National Aeronautics and Space Administration

Lessons from Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) Close Call

SAFETY and MISSION ASSURANCE DIRECTORATE

Code 300

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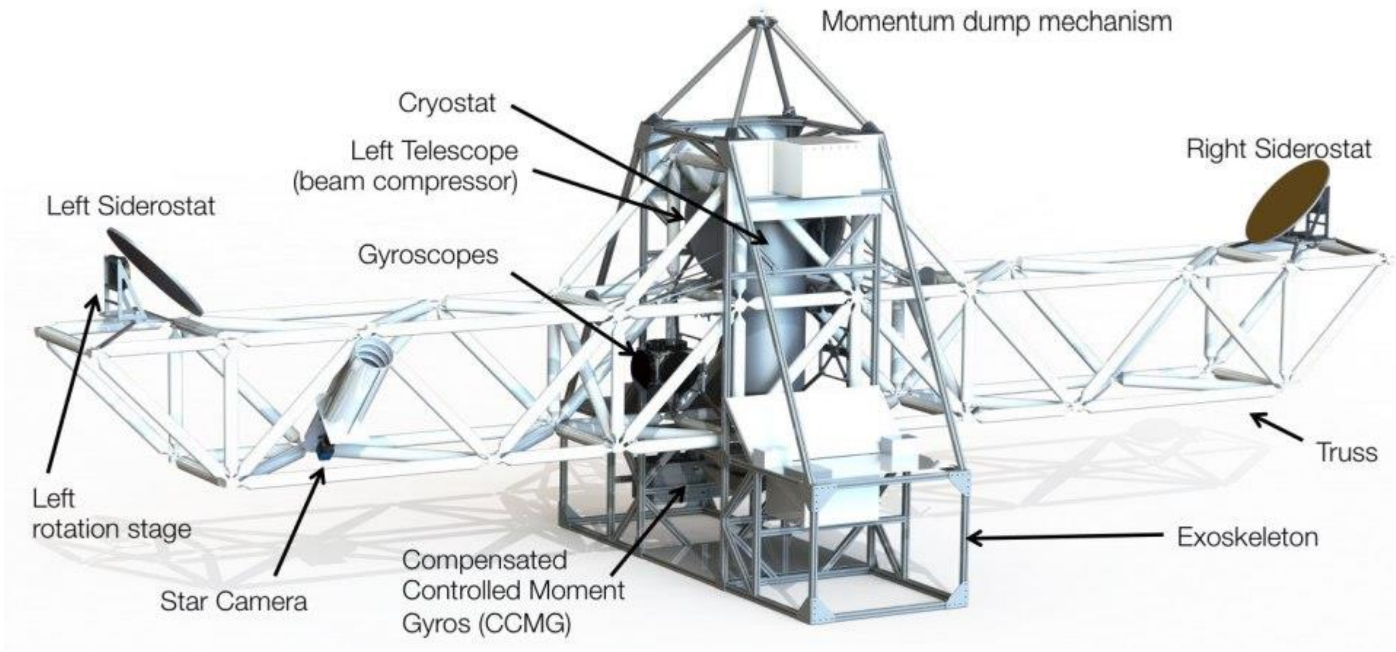
Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

(BETTII) will provide access to the cosmos similar to that of an orbiting observatory. BETTII will explore a region of the electromagnetic spectrum, the far-infrared (FIR), using a technology called interferometry. Astronomers will gain a sharper, more detailed view of star formation, galaxy evolution, and the formation of planetary systems around other stars.



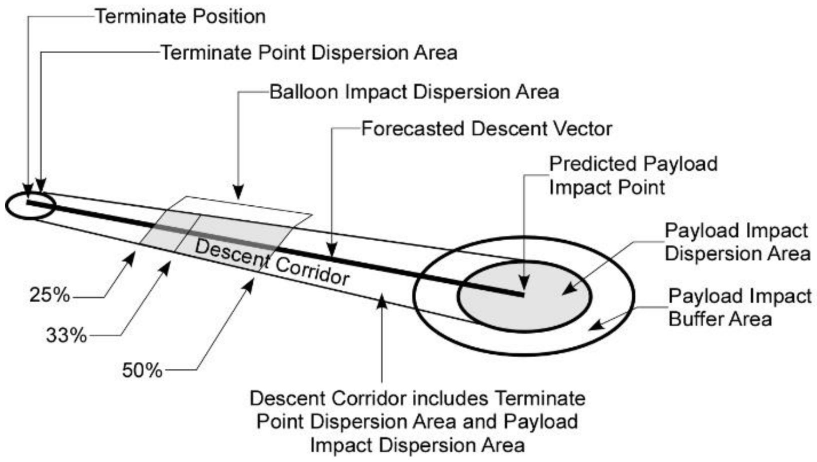
Funding awarded 2011, assembled in 2014, transported to Ft Sumner NM for August 2016 campaign but did not fly until May 2017 campaign from Palestine Texas.

