than 2% of the dry mass was inherited detailed design!

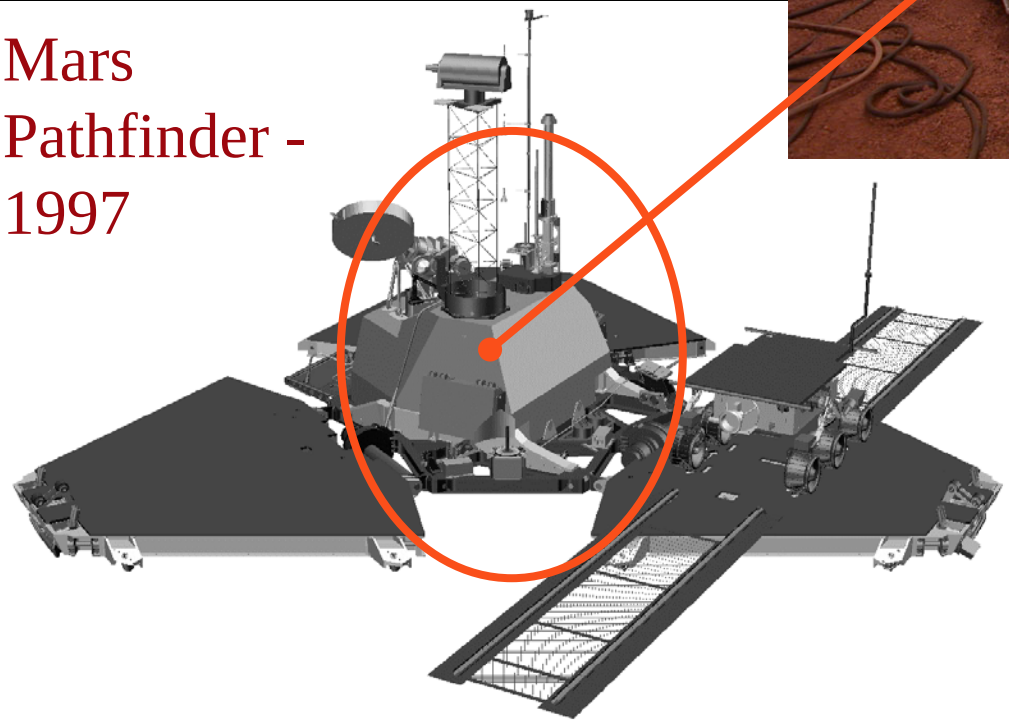
Lesson:

