Rocket Failure Analysis

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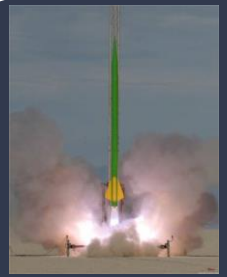


Overview

Outline

1. Process Discussion
    a. Data Collection Examples
    b. Hypothesis Generation Process
    c. Hypothesis Analysis/Assessment
    d. Hypothesis Evaluation & Mitigation
2. Examples
3. Discussion

Failure Analysis Process

Data Collection

- Visual Flight Observations
- Landing Observations
- Sensor Data

Operational Failure Hypothesis Generation

Hypothesis Analysis/Assessment

- Evaluate each hypothesis relative to data
- Identify inadequate data areas and address
- Iterate

Hypothesis Evaluation & Mitigation

- Root Cause Identification
- Mitigation Solution Development
- Implementation Assessment
- Test

Data Collection

Data Sources

1. Imagery
    a. Visual Observations (Flight, Post Flight, Debris Field)
    b. Video
    c. Pictures
2. Audio
    a. Audio Observations
    b. Video Data
3. Tactile (post flight)
    a. Touch/Feel of the physical components
4. Sensor Data
    a. XYZ: Altitude, Velocity, Acceleration, Rotational
    b. GPS
    c. Temperature
    d. User Sensors
    e. Filtered vs Raw Data
5. Other Post Flight Data
    a. X-Ray, CT Scans, ...
    b. Physical Measurements/Machining
    c. Stress/Strain, temperature, …

Hypothesis Generation

Brainstorming (no evaluation - all ideas accepted)

1. Define the Problem (What, Where, and When)
2. Question all Facts & Challenge Assumptions
3. Defer Judgement
4. Be Flexible
5. Think out of the Box - Anticipate multiple causality
6. Listen and Question

There are other techniques/approaches but this one is easily implemented in small groups. Generate as many hypothesis as possible.

Hypothesis Analysis / Assessment

Hypothesis Validation

There is no such thing as a proven hypothesis!

1. Verify all facts!
2. Identify and eliminate all assumptions!
3. Assess Hypothesis relative to validated facts
4. Accept hypothesis only if its assertions are established beyond a reasonable doubt.
    a. If there are not enough facts to support or eliminate a hypothesis go back and find any supporting or refuting verifiable data, if possible.
5. Apply Occam’s Razor (Keep It Simple - KIS) to eliminate complex hypotheses as needed.

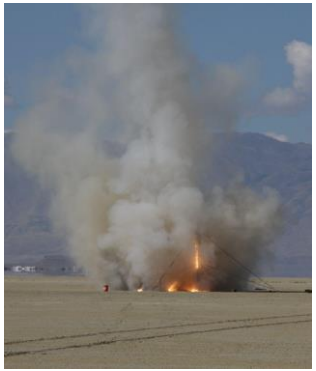
Hypothesis Evaluation & Mitigation

1. Assess hypothesis(es) and identify root cause(s) if not already known.
2. Clearly, specify the operational process(es) that resulted in the failure.
3. Use problem solving techniques identify mitigating solutions (brainstorming discussed previously).
4. Identify and evaluate potential flight scenarios and assess the performance of each mitigating solution.
5. Select the best solution(s) and assess implementation viability and cost.
6. Select the most favorable solution based on your performance, cost, and production criteria and test it to determine viability (ground test, demonstration flight, etc).
7. Implement in full scale design or in iterative larger designs based on scalability.

Hagensick Easy (but expensive) Example







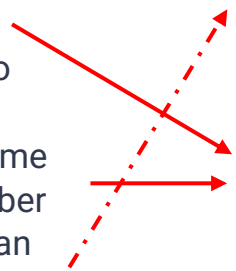
Hypothesis Generation

1. **Motor Overpressurization**
2. **Forward Closure Failure**
3. **Ejection Charge Misfire**
4. **???**

Hypothesis Analysis & Assessment

Facts:

1. Upper airframe & nose cone ejected vertically over 100 ft
2. Motor had ignited and pressurized prior to incident
3. Forward closure imbedded in upper airframe and forced 6 bolts through 6” of carbon fiber
4. No motor components damaged other than forward closure
5. Propellant characterizations and subscale motor tests demonstrate stable motor burn
6. Subscale motor tests successful