7120.8 Research investigations are characterized by unpredictability of outcome, high risk, …..

Scientific Ballooning Launch & Assent

- Launch requires relatively quiescent atmospheric conditions i.e low wind,
- Launch activities require substantial ground support
  - Coordination large volumes of helium
  - Use of the launch crane
  - Balloon craft
  - Scientific payload
  - Associated personnel

Scientific Ballooning Termination and Retrieval

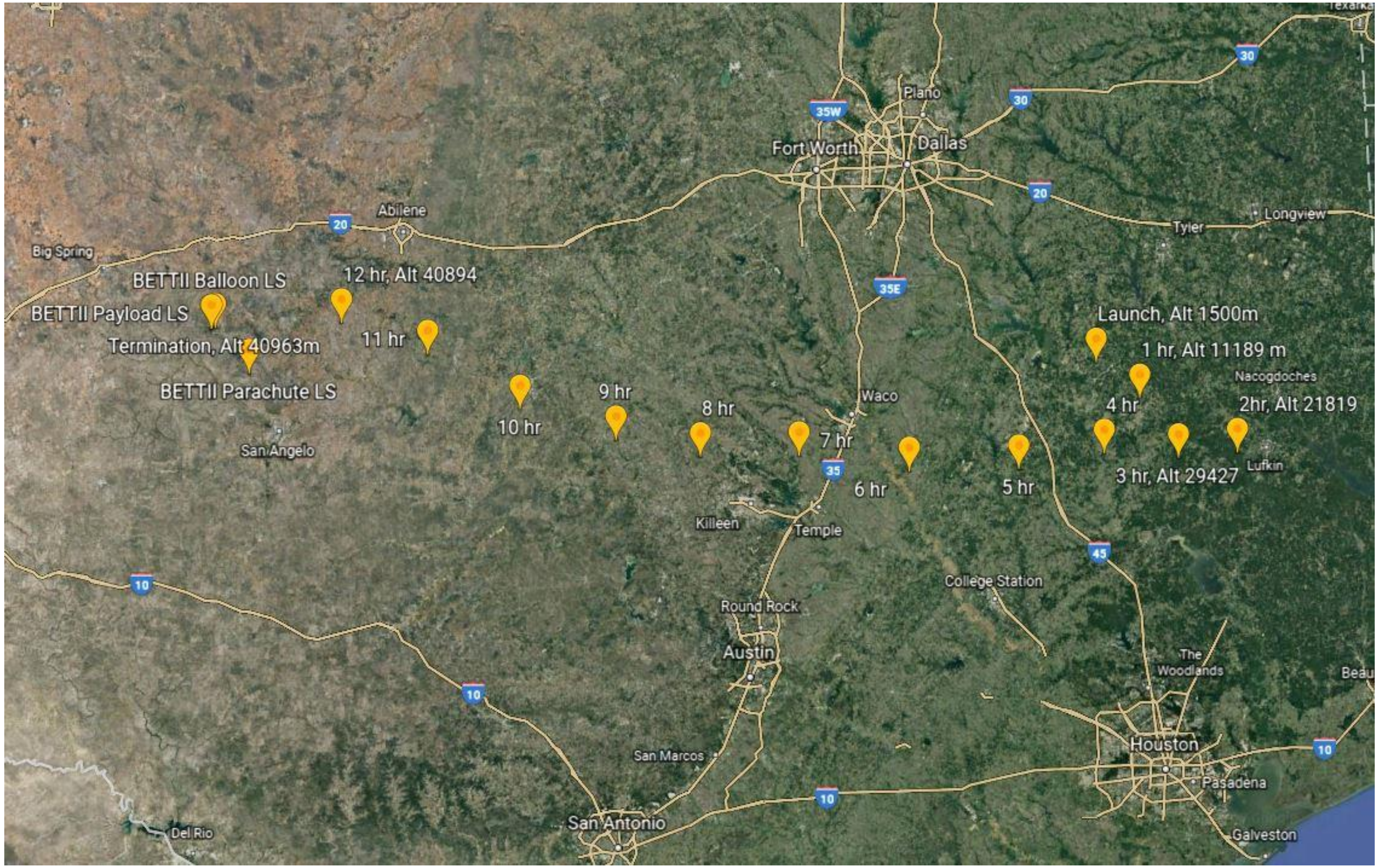


- Balloon and gondola are terminated at float altitude at location deemed appropriate wrt safety
- At termination, the gondola and parachute are separated from the balloon.
- The gondola falls for 4 to 6 seconds until parachute opening, at which time the gondola’s fall is slowed with a deceleration of approximately 2-g to 5-g.
- After termination chase planes are used to track descent
- The size of the Descent Corridor areas is determined by the Termination Point Category payload Imp[act 10 -15 nm
- Payload recovered using suitable vehicle; ,trucks, planes, helicopter

BETTII Launch

BETTII/Flight 1598P was launched the evening of June 8, 2017 (local time) from the Columbia Scientific Balloon Facility (CSBF), Palestine, TX. Palestine was selected for the BETTII flight due to the science requirement for night time observations while at float. This was the first launch of BETTII and was considered an engineering test flight. Nominal wind conditions existed at the time of launch.