Volume is a real constraint

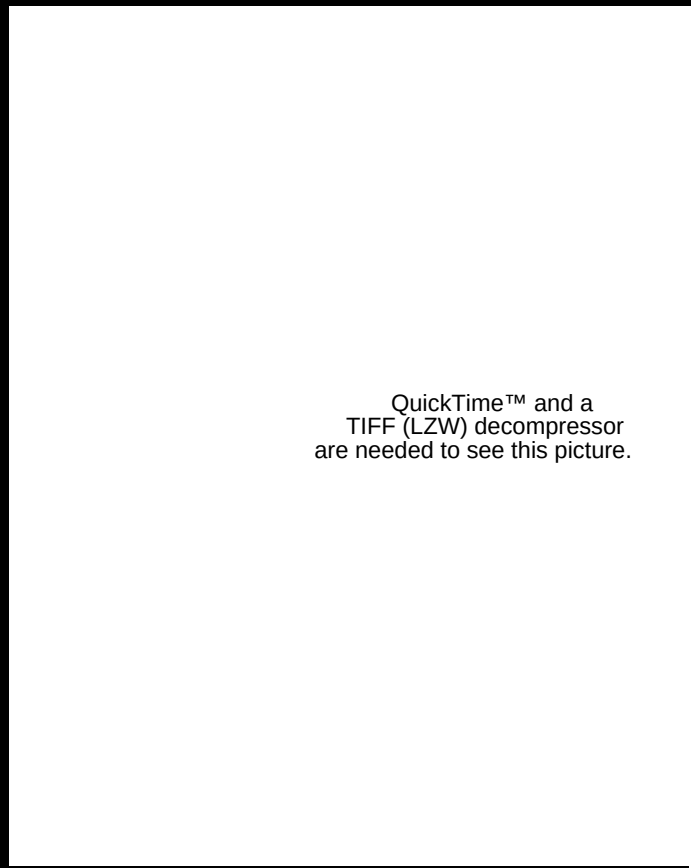
The Concept



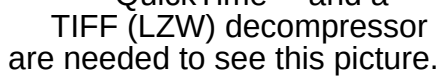
Mars Pathfinder - 1997



Square Pegs in Tetrahedral Boxes



Mars Pathfinder and Sojourner Rover at Florida in 1996



Mars Exploration Rover (Spirit) at JPL in 2003

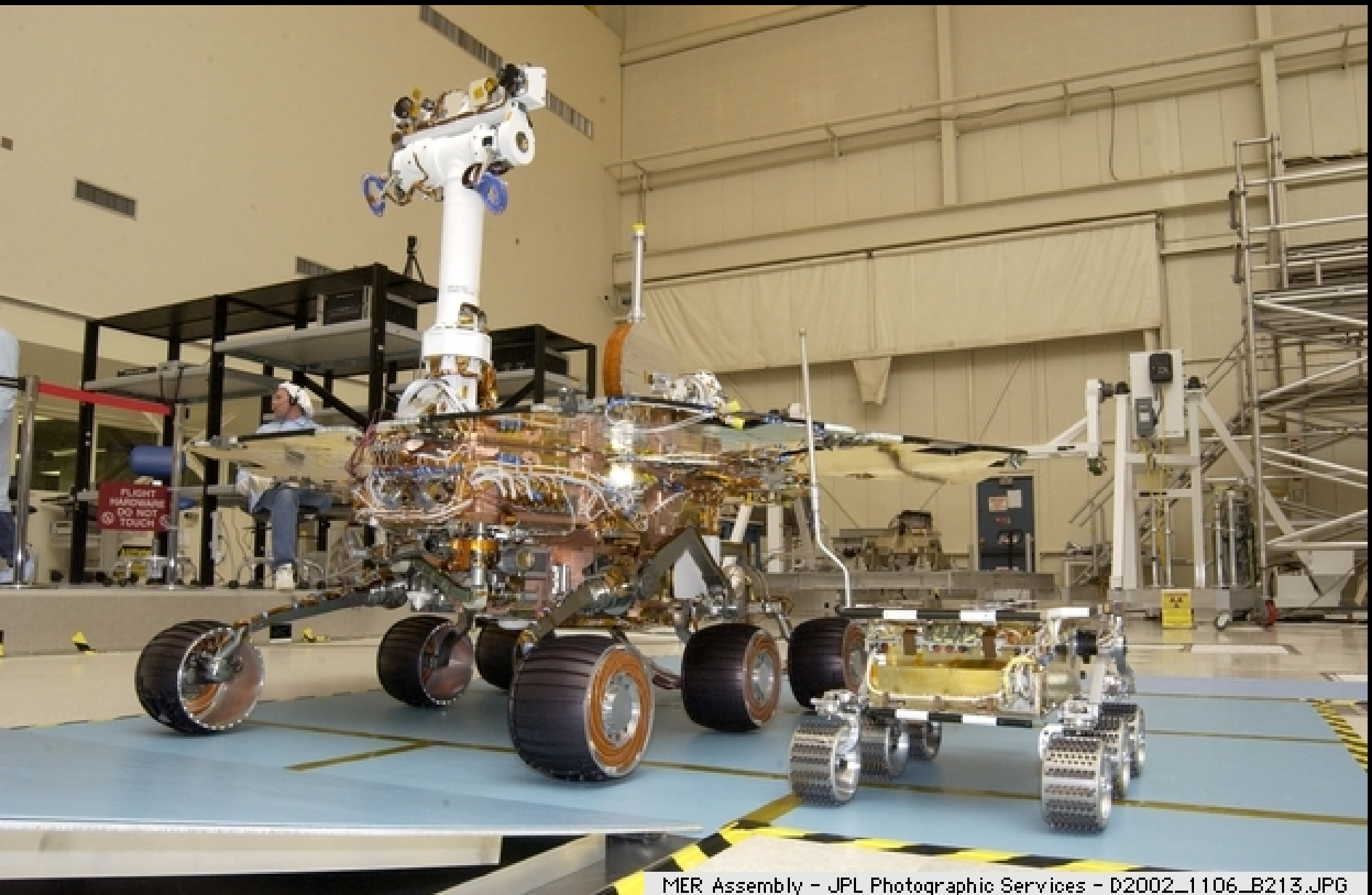
Lesson:

It can “always” get heavier, even if the volume is fixed.

MER will not float!

MER Lander/rover is 2x the density of water.

Rover on Steroids



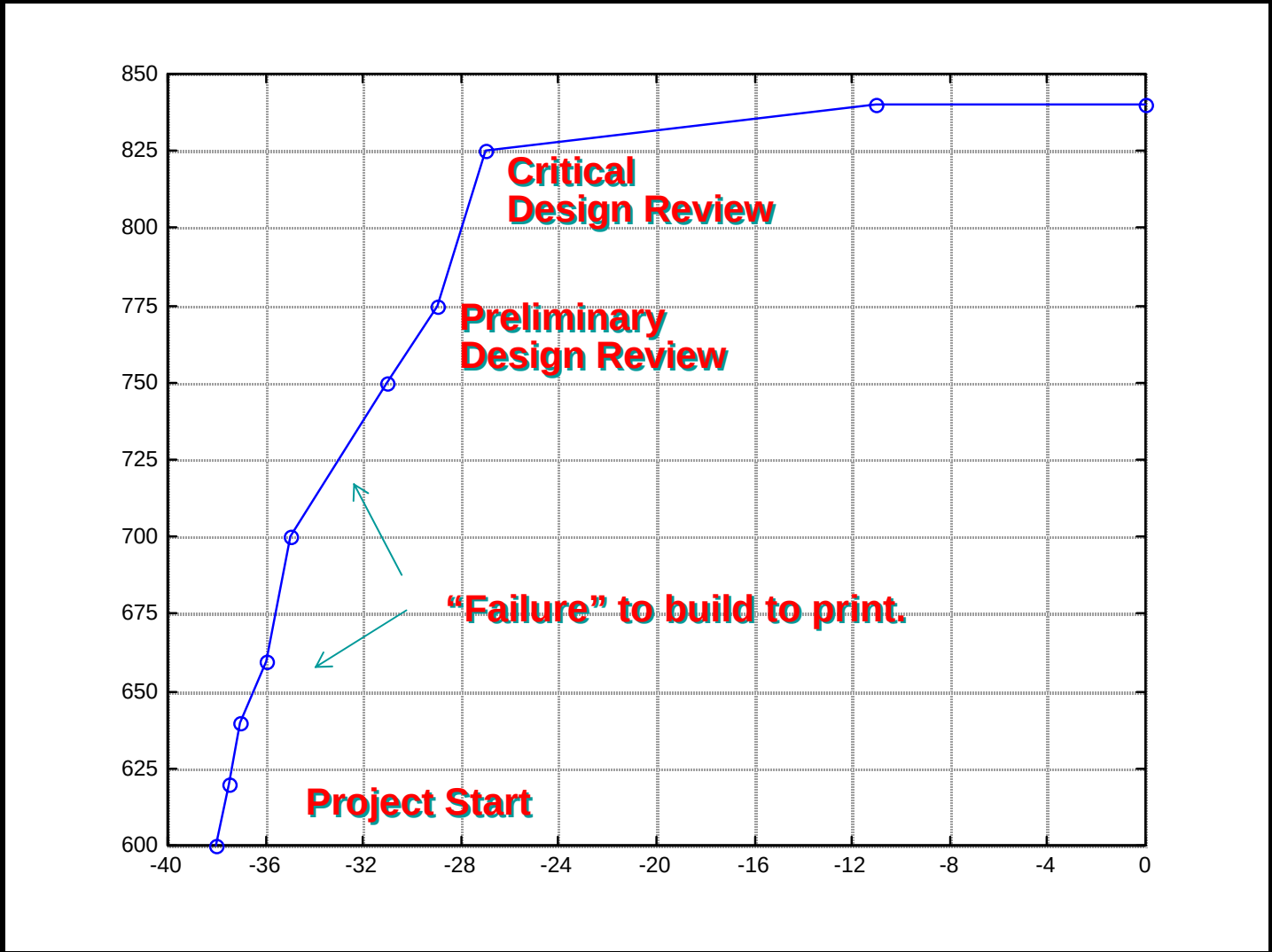
MER Assembly - JPL Photographic Services - D2002_1106_B213.JPG

