**Title:** Sting Influence on Vortex Breakdown on a 65 Degree Delta Wing in Transonic Flow

**Performing Organization:** Department of Aerospace Engineering, University of Glasgow, UK

**Abstract:**
Sting Influence on Vortex Breakdown on a 65 Degree Delta Wing in Transonic Flow

L.A. Schiavetta
Department of Aerospace Engineering, University of Glasgow, UK

R.M. Cummings,
United States Air Force Academy, Colorado Springs, USA

O.J. Boelens,
NLR, Netherlands

W.Fritz,
EADS, Germany

3rd International Symposium on Integrating CFD and Experiments in Aerodynamics
Lambourne and Bryer

Sharp Leading Edge Delta Wing
$M = 0.85$, $\text{Alpha} = 23.0\,\text{deg.}$, $\text{Re} = 6,000,000$
Iso-surface of $X$-vorticity colored by pressure

USAFA
Subsonic Tests

APEX

Trailing Edge

4 degrees
• NASA Langley NTF tests (Chu and Luckring)
  – 65 degree sharp LE
  – Surface pressure measurements
  – Range of freestream Mach numbers
    • 0.4 and 0.85
• These tests formed starting point for VFE-2
Question: why does breakdown move towards the apex so suddenly?
M = 0.85, Re = 6e6

- CFD Results 18.5°
- NTF Wind tunnel results, 18.6°

No Breakdown
Question: why is critical angle different in measurements and CFD?
# CFD Sensitivity Study

## Participants:

<table>
<thead>
<tr>
<th>Participant</th>
<th>Model</th>
<th>Length (m)</th>
<th>Turbulence Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>EADS</td>
<td>Flower</td>
<td>10.6m</td>
<td>k-w and RSM</td>
</tr>
<tr>
<td>NLR</td>
<td>Enflow</td>
<td>4m</td>
<td>k-w with RC</td>
</tr>
<tr>
<td>Glasgow</td>
<td>PMB</td>
<td>7m (2.4m)</td>
<td>k-w with RC, NLEVM</td>
</tr>
<tr>
<td>USAFA</td>
<td>Cobalt</td>
<td>6m</td>
<td>SA-DES</td>
</tr>
</tbody>
</table>

## Tests:

- Code-to-Code: Glasgow, NLR, EADS
- Grid refinement: Glasgow coarse and fine
- Turbulence Model: k-w, k-w with RC, RSM, NLEVM
- Time Accuracy: Glasgow (steady) and USAFA (DES)

## Purpose:

1. Interested in the mechanism – does the sting shock always trigger the breakdown?
2. Interested in the influence of the shock strength and the axial flow on the critical angle
Sharp Leading Edge Delta Wing

$M = 0.85, \ Alpha = 23.0\ deg.,\ Re = 6,000,000$

Iso-surface of X-vorticity colored by pressure
On-wing pressure gradient along symmetry plane
Axial Velocity Distribution Along Vortex Core
Rossby number = axial component/azimuthal component

Robinson et al, AIAA Journal, 1994
Ashley et al, J Fluids and Structures, 1991
Mach 0.8, incidence 26 degrees, Re=3 million
Mach 0.8, incidence 26 degrees, Re=3 million

On same scale but not that illuminating!
Comments

• Here balance is between
  – Axial flow
  – Sting shock strength

• Closely coupled CFD-Experimental effort needed to nail this problem

• More to be extracted from the CFD trends
<table>
<thead>
<tr>
<th>Incidence</th>
<th>Breakdown</th>
<th>Maximum Axial Speed</th>
<th>Maximum Pressure Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.5</td>
<td>No</td>
<td>1.74</td>
<td>1.50</td>
</tr>
<tr>
<td>19</td>
<td>No</td>
<td>1.76</td>
<td>1.67</td>
</tr>
<tr>
<td>20</td>
<td>Yes</td>
<td>1.74</td>
<td>3.73</td>
</tr>
<tr>
<td>21</td>
<td>Yes</td>
<td>1.74</td>
<td>4.87</td>
</tr>
<tr>
<td>22</td>
<td>Yes</td>
<td>1.79</td>
<td>4.67</td>
</tr>
<tr>
<td>23</td>
<td>Yes</td>
<td>1.80</td>
<td>5.25</td>
</tr>
<tr>
<td>Incidence</td>
<td>Breakdown</td>
<td>Maximum Axial Speed</td>
<td>Maximum Pressure Gradient</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------</td>
<td>---------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>18.5</td>
<td>No</td>
<td>1.74</td>
<td>1.50</td>
</tr>
<tr>
<td>19</td>
<td>No</td>
<td>1.76</td>
<td>1.67</td>
</tr>
<tr>
<td>20</td>
<td>Yes</td>
<td>1.74</td>
<td><strong>3.73</strong></td>
</tr>
<tr>
<td>21</td>
<td>Yes</td>
<td>1.74</td>
<td>4.87</td>
</tr>
<tr>
<td>22</td>
<td>Yes</td>
<td>1.79</td>
<td>4.67</td>
</tr>
<tr>
<td>23</td>
<td>Yes</td>
<td>1.80</td>
<td>5.25</td>
</tr>
</tbody>
</table>

PSP measurements to locate shocks

PIV slices (from apex to TE) to assess axial flow
Conclusions

• sting-shock and primary vortex
  – sudden upstream motion of breakdown

• critical angle consistently different
  – large scatter in published measurements also
  – More coordinated effort needed

• artefact of the experimental setup