BETTII Flight Path

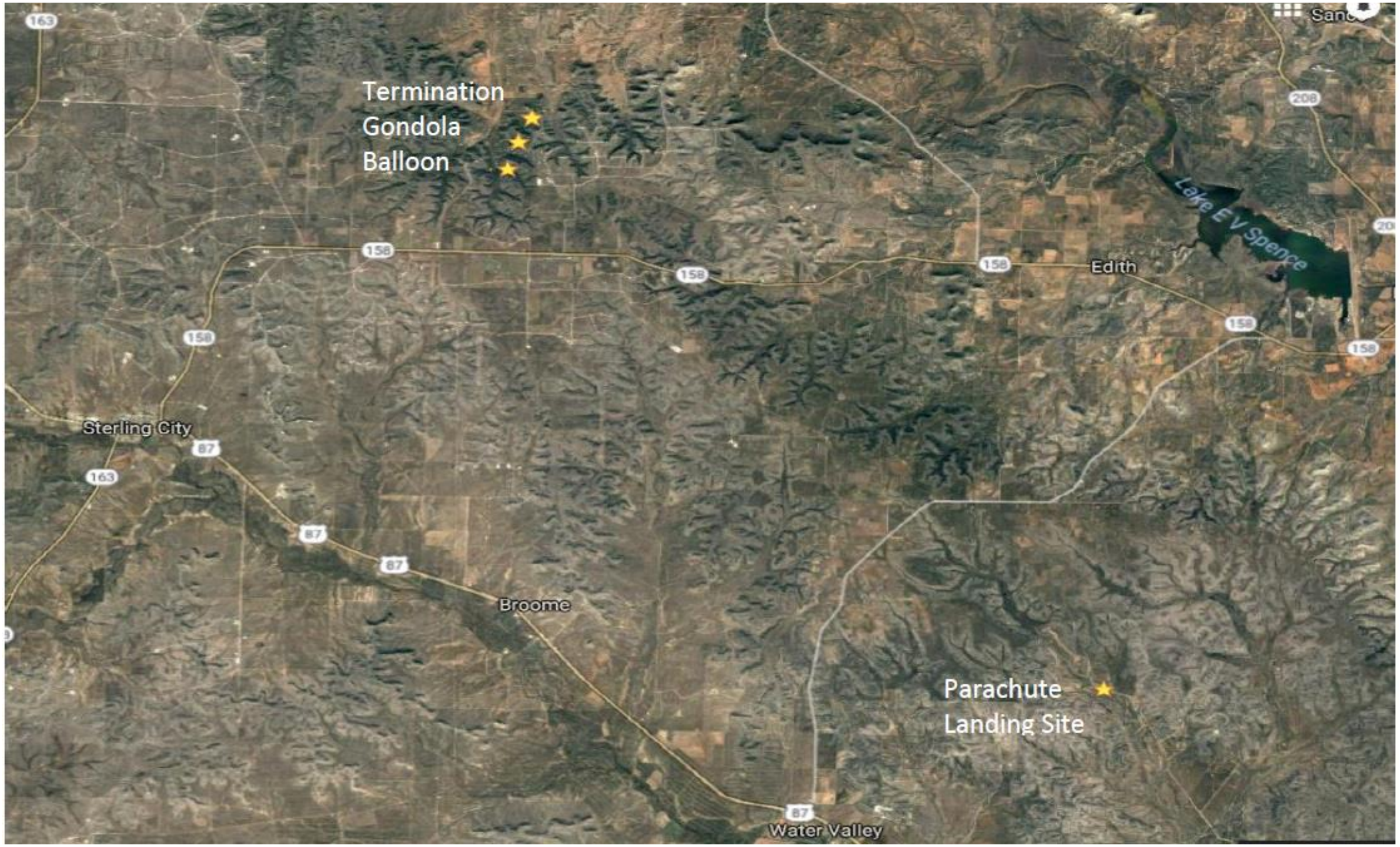


BETTII-Balloon Flight 1598P lasted 12 hours and tracked approximately 300 miles across Texas.

On the morning of June 9, at 7:35am Flight 1598P was sent the command to terminate. After termination, there was an immediate loss of telemetry from BETTII.

This was anomalous as the telemetry is typically received until parachute is below the horizon

BETTII Flight Termination



The parachute with the Universal Termination Package hardware was located on the afternoon of June 9, 2017, approximately 20 miles south of the termination positon. Landing some 120 minutes after termination.

The balloon landed approximately 1.5 miles south-southwest of the termination.

The BETTII payload was located approximately ¾ mile southwest of the termination site.

