ULDB Flight 517NT

Anomaly Review Status Report

presented to

NASA Balloon Working Group

30 June 2003

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Presentation Agenda

Review of Flight 517 NT Critical Events

Review Board Operations, Charter and Members

Review of Board Activities

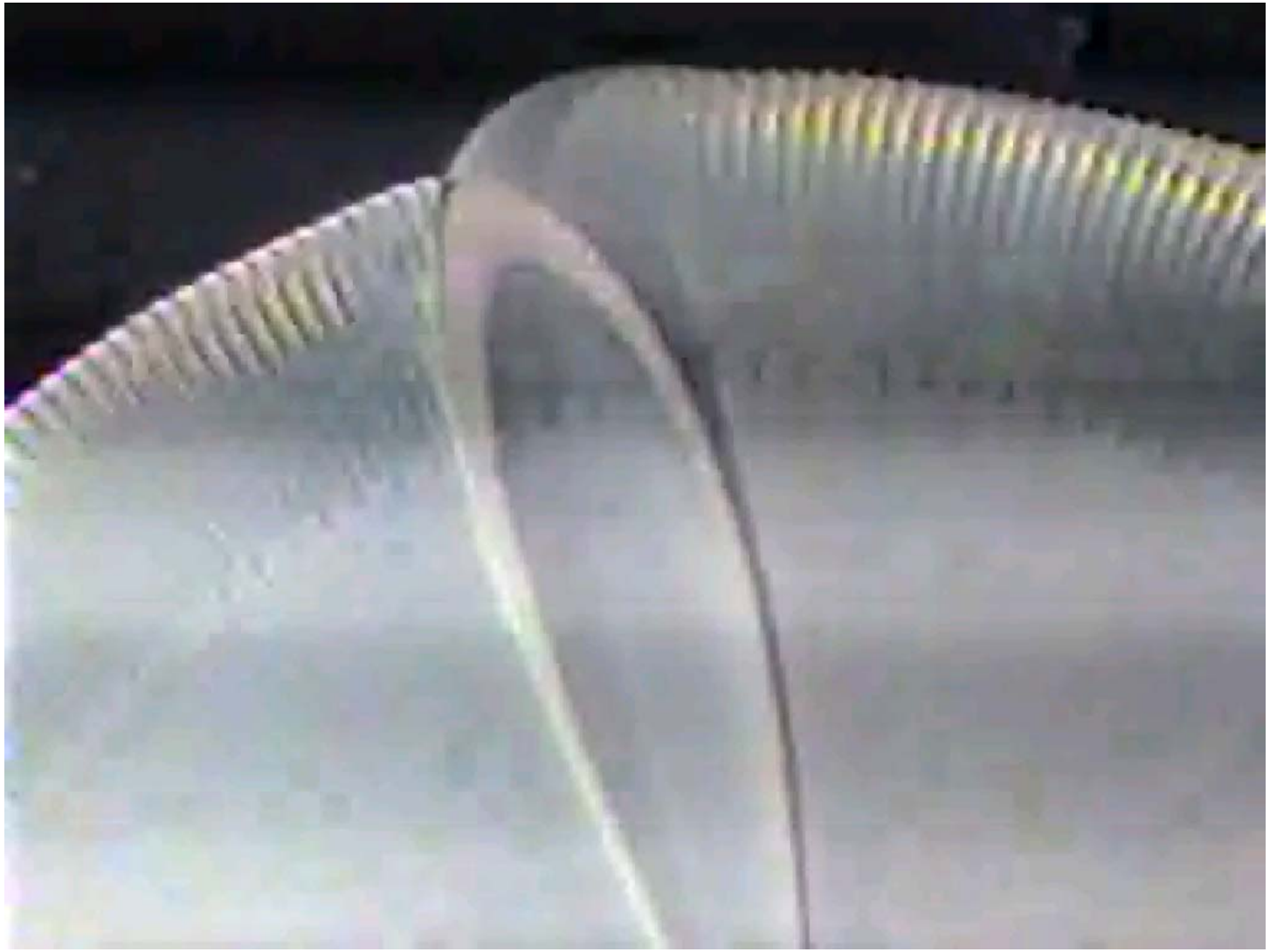
Interim Recommendations

Flight 517 NT Critical Events

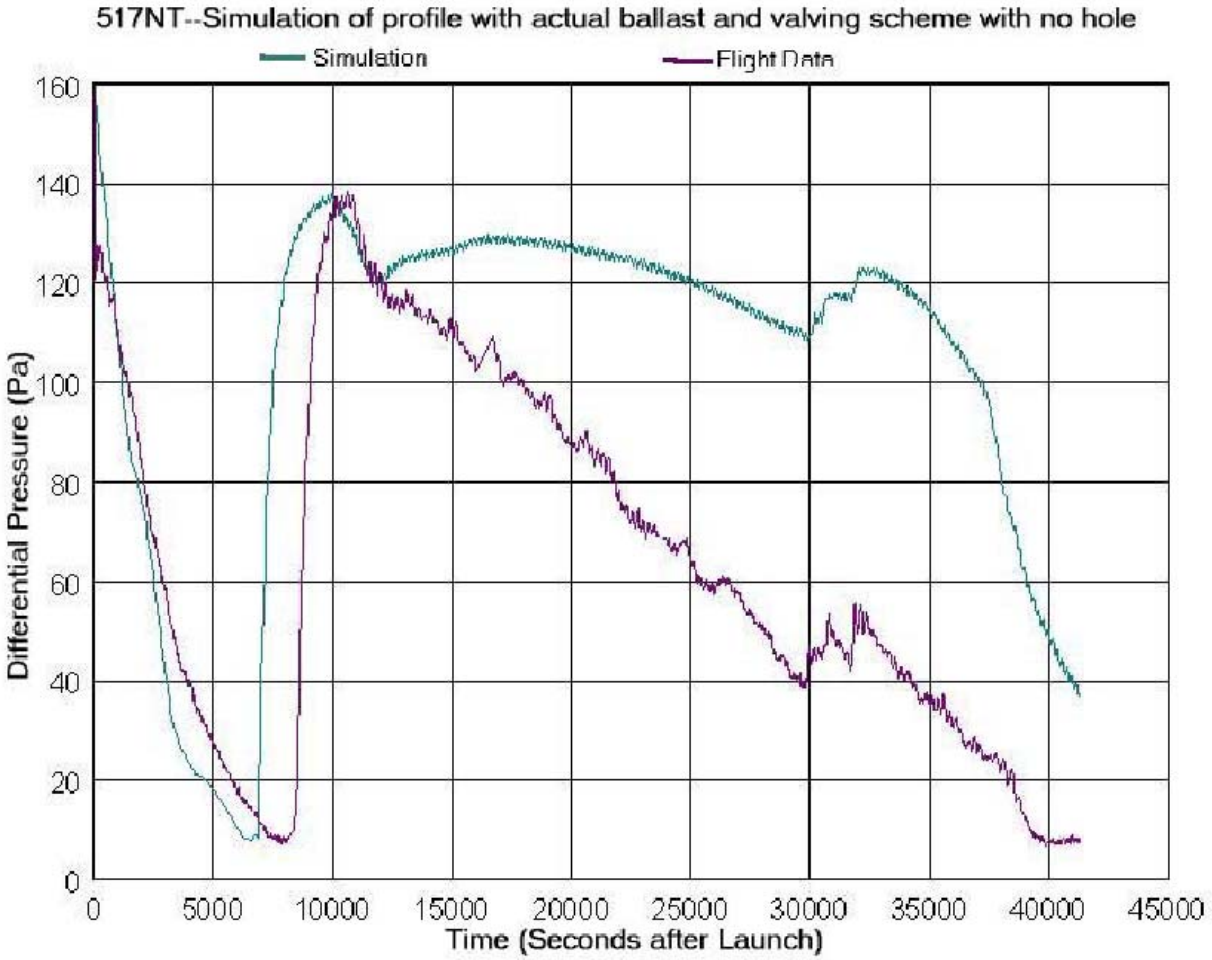
Summary of Events

- At 2309Z on March 16, 2003, the ULDB/NIGHTGLOW mission was launched from Alice Springs Australia
- As the ULDB vehicle entered float altitude, a multiple gore "super-lobe" was observed (via up-looking video from the payload) in the balloon
- The balloon's differential pressure peaked at approximately 137 Pa before release of helium from the CAP and UTP helium valves at L+2.5 hours
- Differential pressure continued to decrease after valving ended
  - SINBAD simulations show that to match the rate of gas loss a hole 85% of the area of a helium valve is needed
- At L + 8.3 hours three ballast drops totaling approximately 500 pounds of ballast failed to arrest the pressure loss
- The flight was terminated at L + 11.5 hours

