The Range Safety Debris Catalog Analysis in Preparation for the Pad Abort One Flight Test

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Constellation, Orion Overview

- Space Shuttle set to retire in the near future
- Constellation to succeed the Space Shuttle Program
- Orion Program consists of crewed portion of Constellation
Abort Flight Test, PA-1 Overview

- Abort Flight Test (AFT) Program dedicated to flight testing the Launch Abort System (LAS)
- LAS provides the crew with an egress system in the event of an emergency
- AFT includes a series of flight tests (pad and ascent) that Orion will leverage in developing the LAS
- Pad Abort One (PA-1) is the first flight test scheduled for early 2010, at White Sands Missile Range (WSMR), New Mexico
Debris Catalog Analysis

• With each flight test a Range Safety Data Package is assembled to understand the potential consequences of various failure scenarios
• Debris catalog analysis considers an overpressure failure of the Abort Motor and the resulting debris field created
  1. Characterize debris fragments generated by failure: weight, shape, and area
  2. Compute fragment ballistic coefficients
  3. Compute fragment ejection velocities
Fragment Distribution

- Propellant only distribution – motor case fragments considered negligible due to composite material
- Statistical model is applied to characterize AM fragments created in overpressure failure
- Previous investigations of solid rocket launch vehicle failures reveal consistent trends in fragment distribution
- Log-normal Distribution can be used to represent fragment distribution

![Graph showing Normal and Log-normal distributions](image)
Fragment Distribution

- Distribution model applied at four points, burn stages, along the PA-1 trajectory
- Burn stages correspond to amount of propellant burned at time of destruct:
  - 1: 0 % Burned (on the pad)
  - 2: 25% Burned
  - 3: 50 % Burned
  - 4: 75 % Burned

![Graph showing fragment distribution with different burn stages]
Ballistic Coefficient Computation

• Function of mass, area, and drag coefficient:

\[ \beta = \frac{m}{c_d A} \]

• Lower drag coefficients and higher mass to area ratios yield higher ballistic coefficients
• Higher ballistic coefficient items travel farther downrange
• Mass and area of fragment obtained during catalog distribution determination
• Drag coefficient taken from accepted aerodynamic data
Ejection Velocity Model

• Energy transfer approach
  – Potential energy from overpressure is converted into fragment kinetic energy
  – Pressure wave results, distribution of force is applied to fragments
  – Fragments attain an ejection velocity within a few microseconds

• Assume that case debonds from propellant creating a pressurized control volume

*Not to scale
Velocity Model Energy Balance

• Three control volumes:
  – motor chamber
  – propellant-case gap
  – atmosphere

• For each control volume:

\[ \dot{E}_i = \dot{E}_{i, \text{flowin}} - \dot{E}_{i, \text{flowout}} - \dot{W}_{\text{fragment}} \]

• Assume that energy can only flow out of the chamber and into the atmosphere:

\[ \dot{E}_{1, \text{flowin}} = 0 \]
\[ \dot{E}_{3, \text{flowout}} = 0 \]
Project Orion Abort Flight Test

**Final Ejection Velocity**

- Pressure of each control volume can be calculated from corresponding energy states
- Force applied to fragment is obtained from pressure distribution
- Acceleration and velocity are derived from force
- Simulation is propagated until pressures reach equilibrium and velocity asymptotes
Results

• Key behavior is inverse relationship between fragment size and fragment ejection velocity
• As fragments become more massive, force is applied on a smaller area per unit mass
• This behavior accounts for two trends:
  – Decrease in velocity with increasing weight class
  – Increase in velocity with increasing burn stage

<table>
<thead>
<tr>
<th>Burn Stage</th>
<th>Smallest Fragment</th>
<th>Largest Fragment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mass (lbm)</td>
<td>Velocity (ft/s)</td>
</tr>
<tr>
<td>0%</td>
<td>0.43</td>
<td>690</td>
</tr>
<tr>
<td>25%</td>
<td>0.41</td>
<td>730</td>
</tr>
<tr>
<td>50%</td>
<td>0.31</td>
<td>790</td>
</tr>
<tr>
<td>75%</td>
<td>0.29</td>
<td>860</td>
</tr>
</tbody>
</table>
Results

- Minimum and maximum velocities converge towards later burn stages
- Converging behavior reflects reduction in propellant remaining at progressive burn stages
Assumptions, Suggested Future Work

• Assumptions
  – Applicability of statistical distribution model towards PA-1 Abort Motor
  – Effect of composite case on distribution model and velocity model

• Future Work
  – More robust distribution discretization method
  – Complete analysis for future AFT missions
Questions?
References

AM Propellant Grain Geometry

True grain geometry

AM case
AM propellant

AM grain cavity

Idealized grain geometry

Web thickness

*Not to scale
Fragment Class Clustering

Group Distribution

Class Distribution