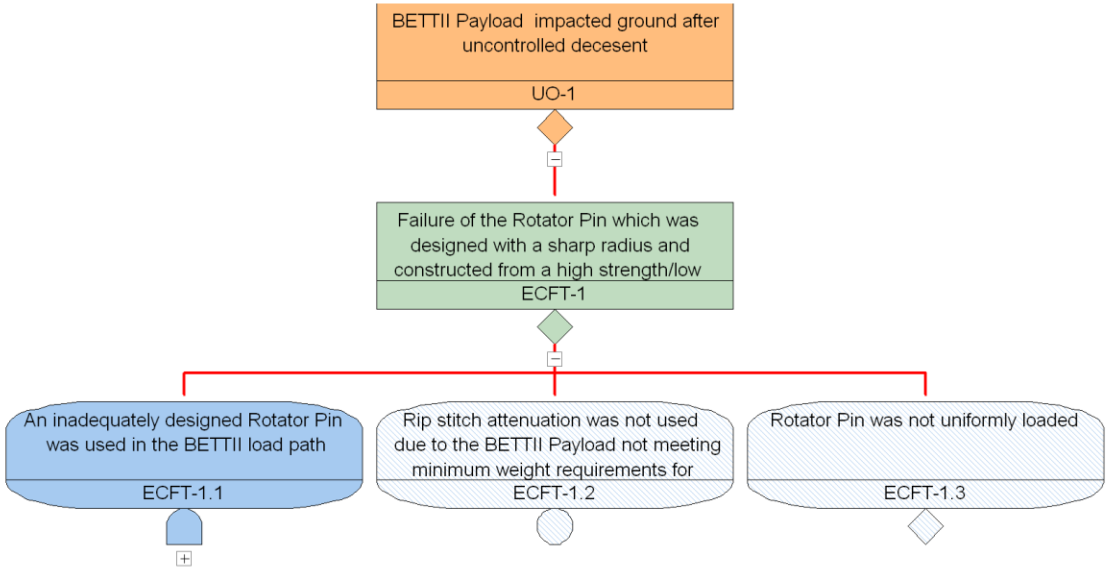
Due to the remote location the BETTII hardware had to be transported via helicopter.

