Pyrotechnically Actuated Gas Generator Utilizing Aqueous Methanol

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LDSD Ballute Overview

- Ram-air inflated isotensoid ballute is used to extract the parachute from the SFDT vehicle.

- Ballute Key Stats
  - 4.4 m diameter, 28.1 m³ volume
  - Nominal deployment altitude 50 km
  - Deployment speed up to Mach 3

- Goodyear Aerospace Corporation (GAC) developed similar ballutes in the 1960’s.
  - Ballutes pre-inflated via a device that dispersed methanol, which rapidly evaporated inside the ballute at ambient conditions.
  - A 5.5 m ballute deployed at Mach 3.15 failed to inflate fast enough and was destroyed.
    - Only documented deployment of ballute without pre-inflation device
    - Results drove requirement for pre-inflation device on SFDT.
Design Requirements

- Only two formal requirements levied on Inflation Aid (IA):
  - The IA shall supply at least 50% of the expected ballute internal pressure in approximately 0.4 seconds with a 95% likelihood.
  - The IA must not degrade the aerodynamic performance of the ballute and must not preclude the use of the ram-air inlets for inflation should the IA malfunction in flight.
Gas Generation

- Several methods for gas generation were explored:
  - Pyrotechnic propellant
  - Compressed Helium
  - Liquid methanol/water solution

- Methanol solution was ultimately selected due based on lowest risk to ballute hardware, device mass, and personnel safety.

- IA takes advantage of phase change parameters for methanol. Liquid at standard temperature and pressure, vaporizes under reduced pressure experienced at ballute deployment.

\[ Q_{v,CH_3OH} = m_{CH_3OH} \Delta H_{CH_3OH} \]

- Energy for vaporization is derived from several sources: sensible heat from depressurization, heat of fusion of water, heat from ballute and IA itself.

\[ Q_{avail} = Q_{s,CH_3OH} + Q_{f,H_2O} + Q_b + Q_{IA} \]
## Predicted Performance

### Deployment at 3°C

<table>
<thead>
<tr>
<th>Energy</th>
<th>Amount (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Req’d for methanol vaporization</td>
<td>-317.1</td>
</tr>
<tr>
<td>Depressurization</td>
<td>+38.9</td>
</tr>
<tr>
<td>Fusion of liquid water</td>
<td>+29.4</td>
</tr>
<tr>
<td>Ballute contact</td>
<td>+87.4</td>
</tr>
<tr>
<td>Inflation aid contact</td>
<td>+12.0</td>
</tr>
<tr>
<td>Deficit for full vaporization</td>
<td>-149.3</td>
</tr>
</tbody>
</table>

Vaporized Mass, $m_{\text{avail},\text{CH}_3\text{OH}}$: 0.148 kg
Pressure Generated, $p_{\text{avail},\text{CH}_3\text{OH}}$: 295.1 Pa

### Deployment at 40°C

<table>
<thead>
<tr>
<th>Energy</th>
<th>Amount (kJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Req’d for methanol vaporization</td>
<td>-303.0</td>
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<tr>
<td>Depressurization</td>
<td>+68.4</td>
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<tr>
<td>Fusion of liquid water</td>
<td>+29.4</td>
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<tr>
<td>Ballute contact</td>
<td>+140.7</td>
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<tr>
<td>Inflation aid contact</td>
<td>+19.3</td>
</tr>
<tr>
<td>Deficit for full vaporization</td>
<td>-45.2</td>
</tr>
</tbody>
</table>

Vaporized Mass, $m_{\text{avail},\text{CH}_3\text{OH}}$: 0.246 kg
Pressure Generated, $p_{\text{avail},\text{CH}_3\text{OH}}$: 489.1 Pa

![Graphs showing frequency and cumulative frequency distributions for different percentiles at 3°C and 40°C.](image-url)
Inflation Aid Architecture

- Possible methanol vessel architectures:
  - Compliant vessel, pulled apart during ballute bag strip (used by GAC)
  - Rigid vessel, pressurized until rupture at desired time.
- Rigid vessel was selected based on large ballute packing pressures, and high acceleration experienced at mortar-fire and line stretch.
- Black powder was selected as a gas-generating propellant to pressurize the reservoir.
- Initiation methods considered:
  - Vehicle-commanded electrical initiation
  - Timer-based electronic initiation
  - Timer-based pyrotechnic fuse
  - Mechanical initiation by ballute itself
- Selected method involved mechanical initiation via lanyard connected to ballute.
Device Components, Cont’d.

Section A

Section B
Interfaces

- IA interfaces to ballute via an aluminum attachment collar.
  - Collar attaches to 16 meridional tapes

- IA interfaces to SFDT vehicle via a 1” kevlar riser and pin.

- IA is initiated via two trigger lanyards that run along side the ballute, and are attached at the burble fence.
Device Components

- Firing mechanism contains the same basic components as modern small firearms.
- Lanyards are extracted from ballute as it is stretched taught during bag strip.
- Lanyard extraction initiates firing mechanism.
Deployment of a 4.2 m ballute in 10 ft diameter vacuum chamber at 300 mTorr
Deployment of a 4.2 m ballute in 10 ft diameter vacuum chamber at 300 mTorr
Bench Top Mechanism Testing

- Verified operation of firing mechanism under a variety of conditions
  - Hot, cold temperature
  - Varying Lanyard orientations
  - Varying Lanyard Actuation Methods
    - Hand pull with load cell
    - Preloaded to various forces
    - Preloaded via various amounts of lanyard deflection
  - Helped to inform development of trigger lanyard design
Propellant Margin Testing

- Qualification of mechanism performance and hardware safety was verified using two propellant margin tests.
  - In both tests, chamber was filled with water to simulate the proper amount of ullage.
  - Strength margin test
    - 120% of nominal amount of propellant in both chambers.
    - No catastrophic hardware failure was observed.
  - Energy margin test
    - 67% of nominal amount of propellant in only one chamber.
    - Rupture of burst disk and fluid discharge were acceptable.
Energy Margin Test, 67% propellant load, H₂O in reservoir, ambient conditions
Propellant Testing Issues

Abnormal Dispersion

Nominal Dispersion

Abnormal Disk Failure, Post Test

Nominal Disk Failure, Post Test
• Final verification of flight hardware operation prior to delivery.
• Reservoir filled with methanol solution, nominal amount of propellant
• In-flight conditions simulated using a vacuum chamber
  – 300 mTorr initial pressure
  – Ambient temperature
• Actuated using solenoids, operated from outside chamber.
Full Functional Test Video

Full Functional Test, 100% propellant load, methanol in reservoir, 300 mTorr, 20°C
In-Flight Performance

- SFDT-1 Test conducted on June 28, 2014
- PDD Deployment at altitude of 50 km, Mach 2.73
- Predicted temperature of IA at deployment was 50°C
- Predicted inflation pressure was 99% of expected ballute pressure
- Complete inflation occurred in approximately 0.56 seconds
Deployment altitude 50 km, Mach 2.73, predicted PDD temperature 50°C