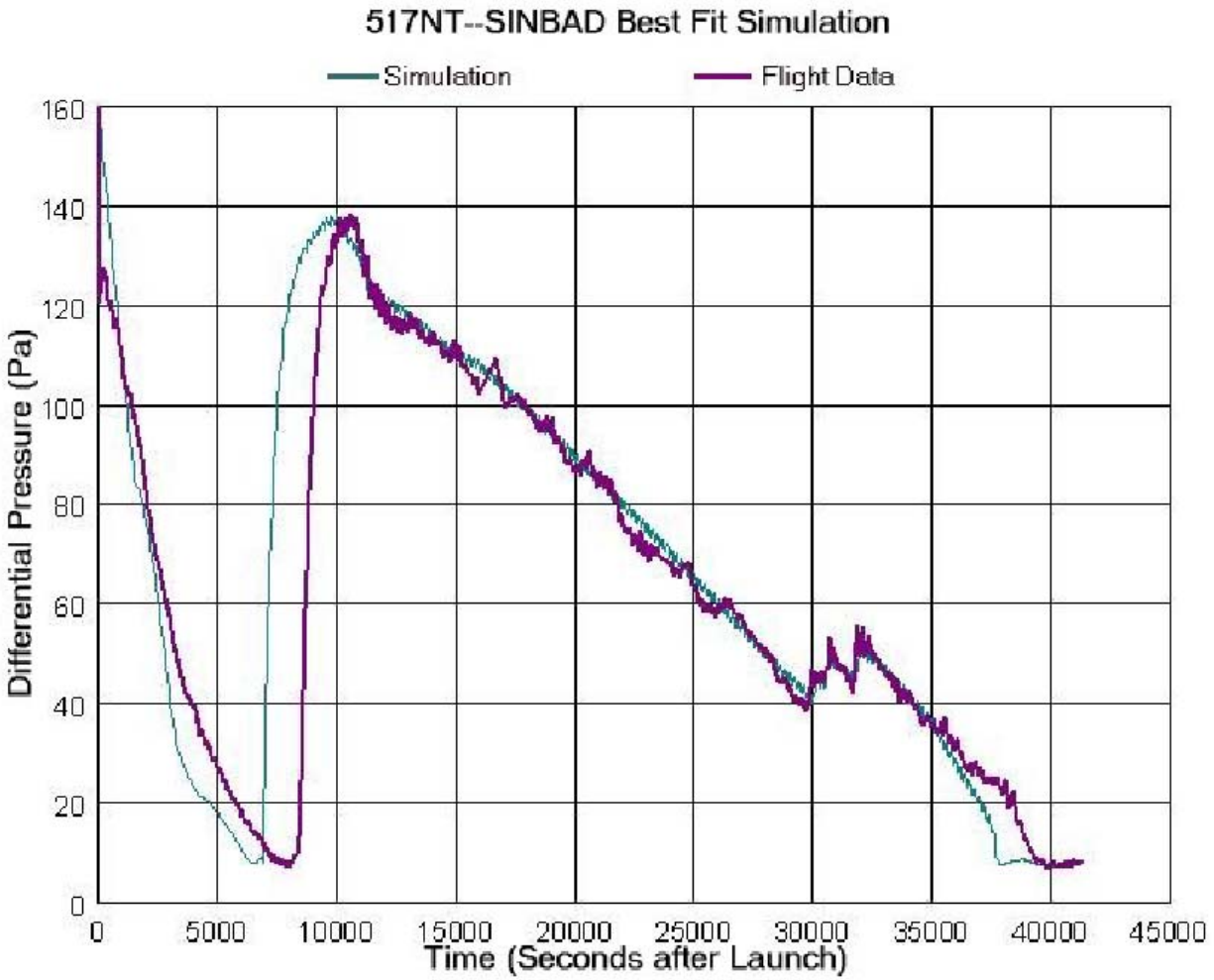
Cleft Observed During 517-NT



Flight 517NT Differential Pressure



SINBAD Simulation Results



Anomaly Review Board

- In response to the failure of mission 517 NT, Dr. John H. Campbell, Code 800/Director of Sub-Orbital and Orbital Projects Directorate, appointed a investigation review board on 20 March 2003.
- Bill Gibson, Southwest Research Institute, was asked to chair the board and develop an approach to determining the most likely cause of the failure.
- The anomaly review board has now met three times, and held one Board telecon, developed a detailed fish bone analysis of the failure(s), and is nearing completion of the actions created by the fish bone analysis
- A summary of the results of the telecon and meetings follows

Review Board Members

- **The Flight 517-NT investigation board is comprised of the following personnel**

Mr. Bill Gibson, Chair	Southwest Research Institute
Mr. Steve Smith, Secretary	NASA/GSFC/Code 820
Mr. Rodger Farley	NASA/GSFC/Code 543
Dr. John Johnston	NASA/GSFC/Code 542
Mr. Victor Eyo	NASA/GSFC/Code 548.W
Dr. James Rand	Winzen Engineering, Inc.
Dr. Holland Ford	The Johns Hopkins University
Dr. E.S. Seo	University of Maryland

Review Board Charter

- The investigation shall include, but not be limited to the following:
  - 1) Review of the events surrounding Flight 517-NT and all previous flights of this model balloon,
  - 2) Review of the ULDB pumpkin balloon design,
  - 3) Review of balloon fabrication and material records,
  - 4) Review of all pertinent operational procedures, flight hardware records, flight performance and flight records,
  - 5) Conduct of tests in support of the investigation,
  - 6) Review of and identification of possible cause(s) of any failures and anomalies,
  - 7) Recommendations to eliminate reoccurrence,
  - 8) Recommendations for testing and resumption of flights and
  - 9) A written final report addressing findings, conclusion and recommendations.

Review Board Operation

- The ULDB Anomaly Review Board will conduct business in two phases
  - Phase I is fact finding and long range planning
    - This first core team will consist of people directly involved with the development, production, flight and recovery, and management of flight 517-NT
    - The Core Team is expected to serve as a pathfinder for a larger board to follow
    - The Core Team is expected to identify the high probability anomaly possibilities based on observations of the flight and a fish bone analysis
    - A status report and list of recommendations for follow on action will be produced as a result of the 9-11 April meeting of the Core Team

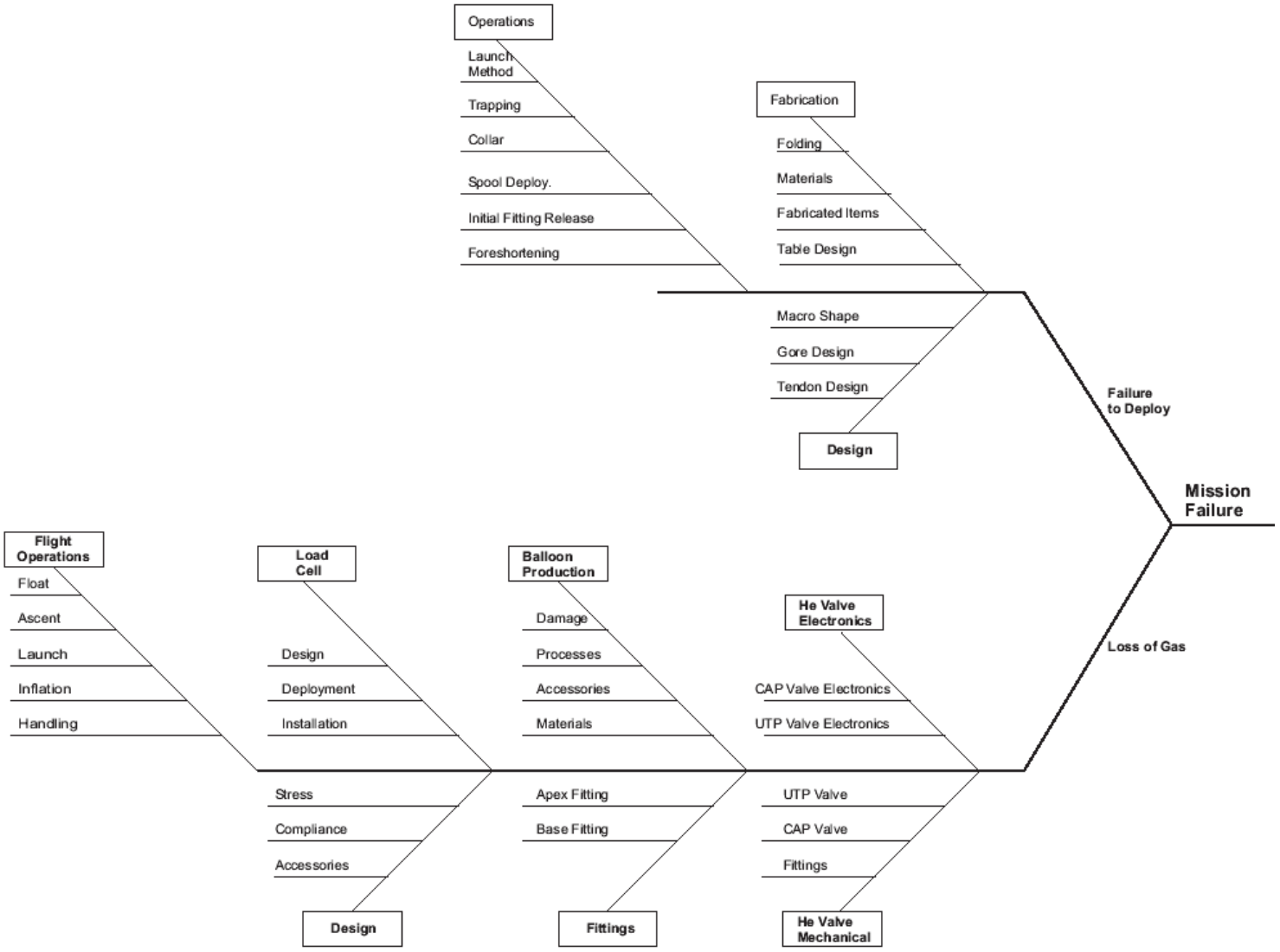
Review Board Operation (2)

