SUMMARY

1. PURPOSE. To provide security and policy review on the presentation at Tab 1 prior to release to the public.

2. BACKGROUND.

Authors: Robert K. Decker

Title: Starting Characteristics of the US Air Force Academy Mach 6 Ludwig Tube

Circle one: Abstract Tech Report Journal Article Speech Paper Presentation Poster

Thesis/Dissertation Book Other:

Check all that apply (For Communications Purposes):

[] CRADA (Cooperative Research and Development Agreement) exists
[] Photo/Video Opportunities [] STEM-outreach Related [] New Invention/Discovery/Patent

Description: Presentation on Computational Fluid Dynamics (CFD) research into the starting behavior of the Ludwig tube.


Previous Clearance information: None

Recommended Distribution Statement: Distribution A, Approved for Public release, distribution unlimited.

3. DISCUSSION. N/A

4. RECOMMENDATION. Sign coord block above indicating document is suitable for public release. Suitability is based solely on the document being unclassified, not jeopardizing DoD interests, and accurately portraying official party.
<table>
<thead>
<tr>
<th>TO</th>
<th>ACTION</th>
<th>SIGNATURE (Surname), GRADE AND DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>USAFA/DFAN</td>
<td>sig</td>
<td>[Signature]</td>
</tr>
<tr>
<td>USAFA/DFER</td>
<td>approve</td>
<td>[Signature]</td>
</tr>
<tr>
<td>USAFA/DFAN</td>
<td>action</td>
<td>[Signature]</td>
</tr>
</tbody>
</table>

**SURNAME OF ACTION OFFICER AND GRADE**
Decker, Ctr

**SYMBOL**
USAFA/DFAN

**PHONE**
333-7987

**TYPIST'S INITIALS**
rkd

**SUSPENSE DATE**
20150523

**DATE**
20150516

**SUBJECT**
Clearance for Material for Public Release

**SUMMARY**
1. PURPOSE. To provide security and policy review on the presentation at Tab 1 prior to release to the public.
2. BACKGROUND.

Authors: Robert K. Decker

Title: Starting Characteristics of the US Air Force Academy Mach 6 Ludwieg Tube

Circle one: Abstract Tech Report Journal Article Speech Paper Presentation Poster

Thesis/Dissertation Book Other: ____________

Check all that apply (For Communications Purposes):

[] CRADA (Cooperative Research and Development Agreement) exists

[] Photo/Video Opportunities [] STEM-outreach Related [] New Invention/Discovery/Patent

Description: Presentation on Computational Fluid Dynamics (CFD) research into the starting behavior of the Ludwieg tube.


Previous Clearance information: None

Recommended Distribution Statement: Distribution A, Approved for Public release, distribution unlimited.

3. DISCUSSION. N/A

4. RECOMMENDATION. Sign coord block above indicating document is suitable for public release. Suitability is based solely on the document being unclassified, not jeopardizing DoD interests, and accurately portraying official party.

ANDREW J. LOFTHOUSE, Lt Col, USAF
Director, High Performance Computing Research Center

2 Tabs
1. Starting Characteristics of the US Air Force Academy Mach 6
2. CD of presentation

AF IMT 1768, 19840901, V5
PREVIOUS EDITION WILL BE USED.
Starting Characteristics of the US Air Force Academy Mach 6 Ludwig Tube

Mr. Robert Decker
CFD Research Engineer

Cleared for public release, USAFA-DF-PA-

Overview

- Introduction
- Setup
- Results
- Conclusion
Introduction

- “New” installation of Ludwieg tube at US Air Force Academy
- Special kind of blow down tunnel
- Mach 6 flow, 100ms runtime, 10 min recharge

Project Motivation

- Blunt test articles can cause unstart
- Unstart is the inability of the test section flowfield to reach sustained Mach 6 flow
- CFD to predict when unstart will happen??
- Test out potential “fixes” to unstart
Wind Tunnel Study

- Wind tunnel study by Metro and Bureau
  - 3 model sizes (160mm, 180mm, 200mm diameter)
  - 3 charge tube pressures (14bar, 23bar, 32bar)
  - Concluded higher charge tube pressure increased likelihood of started flow
  - Recommended further CFD studies