Initial Mass Breakdown May ‘00

- Masses = Best estimate + contingency
  - Delta 7925 capability of 1020 kg (1077 kg)
  - Launch mass 890 kg (1070 kg) includes:
    - 50 kg fuel (52 kg)
    - 210 kg cruise stage (183 kg !)
    - 230 kg backshell/chute/rockets/heatshield (290 kg)
    - 280 kg bags and lander (368 kg)
    - 120 kg Rover (176 kg)

- Numbers in RED are what turned out to be the truth!

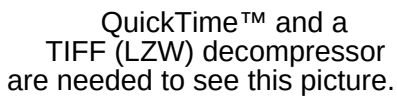
Entry Mass Growth



Lesson:

It can always get more complex.

Complex??


QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Complexity ⇒ Test, test, test

Lesson:

Do not skip a year.

The “right” way & the MER way

The “right” way:
4 years in Phase (Φ) A,B,C & D:

Year 1: Team gets to know, like each other and agree. (Φ A)
Year 2: Team gets to design it. (Φ B)
Year 3: Team gets to build it. (Φ C)
Year 4: Team gets to test it like crazy and finally launch it. (Φ D)
Post launch: Team gets to happily operate it (Φ E)

The MER way:
Year 1: Team thinks it is designing it.(Φ A)
Year 2: Oops. Team re-designs it. Finally agrees on a design. (Φ AB)
Year 3: Team gets to know each other, fabs it, build it, tests it, launch it. (Φ CD)
Post launch to Landing: Team gets to *really* test it. (Φ E)
(Team really likes each other *after* landing successfully.)

Lesson:

Do not take soft goods for granite.