- **ULDB Anomaly Review Board**
  - **Phase II is detailed analysis and testing as well as planning for balloon system design or fabrication changes to improve reliability**
    - **Phase II Full Board will consist of members appointed by GSFC and NASA Headquarters**
    - **Full Board members will participate in detailed analysis and test activities, building on the work of the Core Team**
    - **The Full Board will make a presentation to NASA management as soon as possible, commensurate with the complexity of the analyses and tests being conducted**

Review Board Activities 4/9-11/03 Meeting

- A meeting was held on 9-10 April 2003 at the Chincoteague VA Comfort Inn to start the anomaly investigation process for ULDB Flight 517 NT
- There were several purposes for the meeting:
  - Gather as much first-hand information as possible from eye witness reports of the preparations, launch, and recovery of flight 517 NT
  - Make plans for acquiring telemetry and command files, photographs, written records relating to balloon construction and inspection, flight procedures, and design analyses from the original balloon design
  - Initiate a fish bone analysis of both the loss of gas and the failure to deploy
  - Prioritize lines of investigation, assign responsible individuals, and develop a timeline for investigation activities
  - Establish a web site for use in posting information relative to the fish bone analysis activities

Flight 517 NT Fishbone Analysis



Review Board Activities 5/15/03 GSFC Meeting

- First meeting of full review board
  - Included all Board members plus key WFF Balloon Program Office personnel
  - Reviewed ULDB design, fabrication, and flight operations
  - Reviewed analysis performed by Raven Industries on the load cell behavior during 517NT
  - Reviewed status of fish bone analysis action items
  - Made plans to meet at Raven Industries and NSBF in early June

Review Board Activities 6/11-12/03 Meeting

- **Full Board met on 6/11/03 at the Sulphur Springs, Texas balloon manufacturing facility of Raven Industries**
  - Reviewed actions from 5/15/03 meeting at GSFC
  - Toured Raven facility and were briefed on construction details of ULDB balloons
  - Review status of all fish bone analysis action items relative to Raven Industries
- **Full Board met on 6/12/03 at NSBF Palestine, Texas**
  - Briefed on the results of tests performed at NSBF on the CAP and UTP helium valve systems
  - Reviewed fish bone analysis action items assigned to NsBF personnel
  - Updated due dates for all action items

Review Board Activities 6/27/03 Telecon

- All Board members participated
- Review status of fish bone analysis action items with WFF personnel
- Reviewed plans for Board's report
  - The entire Board felt strongly that until the clefting problem was solved all other problems/issues were irrelevant
  - Decided to produce an interim report focusing on need to address the clefting problem
- Updated dues dates for fish bone activities related to the inspection of flight 517NT that has just returned from Australia

Interim Results/Recommendations

- The flight line operations, inflation, launch and ascent of flight 517 NT appeared to be nominal
  - It was later discovered that a significant “rope” section had formed during inflation that could have stressed the balloon film
  - It was also observed that a load cell caused some damage to the film during launch and ascent
    - Load cell readings were zero before inflation, showed compression just as inflation started and changed to tension as the balloon began to pressurize
- The loss of pressure seems to start at nearly the same time as the completion of valving to reduce pressure from 137 Pa to 125 Pa
  - Extensive review and testing of the helium valve system (valve, electronics, telemetry/command interfaces) failed to show any anomaly or misoperation of either valve
  - To duplicate the rate of gas loss experienced during 517 NT, it would be necessary for one of the valves to stick ≈ 85% open