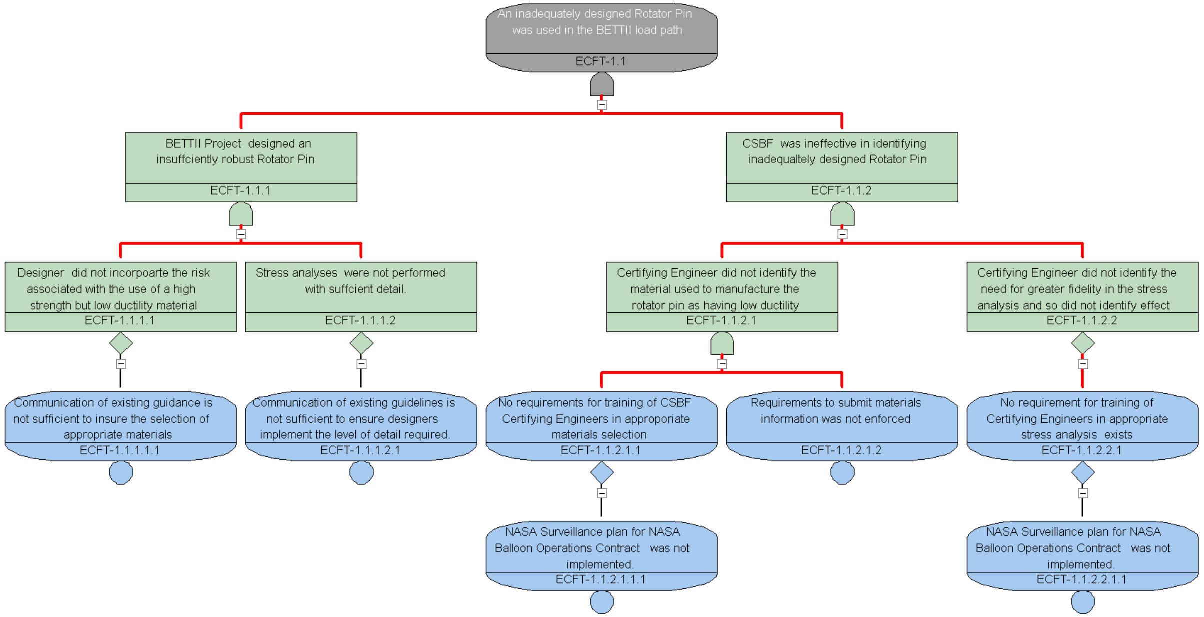
BETTII Gondola and Balloon Landing Site

BETTII Parachute Landing Site

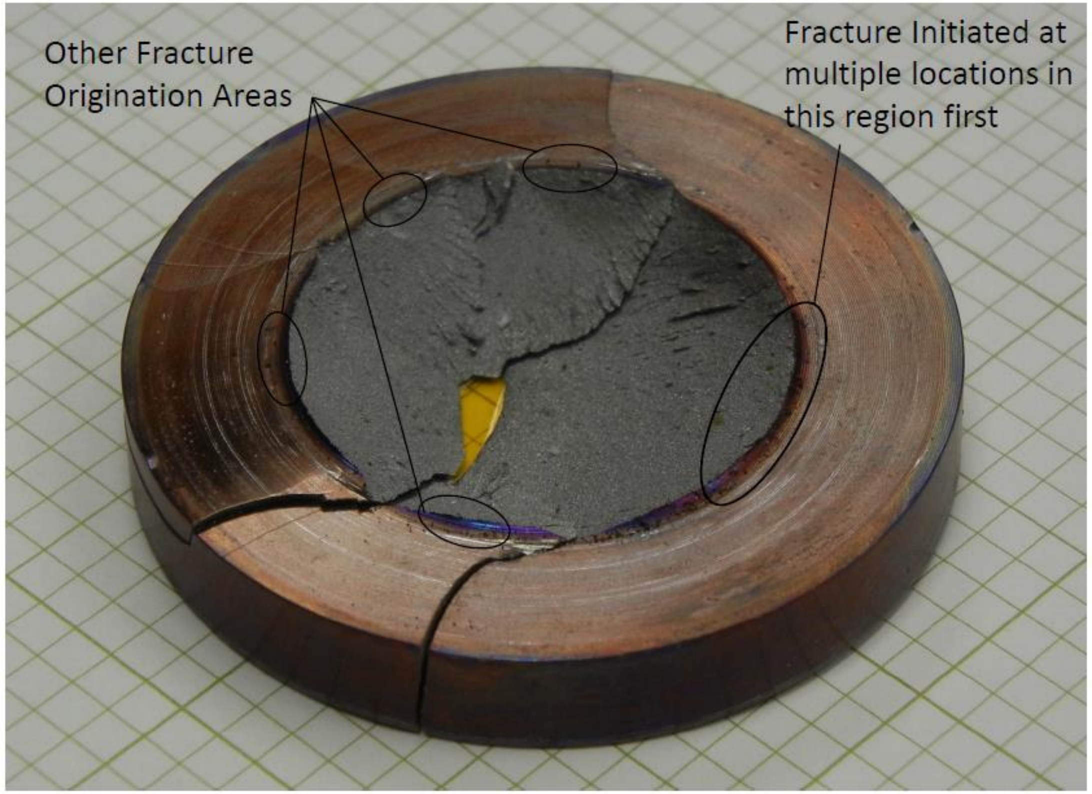
Parachute and associated cable with truck plate was located. The separation of the gondola from the parachute was identified as the fracture of the BETTII Rotator Pin.

Mishap Investigation Performed per NPR 8621.1





Proximate Cause



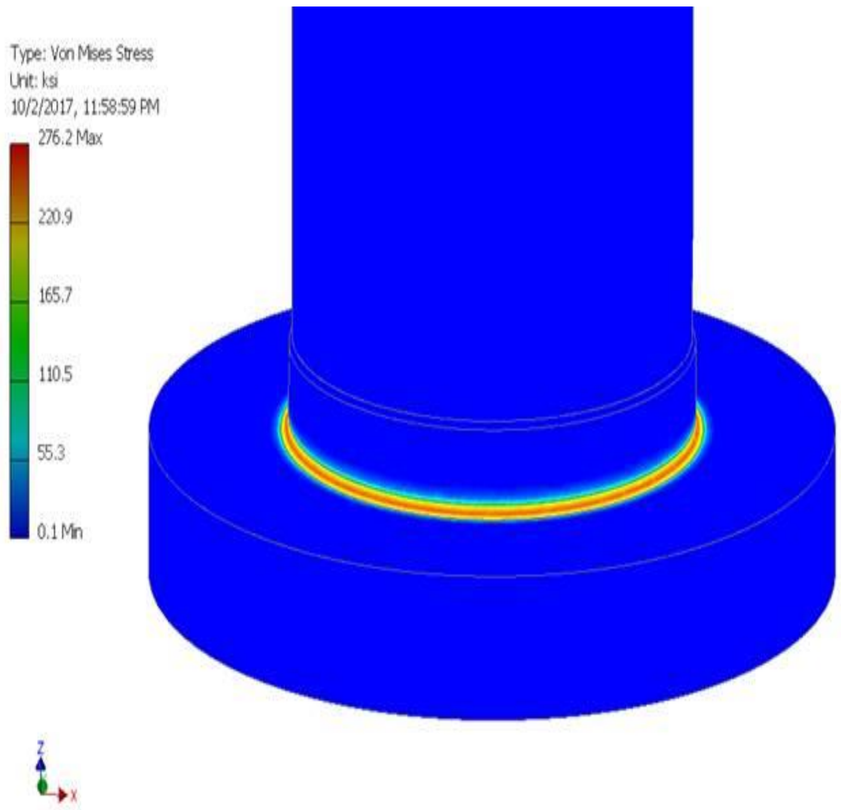
The rotator pin failed due to a single overload event.

•The fracture was primarily brittle fracture, with multiple fracture origins around the circumference at the flange-to-shaft interface.

•Loading on the flange at the time of fracture was uneven, producing a bending moment.

•Although there are indications of pre-fracture rubbing on the shaft, it does not appear to be a cause of fracture.

