Investigations of passive flow control devices for wave drag reduction

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   1. Kuchemann’s Carrot
   2. Shock Control Bumps
   3. Mix KC - SCB
5. Conclusions

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Main Location: Bucharest, Iuliu Maniu 220
Secondary Location: Maneciu, Prahova district
New Location(s) for special activities
Profile:
- State owned company/ Public body
- Founded in 1949
- Leading research establishment for aerospace research in Romania

Major activities:
- Main design authority and system integrator in aeronautics
- Aerodynamic design
- Structural design and analysis
- Experimental wind tunnel validation
- Global performance analysis
- Atmospheric investigations
- Earth Observation
- Research and development in aeronautics and aerospace sciences

INCAS Personnel Structure

- Total positions: 218
- R&D positions: 126
- Total researchers: 106
- Where:
  - PhD: 21
  - PhD students: 14
  - PhD leaders: 3
Subsonic Wind Tunnel

- Atmospheric pressure, continuous type facility
- Maximum speed: 110 m/s
- 2.5m x 2.0m x 4m test section
- Usual Reynolds number up to 1.5 million.

Equipment:

- Traditional closed circuit type
- Solid walls test section
- External 6 component pyramidal type balance
- Standard pressure acquisition systems
- New data acquisition technologies
  - Hot film/wire measurements
  - IR camera
  - PIV system
  - 3D dynamic deformation – fast cameras
- Laser visualization systems
- CTS system – open/closed loop operation
- Aeroacoustics and airframe noise evaluation
  - 72 microphone matrix system
  - Beamforming technology
  - Cross-correlation with dynamic pressure/kulites

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Supersonic Wind Tunnel

- blowdown type
- 1.2m x 1.2m test sections (3D)
- Mach number range: 0.1 ... 3.5
- Reynolds number up to 100 millions/m
- Max test run duration: 90 sec.
- Max pressure: 16 bar (settling chamber)
- Interchangeable porous transonic test section
- Variable porosity from 0.01% up to 9%
- Interchangeable complex 3D/2D 0.8m x 1.2m test section
- Active model/combustion capability

Equipment:

- Sting mounted, internal balance
- Pressure measurements
- Mach control system
- CTS system
- 800 mm schlieren system
- PIV under development
- IR camera
- Ultra fast digital camera

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• SGI UV-2000:
  - 528 cores (Intel Xeon E5-4627v2)
  - 8.4 TB RAM (shared memory)
  - 42 TB for storage / 30 TB for users
  - 12 Intel Phi
  - 4 NVidia Quadro 6000
  - Linux - SuSe.

• SuperMicro:
  - 160 cores
  - 320 GB RAM (distributed memory)
  - Windows.

• Beowulf:
  - 48 cores
  - 512 GB RAM (distributed memory)
  - Windows.

• Ansys Fluent and CFX with 272 cores.
• Numeca Fine/OPEN with 1024 cores.
• In-house codes from 2nd order to 5th order finite volume/finite difference.
Introduction

Three methods for reducing the drag associated with the presence of strong shocks have been investigated:

1. Kuchemann’s Carrot
2. Shock Control Bumps
3. KC + SCB (v0, v1, v2)

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Introduction

Kuchemann’s Carrot:
- Positioned at the wing-strut junction – Local effect
- Below the wing’s leading edge not to affect the suction side
- “Fuselage-waisting” at the strut’s maximum thickness
- Improves the “area-rule”
- Used on a number of aircrafts from the past:
  ✓ Tu 134
  ✓ Hawker Sea Hawk
  ✓ Blackburn Buccaneer
  ✓ Gloster Meteor

- No numerical optimization used
Introduction

Shock Control Bumps:
- Positioned on the wing’s pressure side and the strut’s suction side, placed at 0.25m distance from each other – Distributed effect
- Not on the vertical strut
- Generally they have been observed to reduce drag in transonic flows where Mach number exceeds 1.3 – applicable in this case
- 3D wedge type geometry with rounded sides
- Height on the wing is roughly 70% of the boundary layer thickness
- Height on the strut is around 95%.
- The height of the bump is determined from 2D analyses at three span wise locations of 15, 15.5 and 16m
- Extended tail, flat top, a width to height ratio of approx. 9 and a length to width ratio of 4
- No numerical optimization used
- “Review of research into shock control bumps” - Shock Waves- 2015, P. J. K. Bruce · S. P. Colliss
Introduction

Kuchemann’s Carrot + Shock Control Bumps:
- Local effect of the KC + distributed effect of the SCB
- KC shape taken from previous model
- SCB shape taken from previous model
- SCBs repositioned (according to the shock position) and reduced in number due to massive flow detachment at y = 16m.
Mesh & Solver