Interim Results/Recommendations

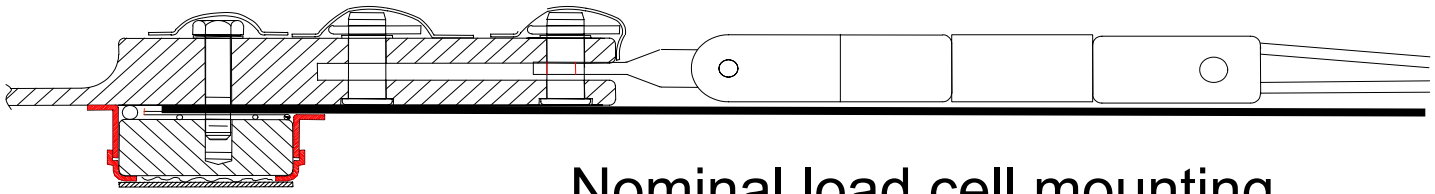
- A review of the design assumptions used in the design of the ULDB has not identified any obvious reason why the balloon should not perform after arrival at float altitude
- A thorough review of the manufacturing records of 517 NT likewise does not reveal any obvious reason for the loss of gas
  - Tolerancing concerns raised during earlier flight anomalies appeared to have been corrected by Raven Industries for 517 NT
  - 517 NT had about the same number of manufacturing defects as a typical zero-pressure balloon
  - No obvious problems with material selection/usage
  - Some concern with the dimensions used for gore dimensions
  - Some concern with the finding that tendons can, and probably do, shift within their sheaths creating a possible cause for clefting