Proximate Cause



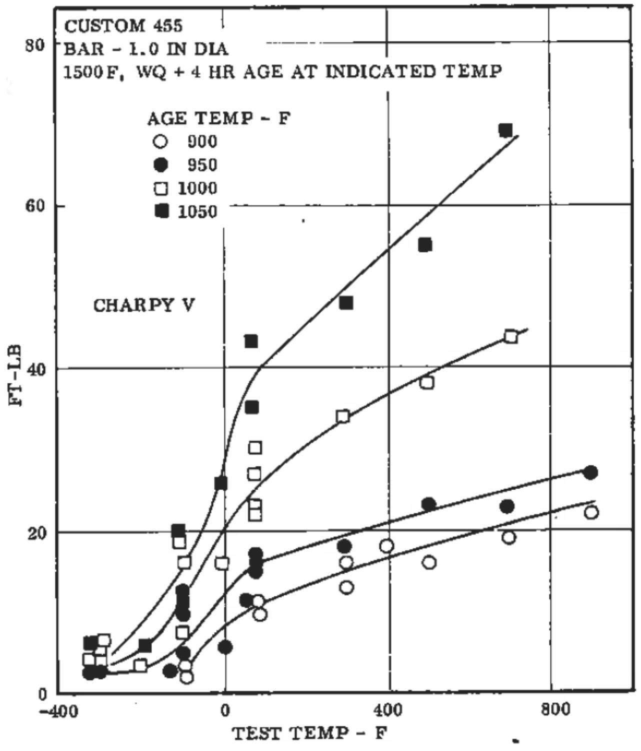


FIG. 3.0331 EFFECT OF TEST TEMPERATURE ON IMPACT STRENGTH OF BAR IN THE 900 - 1050F AGED CONDITION. (5)(12)(13)

- Failure of the Rotator Pin which was designed with a sharp radius and constructed from a high strength/low toughness material.
- FEA of Balloon Interface Pin. Maximum Von Mises stress calculated to be 276 ksi at a 7g loading. Custom 455-H900 which reports a yield strength of 1” bar as 245 ksi (UTS = 250ksi)

Balloon Gondola Design Requirements

GONDOLA DESIGN REQUIREMENTS FOR CERTIFICATION per *Structural Requirements and Recommendations for Balloon Gondola Design Page 19 OM-220-10-H Rev. A*

Suspension Systems

The ductility of all materials used for critical mechanical elements shall be considered in the analysis of the gondola structure. Specifically, the CSBF does not encourage the use of materials that are determined to be brittle or that are not recommended for use in shock loading applications. Close examination of all materials that have a percent elongation less than or equal to 10% at an ambient temperature of - 60°C shall be made to determine if the material is to be considered brittle.

If a material is determined to be brittle, the certification criteria listed in paragraphs 1, 3 and 4 above must be multiplied by a factor of 1.5. That is, the particular element that is fabricated using a brittle material must be able to sustain a 15-g vertical load, a 7.5-g load at 45 degrees, and a 7.5-g horizontal load without failure.

Balloon Flight 335N

4.0 Conclusions

4.1 Primary Cause Of Failure

The primary cause of the payload free fall to impact has been determined to be structural failure of the rotator upper shaft upon application of the parachute opening shock load. The shaft failed because of three design deficiencies; 1) the machining of a sharp corner at the shank/head juncture which created a stress concentration factor of approximately 3.5; 2) an excessively thin (.250in.) shaft head which permitted the head to bend w/r to the shank due to the moment produced by the circumferential bearing reaction load; and 3) selection of a material (17-4H900) which exhibits brittle behavior at the low temperature (-50 deg.C) prevailing at the time of termination. The failure load is estimated to have been axial at a level of 19831 lb., or slightly under 6 g. There may have been lateral loading of the shaft at the time of failure, but the only evidence to support this is the brinelled shaft surface, a condition which could also have occurred at another time, eg., the launch phase. The preponderance of evidence supports shaft failure due to axial loading only.

Flight 335N Failure Investigation Report
24 July 1992

Flight 335N was launched from Alice Springs Australia, June 1 1991. Attained a float level of 125,000 feet for 12 hours and broke free of the parachute at termination.