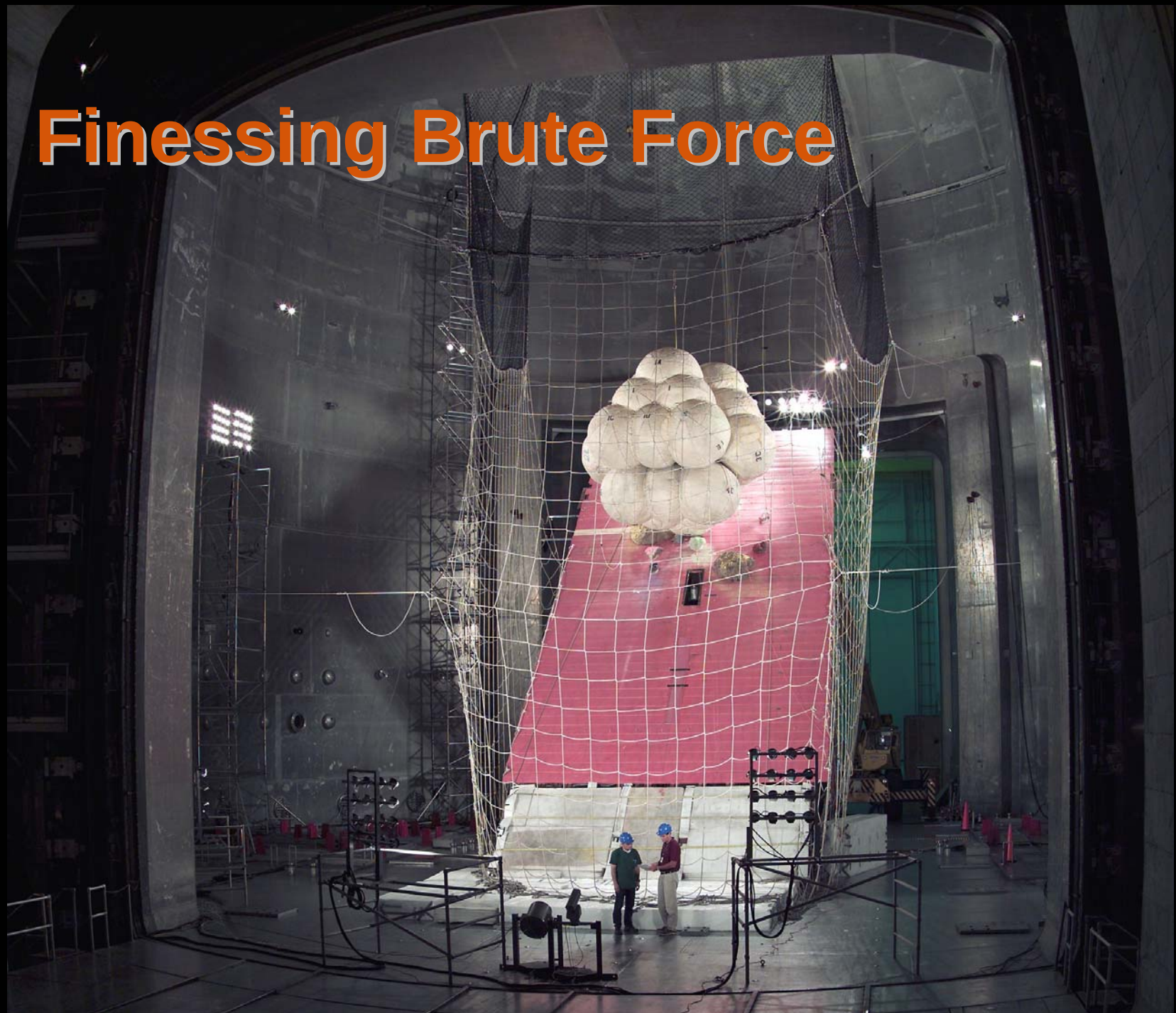
Tear-a-chutes & Squidders

Fun with 1/2 ρ v^2 Cd A

More fabric

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Finessing Brute Force



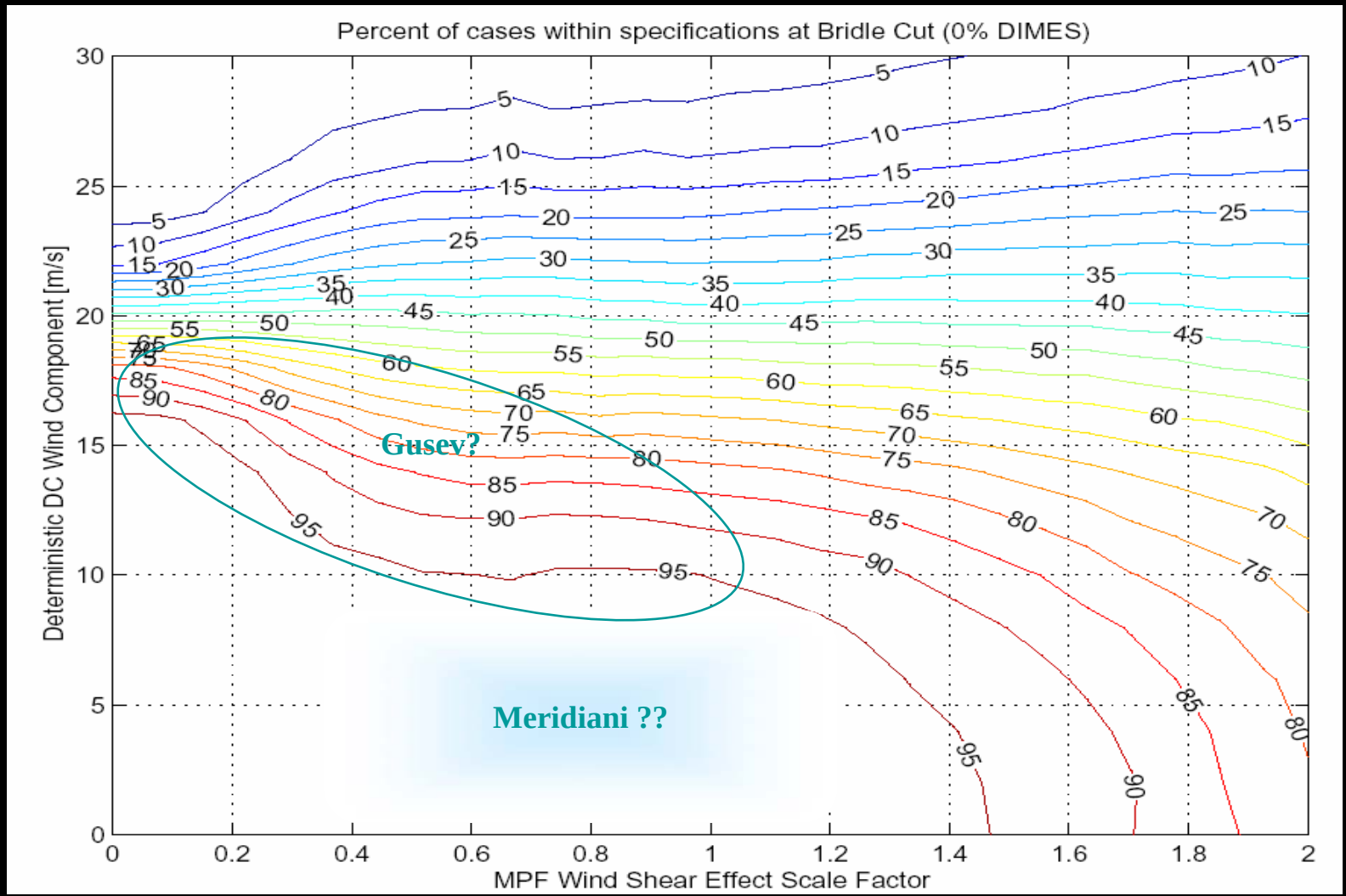
Lesson:

Ignorance is not bliss, or

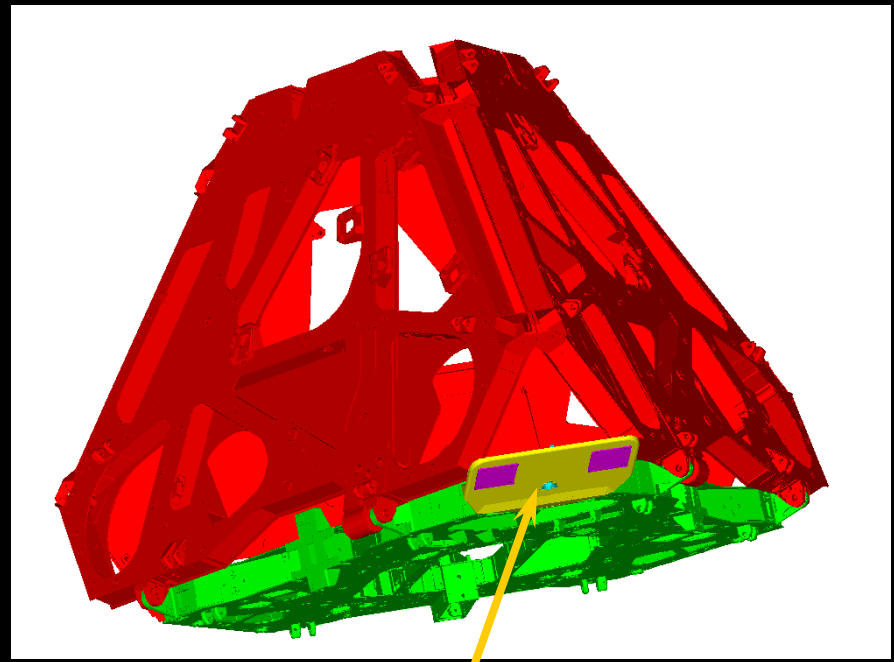
Are there really winds on Mars?