Hypothesis Assessment:

1. Motor Overpressurization - **Possible**
2. Forward Closure Failure - **Probable (KIS)**
3. Ejection Charge Misfire - **Reject**

Hypothesis Evaluation & Mitigation

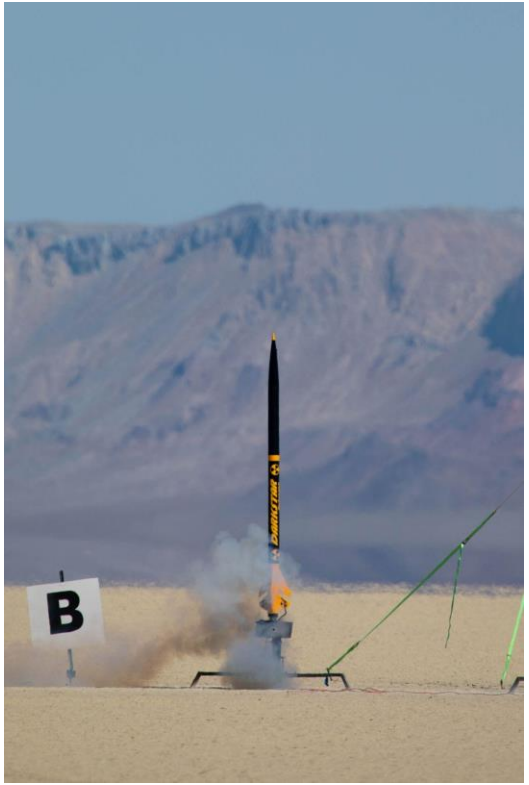
Root Cause:

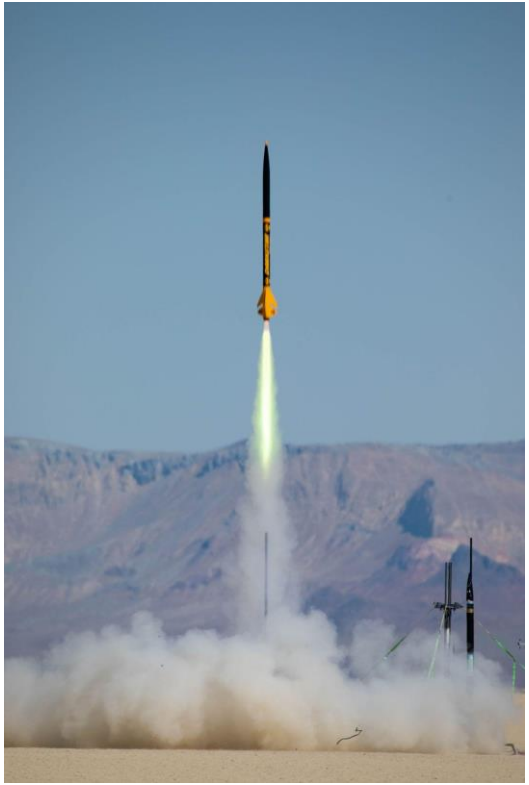
1. Forward closure released unexpectedly
    a. Due to Overpressure or
    b. Ineffective retention
2. Redesign and recharacterize propellant

Mitigation:

1. Redesign forward closure retention
    a. Epoxy and Bolt
2. Redesign case and forward closure retention
    a. Aluminum Case
    b. Bolt, Snap Ring, or Threaded

Kevin Gapstur’s Darkstar





Darkstar Ascent

Darkstar Characteristics:

