Air Intakes for Subsonic UCAV Applications - Some Design Considerations

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<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
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<td>26 JUL 2004</td>
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<th>4. TITLE AND SUBTITLE</th>
<th>5a. CONTRACT NUMBER</th>
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<th>12. DISTRIBUTION/AVAILABILITY STATEMENT</th>
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<td>Approved for public release, distribution unlimited</td>
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<th>13. SUPPLEMENTARY NOTES</th>
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<td>See also ADM001685, CSP 02-5078, Proceedings for Aerodynamic Issues of Unmanned Air Vehicles (UAV)., The original document contains color images.</td>
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<th>17. LIMITATION OF ABSTRACT</th>
<th>18. NUMBER OF PAGES</th>
<th>19a. NAME OF RESPONSIBLE PERSON</th>
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<td>a. REPORT unclassified</td>
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Standard Form 298 (Rev. 8-98)  
Prescribed by ANSI Std Z39-18
Outline

• Some first expectations from theory
• Practical considerations
• Research requirements
Mission Assumptions

• Modest manoeuvre requirements
• Subsonic cruise
What’s New?

• Some additional positioning and packaging freedoms
  – Upper surface front position is available

• ... But many new constraints due to a need for low observability
  – No diverter
  – High lip sweep / edge alignment
  – Engine compressor face obscuration
  – Fixed geometry and no auxiliary intakes (ideally)
Intake Configuration Examples

• Pitot
• Diverter-less pitot
• Semi-flush
• Flush

getting easier to satisfy LO constraints

... but

Increasing aerodynamic integration difficulty

Photos © Jane’s
**Practical Considerations:**

**Vehicle Packaging**

- Tendency for fuel, releasable payload and engine to need to be near to the CG

- Intake options
  - At or near to the front of the vehicle
    . . . but avoiding wing leading-edge vortex ingestion

- Diffuser options:
  - Very short diffusers with compressor-face screening devices
  - Short, highly off-set, obscuring diffusers
Idealised Pitot Intakes

Intake capture area = $A_C$

Area of approach surface = $S$

Intake aspect ratio = width / height = $AR$

$\delta$ is boundary layer thickness at $l$
Divert, Ingest or a Bit of Both?

Comparison based on intakes at the same streamwise location, \( l \). Datum is \( AR = 2 \) pitot intake with a \( 1\delta \) diverter height.

Small UCAV
Turbofan, BPR=0.1
Cruise at \( A_0/A_C=0.67 \)
M=0.8, 9Km ISA

Sized for \( M_{\text{throat}}=0.85 \) in 2g sustained turn, M=0.8, 9Km ISA

Based on Seddon’s approximate theory of skin friction loss (incompressible)

Change in Thrust-minus-Drag / Datum Thrust (%)
Contributions to $\Delta(T-D)/T$

\[
\frac{\delta}{l} = 0.016
\]

\[
\text{AR} = 5
\]

\[
\text{BPR} = 0.1
\]
Divert, Ingest or a Bit of Both?

Datum is AR=2 pitot intake located at $l$ with 1$\delta$ diverter

Small UCAV
Turbofan, BPR=1.0
Cruise at $A_0/A_C=0.73$
M=0.8, 9Km ISA
Sized for $M_{\text{throat}}=0.85$ in 2g sustained turn, M=0.8, 9Km ISA

Intake aspect ratio = $\frac{\text{width}}{\text{height}}$
Divert, Ingest or a Bit of Both?

Datum is AR=2 pitot intake located at \( l \) with 1\( \delta \) diverter

Small UCAV
Turbofan, BPR=1.0
Cruise at \( A_0/A_C=0.73 \)
\( M=0.8, 9\text{Km ISA} \)
Sized for \( M_{\text{throat}}=0.85 \) in 2g sustained turn, \( M=0.8, 9\text{Km ISA} \)

Approximate UCAV design space

High AR UCAV, e.g. X-47?