Solver - Ansys Fluent v18.0:
- density based solver
- Roe Scheme
- second order upwind with Barth – Jespersen slope limiter (1989)
- Modified 3 equation version of the $k$-$\omega$ SST turbulence model with several enhancements:
  - Curvature correction for the modeling of turbulence production (Smirnov & Menter, 2008)
  - Compressibility effects for the modeling of turbulence dissipation (Sarkar & Balakrishnan, 1990)
  - Production Limiter to limit the excessive generation of turbulence energy at stagnation points
    (Menter, 1994 + Kato & Launder, 1993) – standard practice for transition models
  - (the 3rd equation is for the) Intermittency transition model (Menter & Langtry, 2004) with crossflow instability (Arnal, 1984) to avoid Wilcox’s - Low-Reynolds correction

Mesher – Numeca Hexpress
- Unstructured roughly 95M cells each configuration for the semi-span model.
- Full-hexahedral / cut-cell type
- Inflation layer: Y+ < 1 and growth rate = 1.15
- 6 cells on the trailing edge
- Refinement region in the wing-strut region from y=14.5m to y=17m
- Good control of mesh sizing from one geometry to another
Mesh & Solver
Mesh & Solver

KC
Mesh & Solver
Results

The flow conditions are summarized as:

- Mach 0.72, angle of attack 1°
- Cruise altitude 30000ft on an atmosphere ISA+0 with:
  - pressure 30089.59 Pa,
  - temperature 228.71K.
- The reference area is $S = 80.5 \, m^2$, semi-span model
- The reference length is 3.264m.

Drag breakdown:

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<thead>
<tr>
<th>Configuration</th>
<th>Lift</th>
<th>Drag</th>
<th>L/D</th>
<th>aoa</th>
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</table>
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice =12m

Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 12.5m  
Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 13m

Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 13.5m

Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice =14m

Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 14.5m

Little / No difference for KC; detached flow SCB
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 15m

detached flow SCB and less on KC
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 15.5m

No detached flow SCB; separation for KC
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 16m

No detached flow SCB; separation for KC
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice =16.5m

Massive separation SCB; separation for KC but smaller
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 16.8m

Less increased speed on outer panel wing KC
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 17.3m

Little / No difference
Results

Baseline

Kuchemann Carrot

Shock Control Bump

Y slice = 17.8m

Little / No difference
Results

Z slice = 0.87m

Baseline

Kuchemann Carrot

Less separation on vertical strut for SCB and less acceleration on horizontal strut for SCB

Shock Control Bump
Results

Z slice = 0.97 m

Baseline

Kuchemann Carrot

Less separation on vertical strut for KC and less acceleration on horizontal strut for SCB

Shock Control Bump
**Results**

Z slice = 1.07m

Baseline

Kuchemann Carrot

Less separation on vertical strut for KC and SCB and less acceleration on horizontal strut for SCB and KC

Shock Control Bump
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 12m

Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice =12.5m

Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice =13m

Little / No difference
Results

**Baseline**

**KC-SCB_v0**

**KC-SCB_v2**

Y slice =13.5m  
Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice =14m

Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 14.5m  
Separated flow
Results

Baseline
KC-SCB_v0
KC-SCB_v2

Y slice = 15m
Separated flow
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 15.5m

Separated flow
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice =16m

Separated flow
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice =16.5m Separated flow and strong shock
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 16.8m  Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 17.3m

Little / No difference
Results

Baseline

KC-SCB_v0

KC-SCB_v2

Y slice = 17.8m
Little / No difference
Results

Z slice = 0.87m

Baseline

No separation on vertical strut

KC-SCB_v0

Minor separation on vertical strut

KC-SCB_v2
Results

Z slice = 0.97m

Baseline

No separation on vertical strut, but on the wing

KC-SCB_v0

Minor separation on vertical strut

KC-SCB_v2
Results

Z slice = 1.07m

Baseline

No separation on vertical strut, but massively on the wing

KC-SCB_v0

Minor separation on vertical strut

KC-SCB_v2

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Conclusions

KC:
• Mitigates drag by locally controlling the flow at the wing strut junction
• Reduces flow separation on the wing, but induces on the strut--- to be improved!
• Improves flow also on the outer wing panel
• KC to be numerically optimized!

SCB:
• Mitigates drag by globally/span-wise controlling the flow
• To be verified a staggered arrangement on the wing/strut, or other formations
• SCBs to be numerically optimized in shape and orientation w.r.t. local flow direction!

KC-SCB:
• More work required, but there is “hope”!
• The trend is clear to reduce drag, just by “manually” improving the SCB number and position
• To be verified a staggered arrangement on the wing/strut, or other formations (?)
• SCBs to be numerically optimized in shape and orientation w.r.t. local flow direction!
• SCB close to the KC are aligned with the ideal flow direction not the local/KC induced one!
Thank you!

Questions?