“Fold” Observed During Inflation

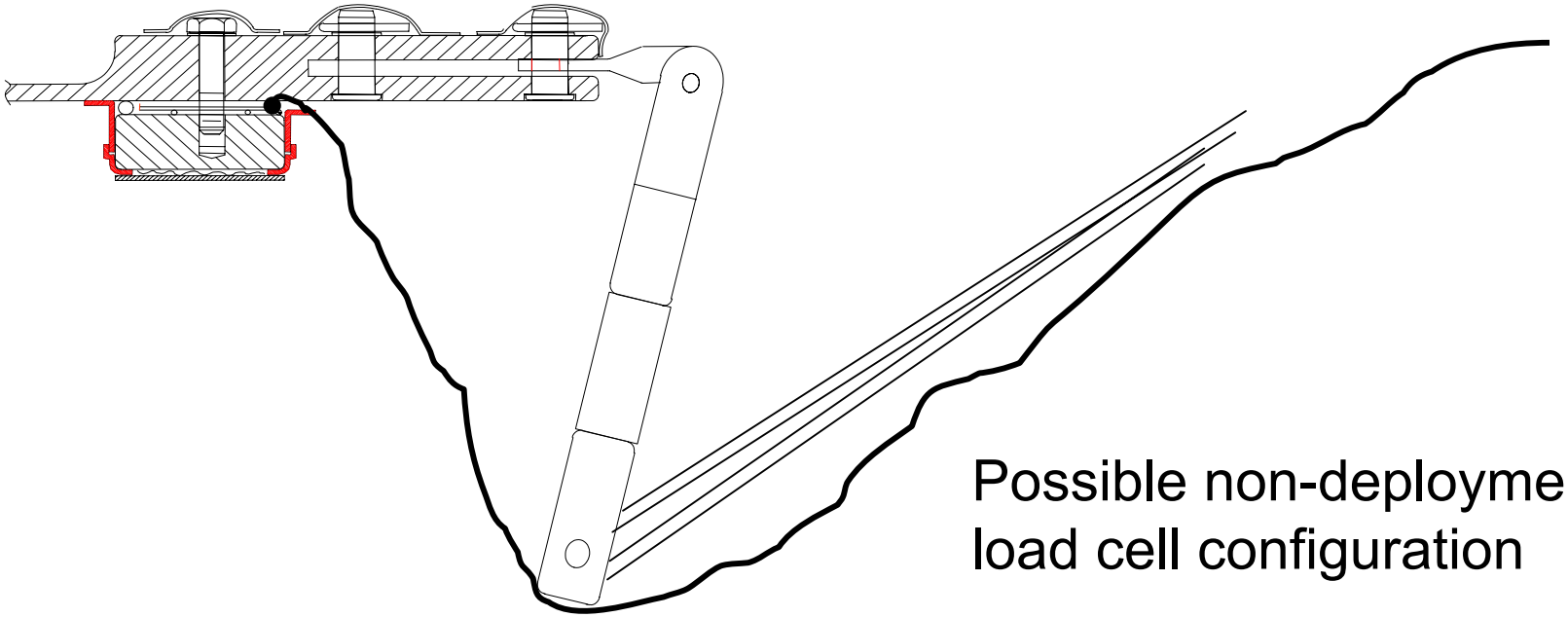
Load Cell Induced Damage

Load Cell Device

Load Cell Mounting Issue

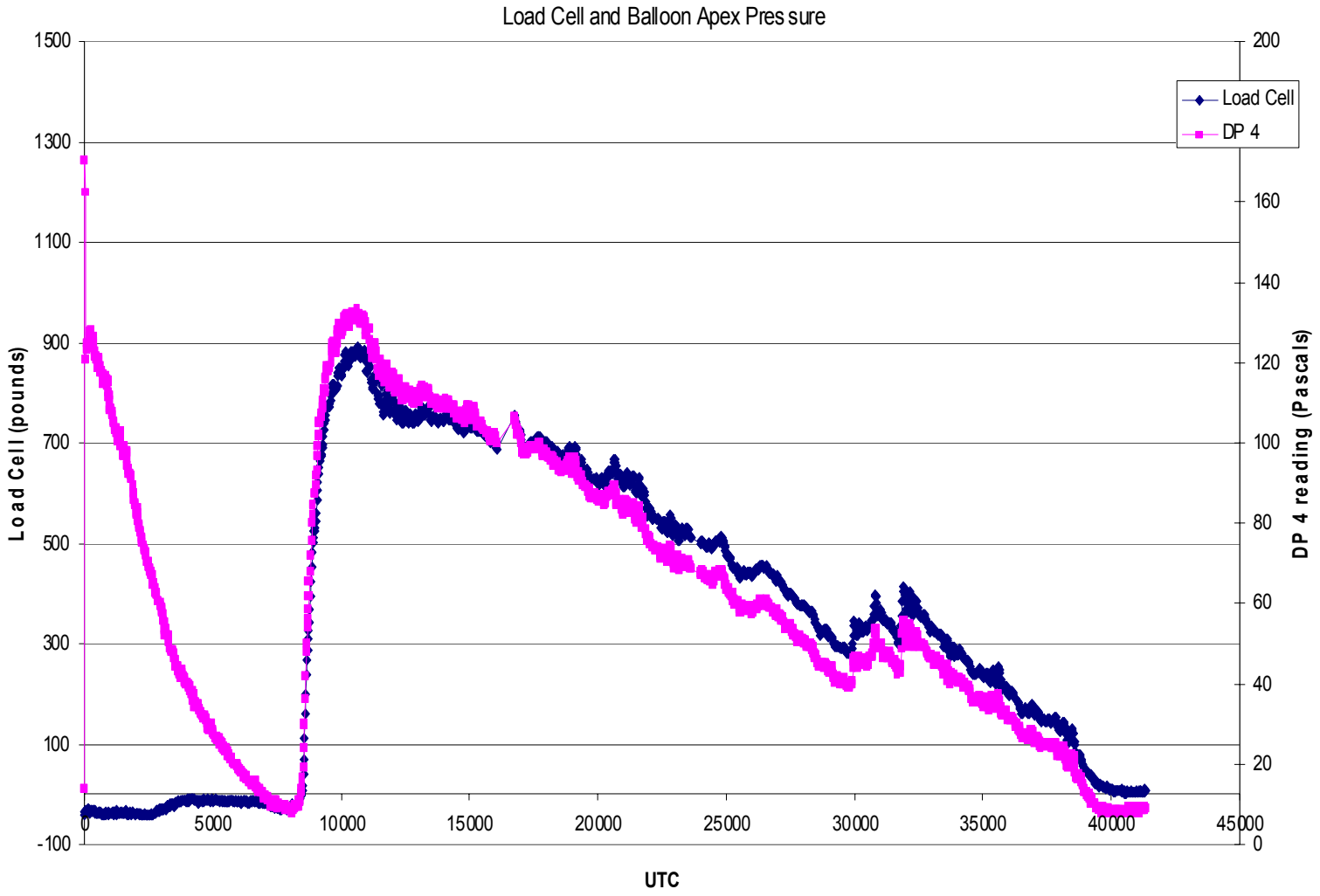


Nominal load cell mounting



Possible non-deployment load cell configuration

Load Cell Reading vs. Balloon DP



Interim Results/Recommendations

- ULDB fundamental design parameters did not include consideration of deployment (Ref 1)
- Flights 496 and 517 NT failed to deploy properly, eventually resulting on a mission failures
- UNTIL THE DEPLOYMENT PROBLEM IS SOLVED, ULDB WILL CANNOT BE TRUSTED FOR SCIENCE MISSION USAGE
  - The unanimous recommendation of the Flight 517NT Anomaly Review Board is to suspend all other ULDB activities and concentrate all available resources on solving the clefting problem
  - The Committee will submit an interim report to this effect including recommendations for a comprehensive program of modeling, laboratory and flight tests, directed at establishing a solid analytical basis for ULDB design and production
  - The most qualified individuals, regardless of institutional affiliation, should be asked to support the clefting problem resolution

Reference 1

- **"Test Flights of the NASA Ultra Long Duration Balloon", Henry Cathey Jr., New Mexico State University PSL, COSPAR 2002 Paper**
  - **"Deployment and Balloon Vehicle Design -** The improper deployment of the balloon was not foreseen as an issue. The balloon designer did make some revisions to the actual gore pattern from the successful 60,600 m3 to the 520,000 m3 balloons. This change actually introduced more material per gore in the hoop direction. This change ended up being the cause of the balloon to not form the desired design configuration. The realization that the pumpkin balloon can have potentially multiple stable configurations that are not the intended desired configuration presents a significant design issue. The approach to address this and the arrived solution are addressed by Schur in this conferences proceeding".