The Wind Threat

Probability of the horizontal velocity being within airbag specification at the moment of bridle cut without the help of a horizontal velocity sensor



DIMES & TIRS to the rescue @ L-15 months



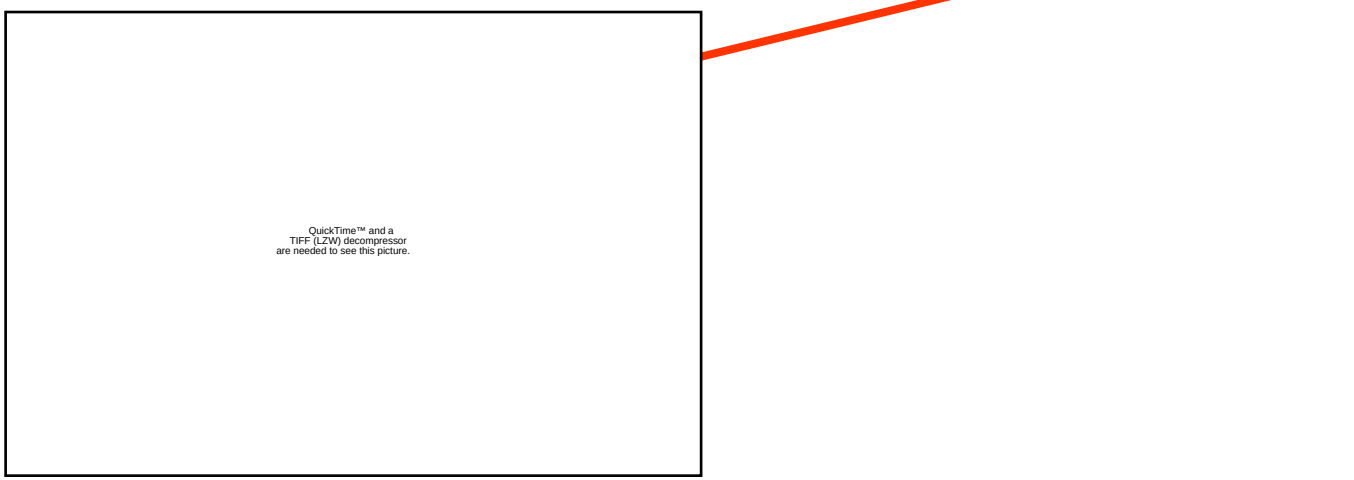
Descent Image Motion Estimation Subsystem Camera on RADAR bracket

Two of 3 Transverse Impulse Rocket Subsystems (TIRS)

23 m/s without DIMES

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

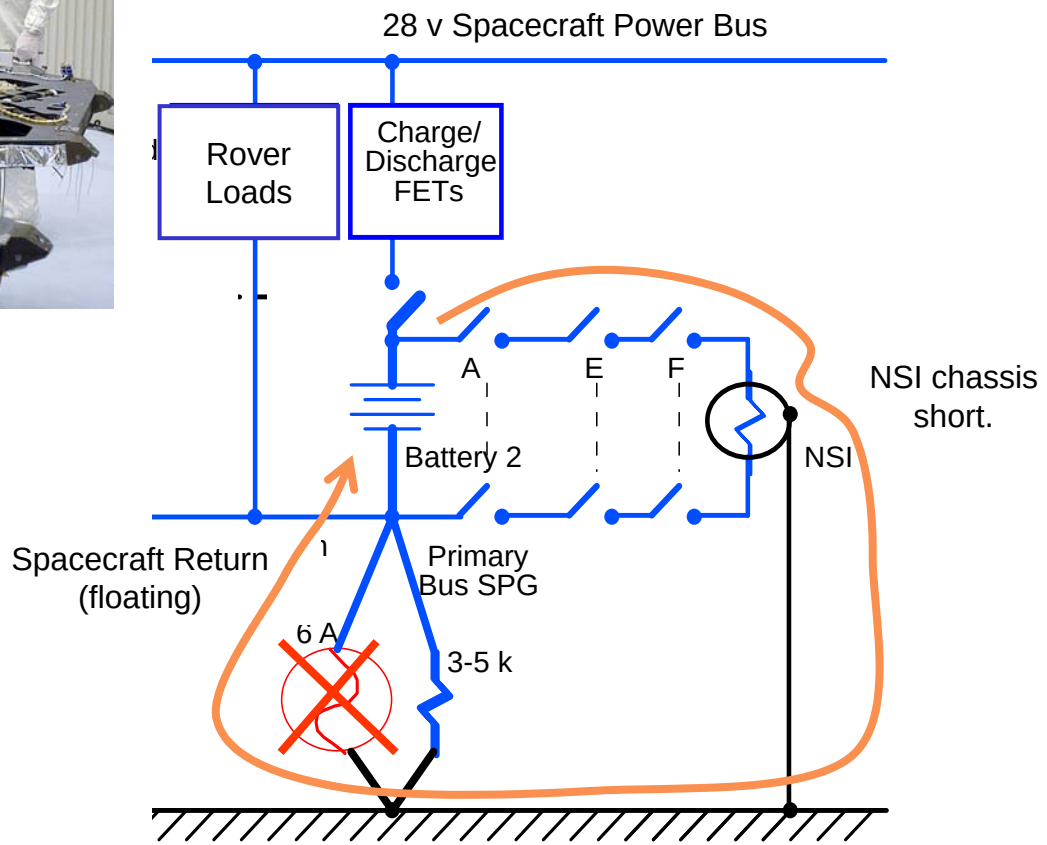
11 m/s with DIMES



Lesson:

Knives and Electricity don’t mix.