Manned, e.g. F-35

Change in Thrust-minus-Drag / Datum Thrust (%)

Position Ratio, \( S/A_c \)
Practical Considerations:
Avoidance of Distortion and Swirl

• Boundary layer ingestion can look like a good idea in principle but:
  – Distorted flow at the diffuser entry can adversely influence the diffuser flow
  
  . . . leading to additional loss, increased distortion and swirl at the compressor face

• The classical diverter gap is a convenient way of avoiding this problem and is seen on almost all non-LO aircraft that operate above M=0.6
Flow Capture Ratio Effects

\[ \Delta P/q_c \]

Theory, ‘\( \mu^3 \)’ law

Design

Lip Separation

Static

Increasing B.L. Diversion

Pre-entry Separation

Duct

Static

Increasing B.L. Diversion

Design

Lip Separation

Duct

\[ A_c/A_0 \]
Practical Considerations:
Pre-Entry Separation Problem

- Design for operation at higher cruise mass flow ratio than normal will lead to:
  - Lower spillage drag at cruise

  ... but increased losses at all conditions due to:
  - A smaller intake capture area with higher throat Mach number
  - An increased internal diffusion requirement

- Static/take-off or manoeuvre thrust requirement and cruise performance requirement are thus likely to conflict
Research Requirements:
Intake Pre-Entry Flows

• Ways of controlling the pre-entry flow e.g:
  – Boundary layer conditioning via surface shaping (e.g. bumps)
  – Boundary layer diversion via intake shaping (forward swept intakes, NACA intakes)

• Efficient ways of accommodating distorted in-flows
Practical Considerations:

Lip Separation Problem (1)

- Lip planform
  - Highly swept planforms can lead to locally high lip loading which is potentially a problem for high mass flow ratio operation (e.g. static and take-off regimes)

- Contraction ratio
  - High CR desirable for performance and compatibility at static, take-off and manoeuvre conditions
  - But, combining high CR and high cruise mass flow ratio would mean:
    - Even higher throat Mach number
    - Even higher internal diffusion requirement
**Practical Considerations:**

**Lip Separation Problem (2)**

- **Spillage drag**
  - High cruise mass flow ratio, so spill drag issue should tend to be of reduced significance
  - But still potentially an issue in the case of very high lip sweep and/or sharp lips
Research Requirements:
Intake Entry and Lip Shaping

• Ways of improving the static and take-off performance of fixed-geometry intakes

• Aerodynamics of highly compromised intake lip profiles (e.g. sharp / bi-convex of varying thickness)
Practical Considerations: Diffuser Flows

• Diffuser likely to provide the most significant contribution to thrust loss at cruise

• High diffuser off-set will tend to significantly increase pressure loss, distortion and swirl so great care is required in design

• Benefits likely through tailoring of area distribution, cross sectional shape / local wall curvature

• Flow control systems could offer very significant benefits
  – Suppression of flow separation
  – Re-distribution of low energy flow
Research Requirements:

Diffusers

• Parametric study of compact diffusers with high aspect ratio entries (both with and without obscuration) using a combination of experiment and CFD

• Ways of reducing total pressure distortion and swirl in compact diffusers with minimal additional diffuser loss
  – e.g. flow control systems of various forms

• Novel approaches to diffusion and screening
Research Requirements: Prediction Methods

- Effective, rapid, methods for the estimation of the contribution of intake components to intake performance (e.g. semi-empirical) for preliminary design
- Methods for the prediction of complex flows (including time-variant flows) in complex intake and diffuser combinations both with and without flow control systems
- Methods for the optimisation of complex intake and diffuser combinations both with and without flow control systems
Conclusions

- Unmanned and LO . . . New freedoms but many new design challenges
- Systematic research on basic intake and duct parameters is required to extend the current knowledge into the full UCAV intake design space
- There is plenty of scope for novel solutions
- A high degree of integration with the airframe is likely to be required . . . so rapid estimation methods are needed more than ever at the conceptual design stage
- High-order CFD systems can capture key flow features of interest . . . target is cost-effective prediction of absolute performance levels
- Optimisation methods could be of great assistance in the later stages of the design process
Thanks for your attention!