Backup Charts

Fish Bone Analysis Details (1)

1.0 - Gas				
	1.1 - Control Electronics			
D. Gregory	**State Diagram 6/20/03**	1.1.1 - UTP Valve Electronics		Post flight validation of system Verify data through independent/redundant mechanism Performance analysis
	Balloon Electrical Cabling - 3 Weeks After Balloon Delivery		1.1.1.1 - Driver-relay	Check verify bit on relay in TM Test driver relay?
			1.1.1.2 - Power-battery	Check battery voltage, etc.
			1.1.1.3 - Cmd rcvr	Check valve echo commands
			1.1.1.4 - Cmd decoder	Check valve echo commands
			1.1.1.5 - Limit microswitch	Check verify bit on relay in TM Inspect microswitch assembly
			1.1.1.6 - Harness	Verify preflight checks Review harness design for potential failure modes
			1.1.1.7 - Signal Conditioning	Check verify bit in TM Verify adjacent TM channels for over voltage condition
			1.1.1.8 - Encoder	Check verify bit in TM Verify adjacent TM channels for over voltage condition
		1.1.2 - CAP Valve Electronics		Post flight validation of system Verify data through independent/redundant mechanism Performance analysis
			1.1.2.1 - Driver-relay	Check verify bit on relay in TM Test driver relay?
			1.1.2.2 - Power-battery	Check battery voltage, etc.
			1.1.2.3 - Cmd rcvr	Check valve echo commands
			1.1.2.4 - Cmd decoder	Check valve echo commands
			1.1.2.5 - Limit microswitch	Check verify bit on relay in TM Inspect microswitch assembly
			1.1.2.6 - Harness	Verify preflight checks Review harness design for potential failure modes
			1.1.2.7 - Signal Conditioning	Check verify bit in TM Verify adjacent TM channels for over voltage condition
			1.1.2.8 - Encoder	Check verify bit in TM Verify adjacent TM channels for over voltage condition
			1.1.2.9 - Microcontroller	Check health/status