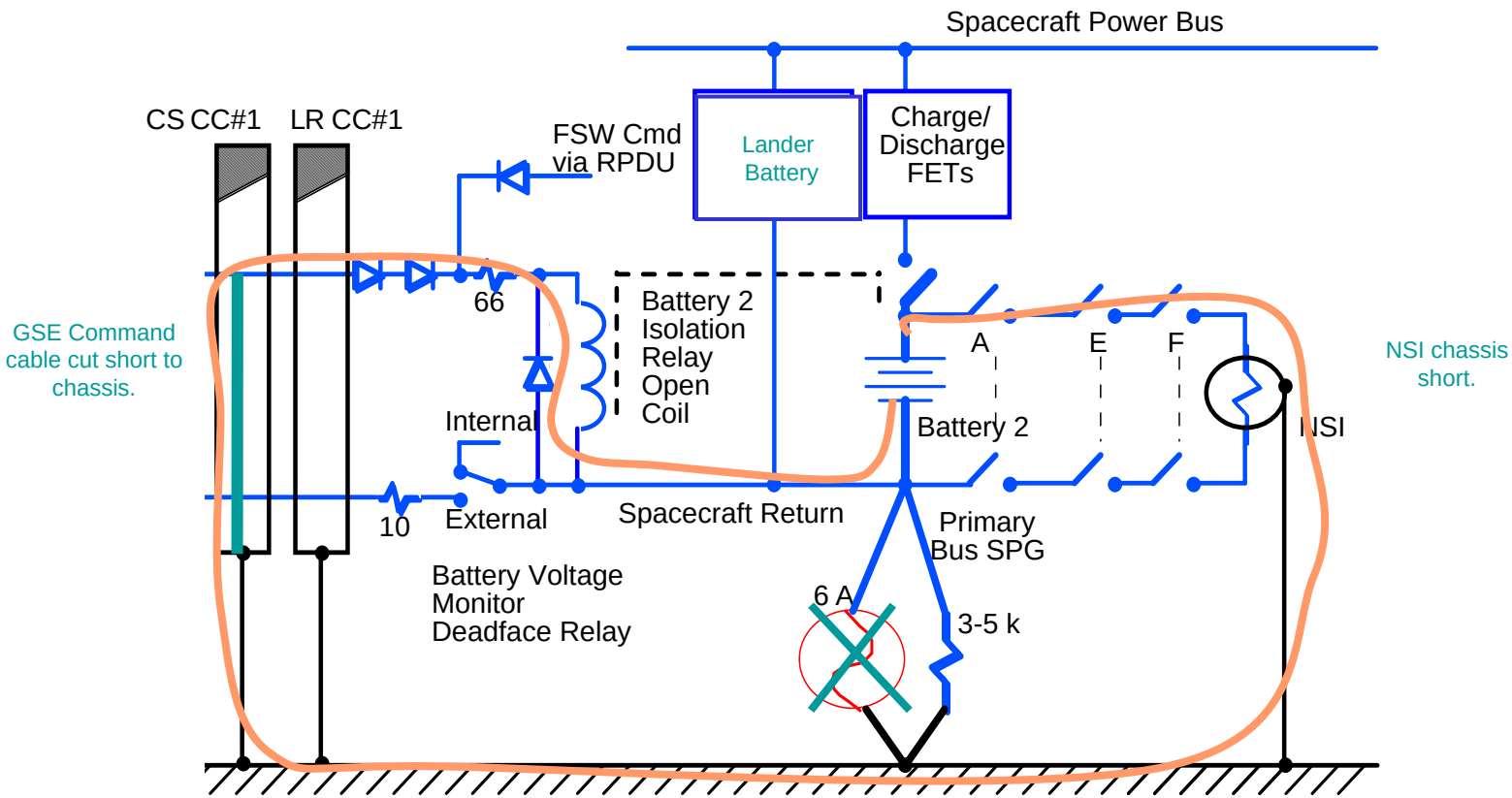
Breaking Spirit's fuse @ L- 2 mo.