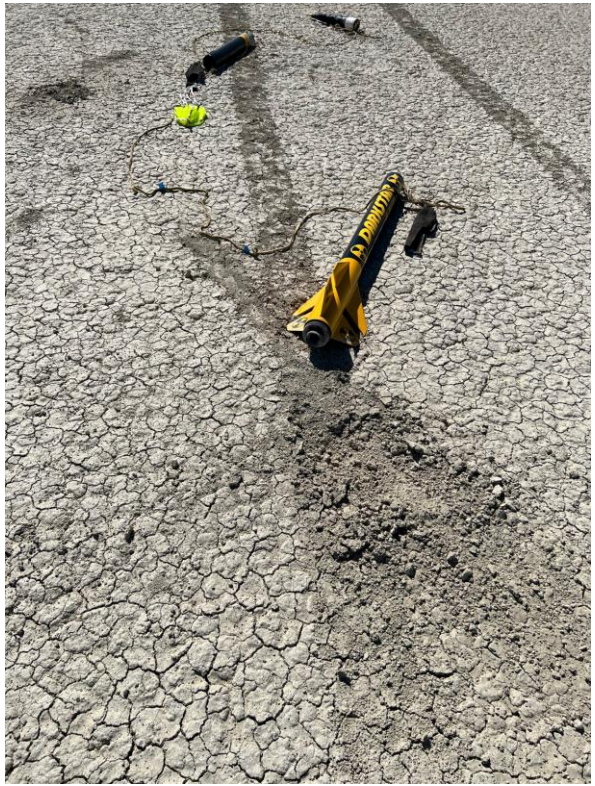
- 4 inch Diameter Rocket
- 75mm CTI M1545 - Green
- Pad Weight - 35 lbs
- Dual Deploy Recovery - Main at 1000ft

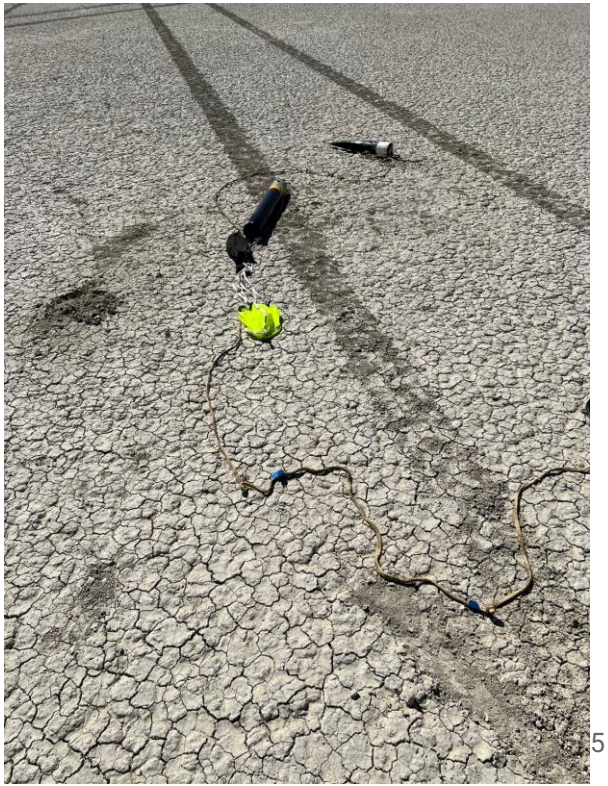
Ascent:

- Good communications with AIM Xtra and good satellite lock
- Motor was a little slow to start
- After liftoff achieved a very straight normal looking flight
- Quickly moved out of visual tracking range
- GPS provided landing Location