Fish Bone Analysis Details (2)

	1.2 - Valve Mechanical			
		1.2.1 - CAP Valve		Post flight validation of valve
			1.2.1.1 - Seal – Valve assembly and plate	Check photographic evidence from recovery
			1.2.1.2 - Microswitch	Check screw adjustment and actuation
			1.2.1.3 - Linear Gear	Visual inspection
			1.2.1.4 - Drive Shaft	Visual inspection
			1.2.1.5 - Drive Motor	Visual and functional inspection
			1.2.1.6 - Plate	Visual inspection
			1.2.1.7 - Detent	Visual and functional inspection
		1.2.2 - UTP Valve		Post flight validation of valve
			1.2.2.1 - Seal – Valve assembly and plate	Check photographic evidence from recovery
			1.2.2.2 - Microswitch	Check screw adjustment and actuation
			1.2.2.3 - Linear Gear	Visual inspection
			1.2.2.4 - Drive Shaft	Visual inspection
			1.2.2.5 - Drive Motor	Visual and functional inspection
			1.2.2.6 - Plate	Visual inspection
			1.2.2.7 - Detent	Visual and functional inspection

Fish Bone Analysis Details (3)

	1.3 - Fittings			
H. Cathey M. Smith	**3 Weeks After receipt of balloon**	1.3.1 - Shell to fittings		
			1.3.1.1 - Apex Fitting	Inspect shell attachment to fitting
			1.3.1.2 - Base Fitting	Inspect shell attachment to fitting

Fish Bone Analysis Details (4)

	1.4 - Balloon Production			
		1.4.1 - Materials		
			1.4.1.1 - Shell / Cap	Review production records
			1.4.1.2 - Sheath	Review production records
			1.4.1.3 - Backup tape	Review production records
			1.4.1.4 - Tendon	Review production records
			1.4.1.5 - Tacking Materials	Review production records
			1.4.1.6 - Repair tape (SSA-10)	Review production records
		1.4.2 - Accessories		
			1.4.2.1 - Destruct Device	Review production records and inspection
			1.4.2.2 - Apex Fitting	Review production records and inspection
			1.4.2.3 - Base Fitting	Review production records and inspection
			1.4.2.4 - Cable Harness	Review production records
			1.4.2.5 - Reefing Sleeve	Review production records and video of ascent
			1.4.2.6 - Red/Yellow wrap	Review production records Eye witness reports

Fish Bone Analysis Details (5)

M. Smith J. Rotter	**6/25/2003**	1.4.3 - Processes		
			1.4.3.1 - Materials Inspection - PLI	Review production records
			1.4.3.2 - Materials Testing	Review production records
			1.4.3.3 - Sealing Process / material layout / Inversion / inspection	Review production records
			1.4.3.4 - Tacking Process	Review production records
			1.4.3.5 - Refolding	Review production records
			1.4.3.6 - Reefing sleeve	Review production records
J. Rotter M. Smith	**6/25/2003**	1.4.4 - Damage		
			1.4.4.1 - Inversion	Review production records
			1.4.4.2 - Tacking Process	Review production records
			1.4.4.3 - Stacking	Review production records
			1.4.4.4 - Packaging	Review production records
			1.4.4.5 - Fitting installation	Review production records
			1.4.4.6 - Loading / Transfer	Review production records

Fish Bone Analysis Details (6)

	1.5 - Load Cell			Review performance of previous flights and inspect hardware
H. Cathey M. Smith	**3 Weeks After receipt of balloon**	1.5.1 - Installation		
			1.5.1.1 - Padding of cell	Visual inspection
			1.5.1.2 - Reinforcement under cell	Review production records Visual inspection
			1.5.1.3 - Swivel	Review load cell data in flight log Visual inspection
			1.5.1.4 - Tendon attachment	Visual inspection
			1.5.1.5 - Time history	Review records and eye witness reports
		1.5.2 - Deployment		
			1.5.2.1 - Improper deployment	Test off-design conditions Review flight data
			1.5.2.2 - Abrasion during flight phases	Visual inspection Testing to replicate damage – static and dynamic
		1.5.3 - Design		
			1.5.3.1 - Padding	Review design and test
			1.5.3.2 - Reinforcement under cell	Review design and test
			1.5.3.3 - Swivel	Review design and test
			1.5.3.4 - Tendon attachment	Review design and test

Fish Bone Analysis Details (7)

	1.6 - Balloon Design			
		1.6.1 - Stress		
D.A.F	**6/27/2003**		1.6.1.1 - Film	Check thickness minimums Verify data and test techniques
W. Schur	**6/20/2003**		1.6.1.2 - Strength thresholds	Review data and interpretation
D.A.F	**6/20/2003**		1.6.1.3 - Launch Stress Index	Recalculate and compare
D.A.F J. Rotter	**6/20/2003**		1.6.1.4 - Flight Stress Index	Recalculate and compare
E. Klein	**6/30/2003**		1.6.1.5 - Spool configuration	Development of Spool compressive loading test Compare photographic evidence from previous flights
V. Eyo	**6/30/2003**		1.6.1.6 - Vacuum at base	Analysis and development of test plan
V. Eyo	**6/30/2003**		1.6.1.7 - Initial pressure in balloon	Analysis and development of test plan
V. Eyo	**6/30/2003**		1.6.1.8 - Long term creep	Review float configuration with test results
V. Eyo	**6/30/2003**		1.6.1.9 - Tacking effect	Review loading over time with analysis/time
		1.6.2 - Design compliance		
D.A.F	**6/30/2003**		1.6.2.1 - Tacking	Review implementation with tack to design
M. Smith D.A.F.	**6/30/2003**		1.6.2.2 - Material distribution	Review implementation (as-built and launched) to design
Rand	**6/30/2003**		1.6.2.3 - Launch / flight process	TBD (Review dynamic effects on structure)
H. Cathey J. Rotter	**3 Weeks After receipt of balloon**	1.6.3 - Accessory Design		
			1.6.3.1 - Clamping of shell at end fittings	Inspection of post-flight hardware
			1.6.3.2 - Destruct device	Inspection of post-flight hardware
			1.6.3.3 - Tendon protective skirt	Inspection and review of installation drawings
			1.6.3.4 - Thermodynamics of fittings	Inspection, analysis, and verification of paint used