Investigation found Primary cause was: sharp corner and brittle material

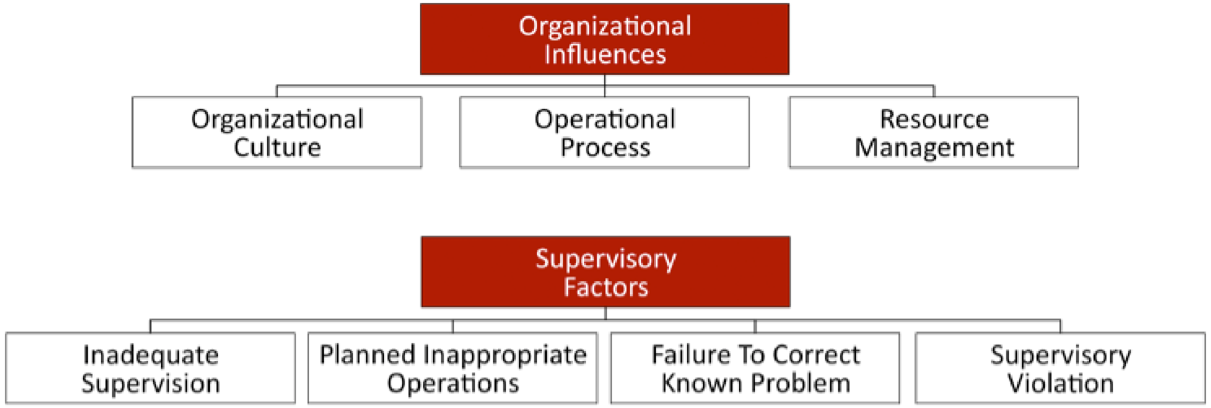
Intermediate Causes

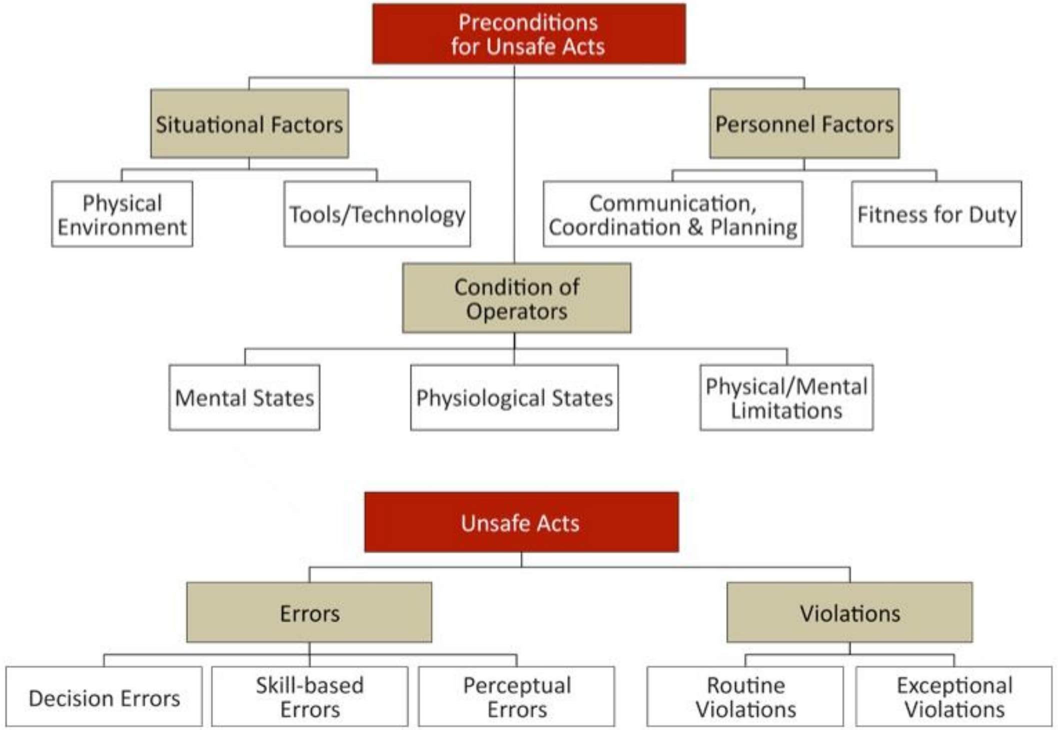
- Inadequate Rotator Pin design:
  - Insufficiently robust Rotator Pin
  - Stress analyses were not performed with sufficient detail.
  - Risk associated with the use of a high strength but low ductility material not assessed
- Certification review was ineffective in identifying inadequately designed Rotator Pin
  - Use of low ductility material was not identified
  - Need for greater fidelity in the stress analysis
- Inadequate training
  - No requirements for training of Certifying Engineers in appropriate materials selection
  - No requirement for training of Certifying Engineers in appropriate stress analysis

Root Causes

- Inadequate communication to ensure designers implement the level of detail required
- Communication of existing guidance is not sufficient to insure the selection of appropriate materials
- Requirements to submit materials information were not enforced
- The existence of appropriate training was not verified

Human Factors Analysis





Human Factors Analysis

Definition	Finding
ORGANIZATIONAL INFLUENCES ***Resource Management –*** Support provided by senior leadership to accomplish the objectives of the organization, including the allocation of human, equipment/facility, and monetary resources.	***Resource Management –*** Allocate funding or direction to insure design is peer reviewed or that an early interface occurs.
SUPERVISORY FACTORS ***Inadequate Supervision –*** Oversight and management of personnel and resources, including training, professional guidance, and operation leadership.	***Inadequate Supervision*** – Adequate training of Certifying Engineer was not insured. Sufficient expertise of design engineer by PI was not ensured

Human Factors Analysis

Definition

PRECONDITIONS FOR UNSAFE ACTS

Situational Factors-*Task* – Refers to the nature of the activities performed by individuals and teams including such things as the complexity, criticality, and consistency of assigned work.

Personnel Factors- *Communication* – The sharing of information among team members including providing/requesting information and the failure to provide two-way (positive confirmation) communication.

Personnel Factors- *Coordination* – This category describes the interrelationship among team members including such things as planning, monitoring, and providing back-up where necessary.

Finding

Situational Factors-*Task* – Neither the Certifying Engineer nor the Design Engineer was fully cognizant of the criticality of the their respective tasks.

