Reefing of Quarter Spherical Ribbon Parachutes used in the Ares I First Stage Deceleration Subsystem

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Agenda

• Introduction
• Ares I Parachutes
• Reefing Ratio Development
• Conclusion
• Acknowledgments

Objectives

• Introduce the Ares I First Stage parachutes
• Discuss reefing quarter spherical parachutes compared to literature
• Identify superior suspension line length drag area normalization curve
Ares I Program

• NASA Constellation Program
  – Ares I man-rated rocket
    • First stage is a reusable solid rocket booster (Space Shuttle variant)
    • Second stage is an expendable liquid rocket (Apollo variant)
  – Ares V unmanned, heavy-lift rocket
    • Uses 2 solid rocket boosters, similar to Ares I first stage
• Currently developing parachutes to recover the first stage of the Ares I Rocket
  – Similar to Space Shuttle Solid Rocket Booster (SRB) recovery system
  – Pilot parachute, drogue parachute with reefed stages, 3 main parachute cluster with reefed stages
• Baseline: quarter spherical ribbon parachutes
Ares I Parachutes - Pilot

Pilot Parachute Properties:
• Nominal diameter of 11.5 ft
• Geometric porosity of 19.5%
• Kevlar structural members, nylon ribbons
• Vent hoop construction

Currently Planned Ares I Flight Configuration:
• Permanently reefed to near full open for Ares I

Successfully Completed Drop Tests:
• Pilot Parachute Drop Test (PDT)-1
• PDT-2
• PDT-3R
• Drogue Parachute Drop Test (DDT)-1
• DDT-2 (two; separate programmer and pilot)
Ares I Parachutes - Drogue

Drogue Parachute Properties:
- Nominal diameter of 68 ft
- Geometric porosity of 19.5%
- Kevlar structural members, nylon ribbons
- Double vent hoop construction

Currently Planned Ares I Flight Configuration
- First stage reefed to near 40% drag area
- Second stage reefed to near 60% drag area
- Third stage reefed to near 80% drag area

Successfully Completed Drop Tests:
- DDT-1
- DDT-2, additional fullness added to vent region
Ares I Parachutes - Main

Main Parachute Properties:
• Nominal diameter of 150 ft
• Geometric porosity of 11.5%
• Kevlar structural members, nylon ribbons
• Double vent hoop construction

Currently Planned Ares I Flight Configuration:
• First stage reefed to near 20% drag area
• Second stage reefed to near 40% drag area

Successfully Completed Drop Tests:
• Main Parachute Drop Test (MDT) -1 (tub)
• MDT-2 (tub)
• DDT-1
• DDT-2, porosity changed to 15.0%
## Measured Reefed Drag Areas (not normalized to $L_e/D$)

<table>
<thead>
<tr>
<th>Drop Test</th>
<th>Reefing</th>
<th>1st Stage Drogue</th>
<th>2nd Stage Drogue</th>
<th>3rd Stage Drogue</th>
<th>1st Stage Main</th>
<th>2nd Stage Main</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot Drop Test #1</td>
<td>Pilot</td>
<td>76.6%</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>Pilot Drop Test #2</td>
<td>Pilot</td>
<td>84.1%</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>Pilot Drop Test #3R</td>
<td>Pilot</td>
<td>98.6%</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
</tr>
<tr>
<td>Main Drop Test #1</td>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>19.7%</td>
</tr>
<tr>
<td>Main Drop Test #2</td>
<td></td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>$\times$</td>
<td>25.1%</td>
</tr>
<tr>
<td>Drogue Drop Test #1</td>
<td></td>
<td>100%</td>
<td>39.3%</td>
<td>59.4%</td>
<td>73.3%</td>
<td>19.8%</td>
</tr>
</tbody>
</table>

*Note: The table entries indicate the percentage of reefing for each stage of the parachute system.*
Reefing Ribbon Parachutes

• Information on quarter spherical parachutes difficult to obtain
• Knacke published reefing line curves for flat circular and conical ribbon parachutes
• Required to normalize parachute data to compare to literature
  – Knacke published normalization curves for ribbon parachutes
• Initially, Space Shuttle Solid Rocket Booster (SRB) and Ares I First Stage Parachutes did not lie on this line
• Normalizations of every kind investigated
  – Primary normalization is to suspension line length
  – Wolf provided additional suspension line normalization curve
Effective Reefing Line Length

- This correction is specific to Ares I parachute design
- CANO is used to help predict suspension line angles
Nominal Diameter

- Nominal diameter used in
  - Reefing ratio definition
  - Suspension line length normalization
- In general, actual nominal diameter is not an important parameter to identify
- Larger effect possible in SRB parachutes when drag areas were investigated after years of flight.
  - Frequent washing and drying may shrink parachutes – full open drag area is reduced
  - New reefing lines each flight maintain reefed stage drag area
Effective Suspension Line Length

- The closer to parallel the suspension lines are, the lower the inboard force on the canopy skirt.
- A reduction of inboard force at the canopy allows the parachute to inflate to a greater diameter.
- Suspension lines may not converge to a point.
- These suspension lines appear to the skirt of the canopy to be longer.
- This effective length, $L_e$, is obtained.
Effective Suspension Line Length

- Curves exist for determining the additional drag produced by longer suspension lines.
- The Parachute Recovery Systems Design Manual (Knacke) provides a normalization.
- Wolf and Croll provide a similar curve, but for ribbon parachutes of different porosities.
- These two curves disagree.
- When Ares I and SRB data are normalized with the Wolf curve, the reefing ratios match the drag areas predicted in the Parachute Recovery Systems Design Manual.

Ares I Drop Test Results – Normalized to $L_e/D = 1$
Conclusions

- Normalizing drop test reefed drag area for suspension line length with data from Wolf allows best match of test results with Knacke reefing ratio curve
- Various sizes and porosities of quarter spherical ribbon parachutes were tested
- All appear to fit the published reefing ratio curve – quarter spherical parachutes match
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