Fish Bone Analysis Details (8)

	1.7 - Flight Operations			
D. Gregory **J. Rotter**		1.7.1 - Handling		
D. Gregory	**6/20/2003**		1.7.1.1 - Field integration	Review of photo's and procedures
			1.7.1.2 - Balloon layout	Review eye-witness reports, procedures, video and photo's
			1.7.1.3 - Spool effects	Review eye-witness reports, procedures, video and photo's Analysis and test
			1.7.1.4 - Collar effects	Review eye-witness reports, procedures, video and photo's Test mock-up section
			1.7.1.5 - Base fitting	Review eye-witness reports, procedures, video and photo's Test mock-up
			1.7.1.6 - Apex on crush pads	Review eye-witness reports, procedures, video and photo's
		1.7.2 - Balloon Inflation		
			1.7.2.1 - Restraint during tow balloon inflation	Review eye-witness reports, procedures, video and photo's Testing
			1.7.2.2 - Release of tow balloon	Review eye-witness reports, procedures, video and photo's
			1.7.2.3 - Balloon deployment through spool	Review eye-witness reports, procedures, video and photo's Testing

Fish Bone Analysis Details (9)

J. Rotter	**6/30/2003**	1.7.3 - Launch		
			1.7.3.1 - Dynamics	Review eye-witness reports, procedures, video and photo's
			1.7.3.2 - Spool release	Review eye-witness reports, procedures, video and photo's
			1.7.3.3 - Collar release	Review eye-witness reports, procedures, video and photo's
		1.7.4 - Ascent		
			1.7.4.1 - Reefing sleeve	Review flight video
			1.7.4.2 - Loading of tack points	Testing
			1.7.4.3 - Expansion dynamics	Review flight video and met data
			1.7.4.4 - Internal destruct line fouling	Friction testing
			1.7.4.5 - Acts of God	TBD
			1.7.4.6 - Deployment	Review video and calculations / analysis Model tests
V. Eyo	**3 Weeks After receipt of balloon**	1.7.5 - Float		
			1.7.5.1 - Apex fitting thermo	Inspection of hardware
			1.7.5.2 - Film and sheath thermo	Verify optical properties
			1.7.5.3 - Mylar and white tape	Inspection of hardware

Fish Bone Analysis Details (10)

V. Eyo	**6/23/2003 2 weeks after receipt of balloon**		1.7.5.4 - Deployment	Review video and calculations / analysis of "super lobe" Develop Model test plan

Fish Bone Analysis Details (11)

2.0 - Deployment/ Clefting				
	2.1 - Design			
		2.1.1 - Macro shape (basic volume, shape)		
Eyo	**6/20/2003**		2.1.1.1 - Inputs	Review assumptions and design calculations
		2.1.2 - Gore design		
Eyo	**6/20/2003**		2.1.2.1 - Global Model	Constant bulge radius
Eyo			2.1.2.2 - Adjustment to global model	Review reasoning for all adjustments to global model and document for all ULDB's flown to date
DAF	**6/30/2003**		2.1.2.3 - Table Pattern	Review implementation of final design to table pattern.
Rand	**6/30/2003**		2.1.2.4 - Number of gore vs stability relationship	Review Calledine – prepare recommendations for follow-on actions
		2.1.3 - Tendon design		
Eyo, Rand	**6/30/2003**		2.1.3.1 - Foreshortening	Review design
Eyo, Rand	**6/30/2003**		2.1.3.2 - Tacking frequency	Review design

Fish Bone Analysis Details (12)

	2.2 - Fabrication			
DAF	**6/30/03**	2.2.1 - Table design		Review design and implementation of pattern to table, measure table pattern
DAF	**6/30/2003**	2.2.2 - Fabricated item		Measurement of ~ 20 gores on SN03 section
		2.2.3 - Folding		Review production records
		2.2.4 - Materials		
Rand	**6/30/2003**		2.2.4.1 - Film Friction	Testing (shear and peel)
Rand	**6/30/2003**		2.2.4.2 - Tape Friction	Testing
	2.3 - Operations			
		2.3.1 - Spool Deployment		Review 40H test inflation report
			2.3.1.1 - Folding techniques	Review all ULDB launch videos and folding techniques used
			2.3.1.2 - Cone Angle	Review photo's and video and measure cone angles during inflation
		2.3.2 - Collar		
			2.3.2.1 - Placement	Review calculation and actual placement
			2.3.2.2 - Size	Review
			2.3.2.3 - Release timing	Review and calculate speed
Gregory	**6/20/2003**	2.3.3 - Initial fitting release (bubble let-up)	2.3.3.1 - Material deployment near apex	Review photo's and video
Rand	**6/20/2003**	2.3.4 - Trapping / locking of gores	2.3.4.1 - during inflation or ascent	Review photo's and video and test
		2.3.5 - Launch Method	2.3.5.1 - Spool/horizontal	Develop a plan for static launch technique