Personnel Factors- *Communication* – No communication between the Certifying organization and the design organization.

Personnel Factors- *Coordination* – Process for insuring that design requirements were met were not coordinate between the launch facility and payload personnel

Human Factors Analysis

Definition

UNSAFE ACTS

Errors-***Decision Errors* –** These "thinking" errors represent conscious, goal-intended behavior that proceeds as intended, yet the plan proves inadequate or inappropriate for the situation. These errors typically result from a lack of information, knowledge or experience.

Violations- ***Routine Violations* –** Often referred to as "bending the rules," this type of violation tends to be habitual by nature, engaged in by others, and is often enabled by a system of supervision and management that tolerates such departures from the rules.

Finding

Errors-***Decision Errors* –** Certifying Engineer was not well trained in the full range of knowledge required to insure complete adherence to requirements: materials, structural analysis, impact loading

Violations- ***Routine Violations* –** The PI did not submit information for review by Certifying Engineer until just prior to launch during the launch campaign.

Materials information was not submitted.

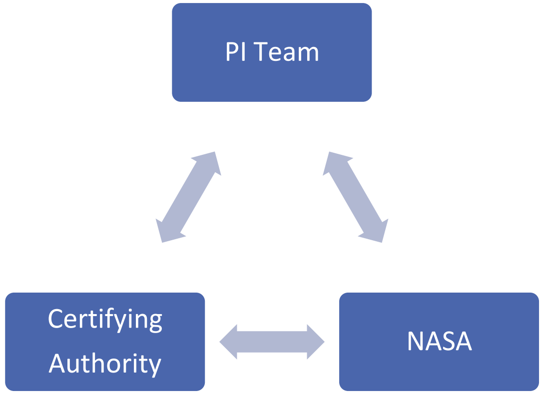
Missed Opportunities

BETTII package was filed between 2016 and 2017 campaigns.

The certifying package was not reviewed between the 2016 Ft Sumner and 2017 Palestine Campaigns

Flight Launch Leads noted small size of Rotator Pin but assumed was okay as it had been Certified

Lessons



- Balloon missions have limited funding so it is understandable that there will be limited opportunity for technical reviews.   It is more important with these missions that there is early communication to insure that requirements are understood.

- Identify the areas of highest risk and allocate resources appropriately.
  - Leverage available technical assets
  - Initiate Table Top Reviews

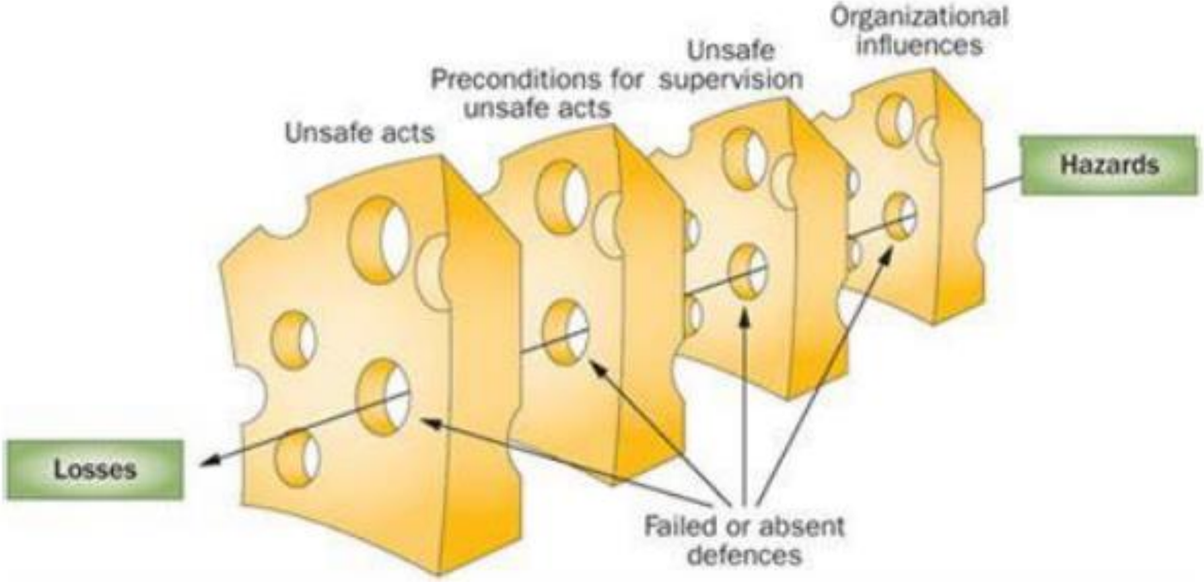
- Insure there are appropriate levels of training, experience and expertise for the assigned tasks.
  - Generate checklists to insure each element is addressed
  - Understand origins of requirements such as the previous rotor pin failure

- Identify situations where there is limited experience on all sides of design

- Watch for normalization of deviation, especially where it impacts the adherence to requirements

Lessons

- Perform ad hoc human factors analysis to look for conditions that create casual factors that could lead to a mishap
    - Human Factors at NASA on the OSMA website
        - NASAHFACS
        - Investigators checklist



Questions