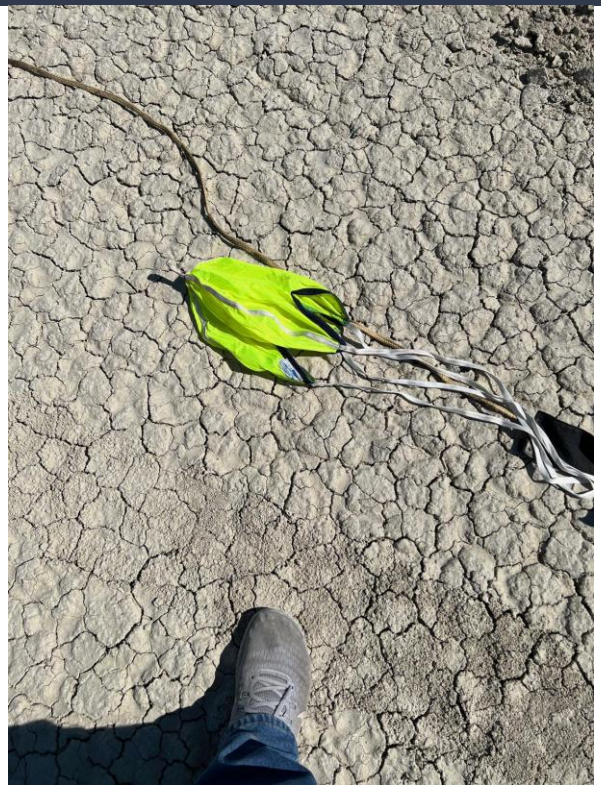
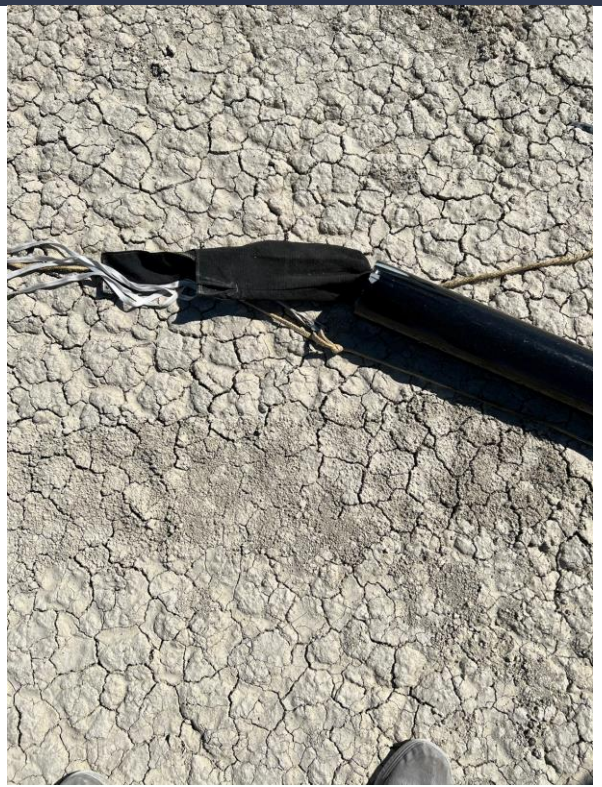
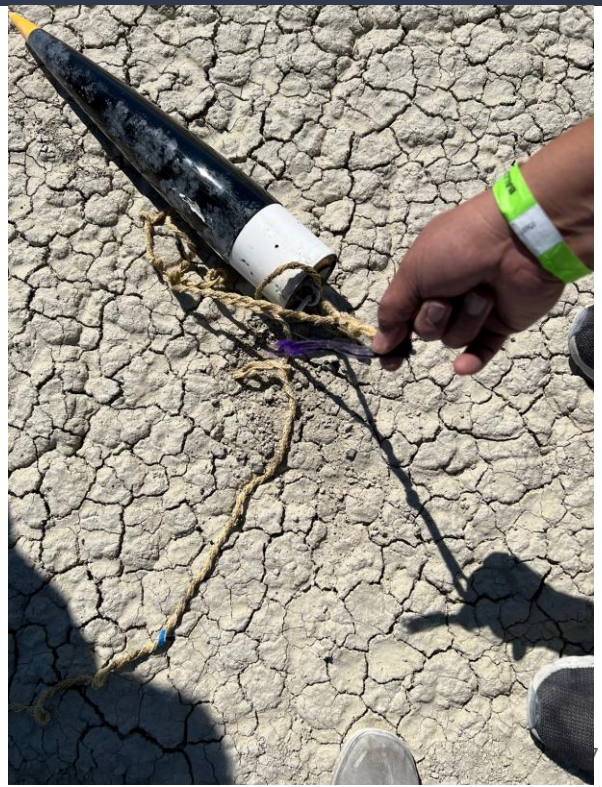
Darkstar Recovery

- Rocket found at location indicated by GPS
- Upon approaching the rocket it seemed normal
- Realize there was considerable damage to the rocket
- Struck the ground faster than expected
- Shock cords tangled
- Drouge parachute was out
- Main parachute was missing
- Fin damage
- Airframe damage - paint flaking
- Considerable nose cone damage







Darkstar Post Mortem

- AIM Xtra Damaged during the flight
  - Buzzer knocked loose
- Rail Button Damage
  - Signs of impact evident
- Motor Case Damage
  - Dent in aluminum casing



Hypothesis Generation

1. **Damage caused by Ground Strike**

2. **Damage caused by Component Collision in the air**

Hypothesis Analysis & Assessment

Facts:

1. Nose cone damage
2. Air Frame damage
3. Dent in aluminum motor case from rail button
4. Primary charge for the main chute not fired
5. Both drouge charges fired
6. Tangled shock cords
7. Missing main chute

Hypothesis Assessment:

1. Ground Strike
2. Component Collision




Questions / Comments