Reflecting on Cable Cutters @ L-8 weeks

	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	tion #			Name	Frm	Ref Des	To	Ref Des	Harness	Dwg#	Connector	Cutter	UMB 1	UMB 2	**CS#1**	**CS#2**	**BS**	**Bridle**	**LR#1**	**LR#2**	**LR#3**	Count	Retained Side Effect	Retained Side Rationale	Discarded side effect
2	002	034	>	UHF COAX SW 2 TO Z PATCH LGA	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2002XCC11P1									X			none	open circuit	none
3	002	026	>	COAX SW 2 TO Z PATCH LGA	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2002XCC11P1									X			none	open circuit	none
4	106	001	<	UMB U/L CMD DATA	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
5	106	002	<	UMB U/L CMD CLK	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
6	106	003	<	UMB U/L CMD LOCK	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
7	106	004	>	UMB D/L TLM DATA	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
8	106	005	>	UMB D/L TLM CLK	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
9	106	006	<	UMB LCE-S/C I/F PWR TO S/C	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
10	106	007	<	UMB U/L CMD ENABLE	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
11	106	008	>	UMB SELECT TEST	TSB	2006TSBJ2	LCE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
12	104	019	<	UMB GSE WAKEUP SIGNAL	BCB	2004BCBJ4	PPSSE	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
13	009	005	>	UHF D/L TLM DATA	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
14	009	006	>	UHF D/L DTAT CLK	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
15	009	007	>	ON-LINE SIGNAL	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
16	009	002	>	BUS MONITOR DATAP	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
17	009	003	>	FEO	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
18	009	004	>	RTI	TSB	2006TSBJ2	9WXXX	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
19	009	001	<	S/C-L/V SEPARATION A	RPSA		CABL	UMBJ1	2009W516	10204753	2009W516J1	UMB 1	X			X	X			X					
20	104	001	<	UMB 28V PWR TO S/C	CLSA	2004CLSAJ1	CABL	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X								1			
21	104	002	>	UMB PWR SENSE LINE	CLSA	2004CLSAJ1	CABL	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X								1			
22	104	003	>	UMB SEC BATT 1 VOLTAGE MON	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
23	104	004	>	UMB SEC BATT 2 VOLTAGE MON	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
24	104	005	>	UMB ROVER BUS VOLTAGE MON	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
25	104	006	>	UMB SEC BATT ON/OFF STATUS	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
26	104	007	<	UMB CMD VOLTAGE MON TO LCE	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
27	104	008	<	UMB SEC BATT 1 ONLINE CMD	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
28	104	009	<	UMB SEC BATT 1 OFFLINE CMD	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
29	104	010	<	UMB SEC BATT 2 ONLINE CMD	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
30	104	011	<	UMB SEC BATT 2 OFFLINE CMD	BCB	2004BCBJ4	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
31	104	012	<	UMB SAFETY INHIBITS - SAFE CMD A	RPSA	2004RPSAP?	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
32	104	014	<	UMB SAFETY INHIBITS - PYRO ARM CMD	RPSA	2004RPSAP?	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
33	104	013	<	UMB SAFETY INHIBITS - SAFE CMD B	RPSA	2004RPSAP?	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
34	104	015	>	UMB SAFETY INHIBITS ST TO LCE	RPSA	2004RPSAP?	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
35	104	001	<	28V PWR TO HRS PUMB B	HRS	2011HRSJ1	CABL	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X								1			
36	104	016	>	UMB ROVER SEC BATT TEMP	RBAT1	2004RBAT1HTR	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
37	104	017	>	UMB LANDER PRI BATT TEMP	LBAT1	2004LBA1J1	PPSSE	UMBJ2	2009W514	10204752	2009W514J1	UMB 2		X	X										
38	009	002	<	S/C-L/V SEPARATION B	RPSA		CABL	UMBJ1	2009W514	10204752	2009W514J1	UMB 2		X	X				X						
39	004	006	=	28 V CRUISE BUS TO ROVER BUS	RSLU	2004RSLUJ5	CSLA	2004CSLAJ5	2009W104	10204791	2009W504P1	CS #1 (+Y)			**X**				**X**			1	OK, but cut wires float. No bleed R	Relay deadfaced in RSLU check S/W	40V not deadfaced and are cut "hot."
40	004	007	>	CSLA CTRL VOLTAGE FROM RSLU	RSLU	2004RSLUJ1	CSLA	2004CSLAJ3	2009W104	10204791	2009W504P1	CS #1 (+Y)			**X**				**X**			1	OK	Relay deadfaced in RSLU. Floating wires on open contacts	OK, Cruise Elec. Stressed, but no energy to retained side. Deadface 30 sec before CC fires. Separation 1 sec after CC cuts.
41	004	030	<	SET/RESET PDE ENABLE RELAY A	CPDU	2004CPDUJ27	RPSA	2004RPSAJ1	2009W104	10204791	2009W504P1	CS #1 (+Y)			**X**				**X**			1	Ok if 4-4-70 switch is not on. If it is ON, 121 ohm resistor may be overstressed with shorted to chassis thru CC blade.		

Surprising Pyro Side Effects @L-3 weeks



Lesson:

Mars does not comply to requirements.

The atmosphere does not behave.

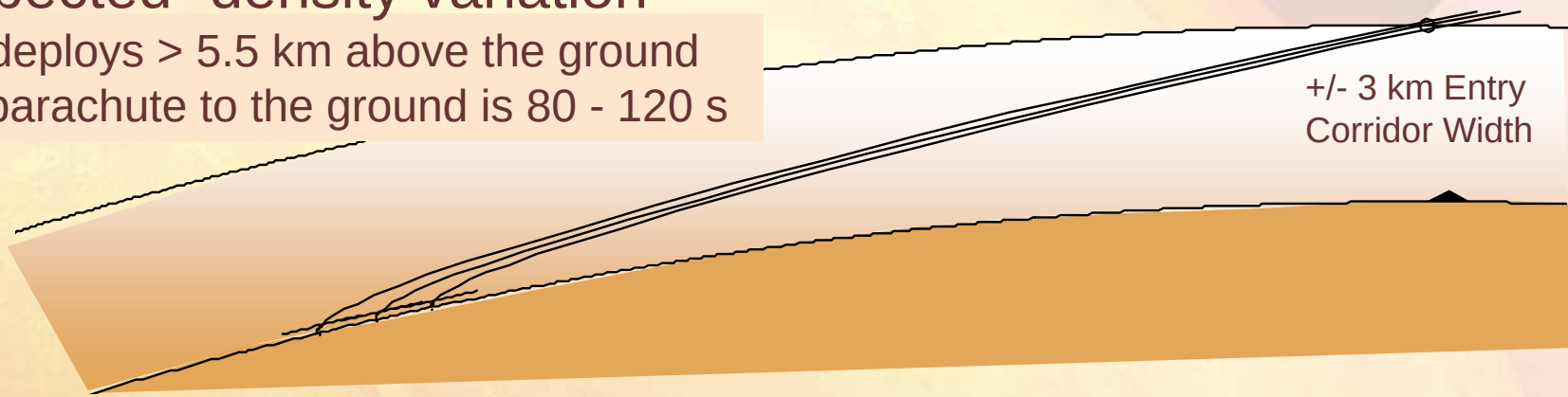
Dust Storm at Landing - 10 days
Where did the air go?