<table>
<thead>
<tr>
<th>Charge tube Pressure (bar)</th>
<th>160mm</th>
<th>180mm</th>
<th>200mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Start</td>
<td>Start</td>
<td>Start</td>
</tr>
<tr>
<td>23</td>
<td>Start</td>
<td>Start</td>
<td>Unstart</td>
</tr>
<tr>
<td>14</td>
<td>Start</td>
<td>Unstart</td>
<td>Unstart</td>
</tr>
</tbody>
</table>
Setup

- Simulations run in Loci-CHEM from Mississippi State
  - A finite rate chemistry unstructured code
  - Additional features include a suite of options for high speed flow, overset grids, and grid adaption

Solver Setup

- Adaptive flux scheme
  - Pressure based sensor switches to HLLE in regions near strong shock, Roe flux otherwise
- Nodal based Barth Limiter
- Menter’s SST model
- 2\textsuperscript{nd} order spatial & 1\textsuperscript{st} order temporal accuracy
- Unsteady runs
  - 2\textsuperscript{nd} order temporal accuracy
  - Increased Newton subiterations (5 instead of 1)
Grid Generation

- Hybrid software approach
  - Gridgen from Pointwise Inc
    - Geometry loaded and cleaned
    - Surface grid generated
  - AFLR3 from Mississippi State
    - Gridgen surface grid used as basis for AFLR3 to grow volume grid
- Reduced time to generate grid while maintaining overall grid quality

Overset Approach

- Overset allows “easy” changes to location of test article in tube
- Tube with walls considered background grid
- Capsule grids overset into background grid
- CHEM uses a “cloud of points” interpolation scheme instead of traditional hole cutting overset
Overset Approach

Conditions

- Tube initialized to 0.01bar, 300K, and U=0 m/s
- Boundary conditions
  - Inflow (charge tube pressure, 500K, U=0 m/s)
  - Outflow (0.01bar then switching to extrapolate)
  - Adiabatic viscous tube walls
  - First order adiabatic slip walls for capsule
## Cases

<table>
<thead>
<tr>
<th>Case</th>
<th>Pressure</th>
<th>Model size</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11.61 bar</td>
<td>160mm</td>
</tr>
<tr>
<td>2</td>
<td>23.23 bar</td>
<td>160mm</td>
</tr>
<tr>
<td>3</td>
<td>34.67 bar</td>
<td>160mm</td>
</tr>
<tr>
<td>4</td>
<td>11.61 bar</td>
<td>180mm</td>
</tr>
<tr>
<td>5</td>
<td>23.23 bar</td>
<td>180mm</td>
</tr>
<tr>
<td>6</td>
<td>34.67 bar</td>
<td>180mm</td>
</tr>
<tr>
<td>7</td>
<td>11.61 bar</td>
<td>200mm</td>
</tr>
<tr>
<td>8</td>
<td>23.23 bar</td>
<td>200mm</td>
</tr>
<tr>
<td>9</td>
<td>34.67 bar</td>
<td>200mm</td>
</tr>
</tbody>
</table>

## Results

- 160mm capsule

Low pressure  
High pressure
Results

• 180mm capsule

Low pressure  High pressure

Results

• 200mm capsule

Low pressure  High pressure
## Results

### Experiment

<table>
<thead>
<tr>
<th>Charge tube Pressure (bar)</th>
<th>160mm</th>
<th>180mm</th>
<th>200mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Start</td>
<td>Start</td>
<td>Start</td>
</tr>
<tr>
<td>23</td>
<td>Start</td>
<td>Start</td>
<td>Unstart</td>
</tr>
<tr>
<td>14</td>
<td>Start</td>
<td>Unstart</td>
<td>Unstart</td>
</tr>
</tbody>
</table>

### Computation

<table>
<thead>
<tr>
<th>Charge tube Pressure (bar)</th>
<th>160mm</th>
<th>180mm</th>
<th>200mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Start</td>
<td>Start</td>
<td>Unstart</td>
</tr>
<tr>
<td>23</td>
<td>Start</td>
<td>Start</td>
<td>Unstart</td>
</tr>
<tr>
<td>14</td>
<td>Start</td>
<td>Unstart</td>
<td>Unstart</td>
</tr>
</tbody>
</table>

## Results

- Modifications explored to reduce unstart
  - Shifting model off tunnel centerline
  - Shifting model upstream in test section
Conclusion

- CFD appears to be a reliable tool to determine when unstart will occur
- Confirmed that larger model increases unstart while larger pressures decrease unstart
- Model offset looks promising to help with unstart
- More study needed to understand exact mechanism behind unstart