We needed 50 seconds between when the parachute opens and getting to the ground

100 km

With “expected” density variation

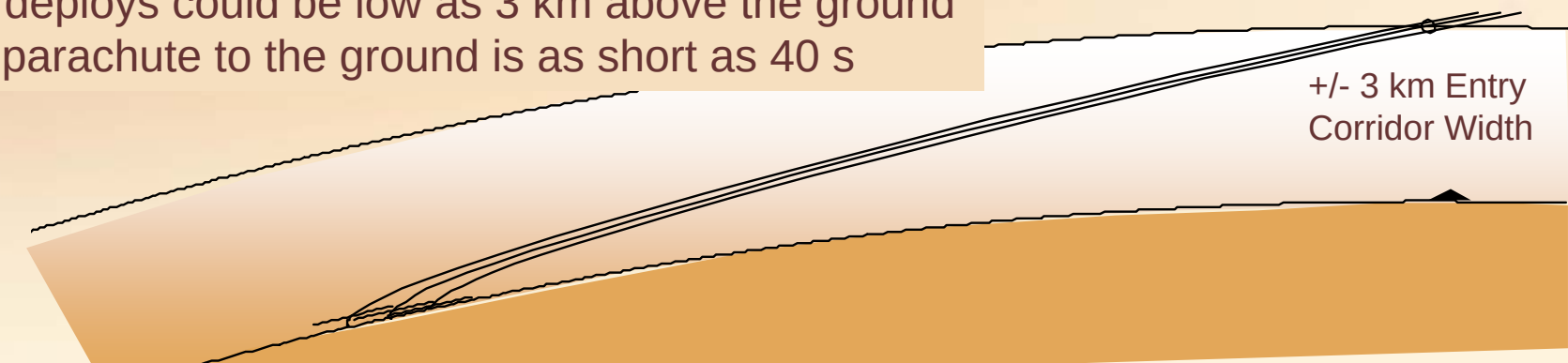
Parachute deploys > 5.5 km above the ground
Time from parachute to the ground is 80 - 120 s



With up to 10% lower density in upper atmosphere (our fear after the Christmas 2003 dust storm)

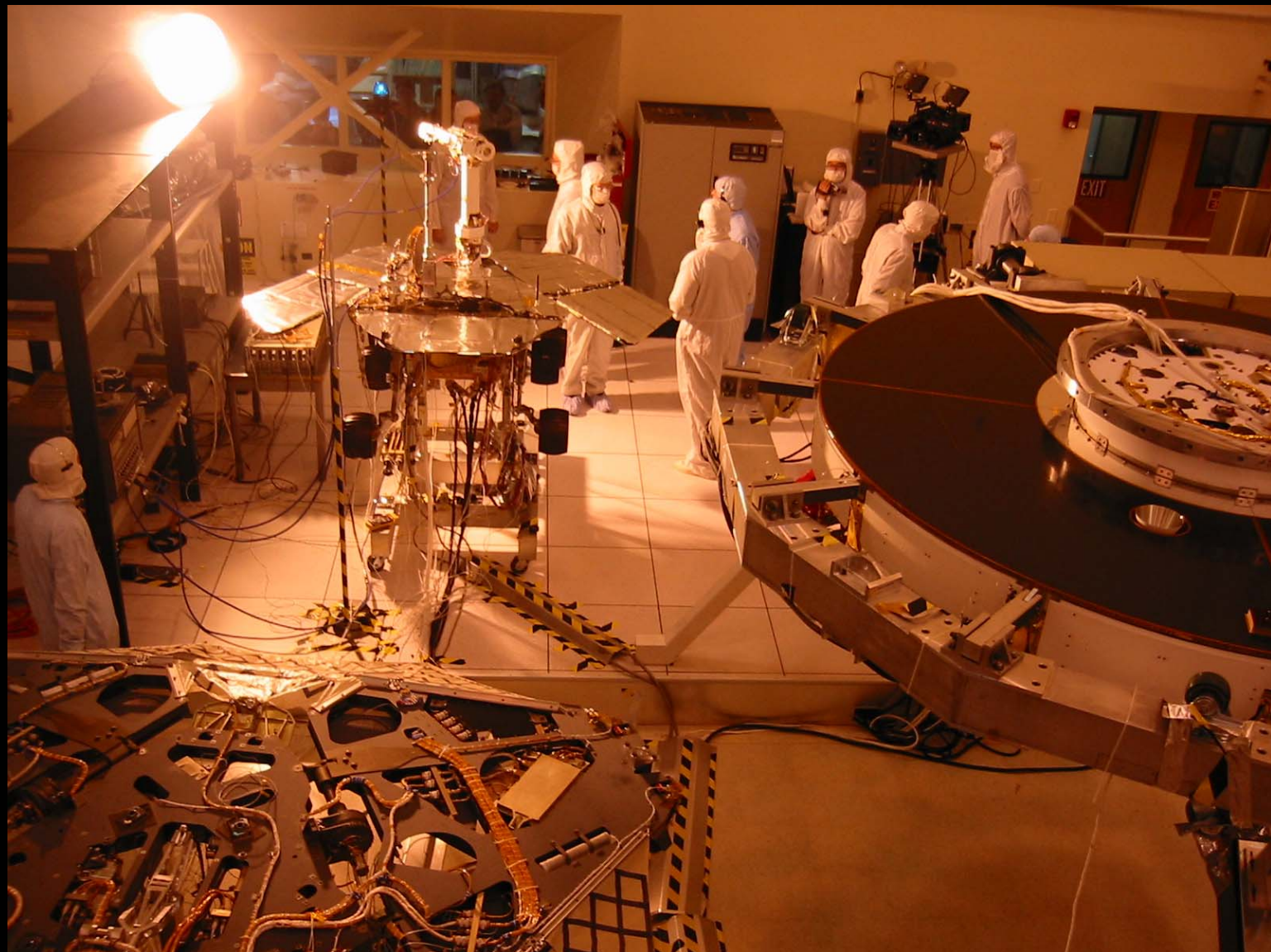
100 km

Parachute deploys could be low as 3 km above the ground
Time from parachute to the ground is as short as 40 s



Lesson

“There is more time to solve problems than you think.
There is less time to find problems than you think.” (*)



(*) With thanks to
Adam Steltzner

Surprises at E-30 hrs

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

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Was MER Lucky?

Yes!

- We were lucky that NASA and JPL supported MER 110%.
- We were lucky to have a great team of eagle-eyed system and subsystem engineers at JPL and around the world.
- We were lucky that these people cared so much about success that they dedicated themselves and their personal lives to MER.

Relish your luck… you may never see it again.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

Lesson

Spacecraft are built by people, not processes.

Good processes should help them succeed.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

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W) decompressor
to see this picture.

QuickTime™ and a
TIFF (LZW) decompressor
are needed to see this picture.