Vehicle Sketch Pad Applied To Propulsion-Airframe Integration

Presented

by

Steven H. Berguin

stevenberguin@gatech.edu
1. Introduction

2. Modeling & Simulation

3. Example: Isolated Nacelle (Powered)

4. Conclusion

5. Appendix: Over-Wing Nacelle (Thru-Flow)
Introduction
Example Advanced Concepts

Joined-Wing

Over-Wing Nacelle (OWN)

Hybrid Wing Body (HWB)

Ultra-High Bypass (UHB)

UHB makes integration more difficult

“The increase of the bypass ratio of the turbofan entails a growth of the engine diameter, thereby intensifying the problem of the aerodynamic interaction between wing and engine.” [2]

Propulsion-Airframe Integration

Scope of Research

Mission Specifications

Assumptions

Mission Analysis

Constraint Analysis

Starting Geometry

Empirical Knowledge

• Starting airfoils
• Starting engine location
• etc.

Non-technical Factors

• Maintenance access
• Safety
• Clearance
• FOD
• Manufacturing
• Marketing needs

Flight Conditions

S_{ref}, W_{to}, T_{sl}

Opt

Updated Geometry

PAI

Aerodynamics

Engine BC

Propulsion

Noise

Structures

Weight & Balance

S & C

Performance

Converged?

Final Geometry
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Flight Conditions

S_{ref}, W_{10}, T_{SL}

OPT

Updated Geometry

Aerodynamics

CO

T_{eq}

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NOTIONAL EXAMPLE

Nacelle x-location

Drag

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Flight Conditions
- $S_{nc}$, $W_{to}$, $T_{sl}$

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- OPT
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- Propulsion
- Engine BC
- Noise
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Converged?

NOTIONAL EXAMPLE

Nacelle x-location

- Drag
- Noise

Friday, August 9, 13
Problem To Be Addressed

- High-Dimensionality
  - [1] → 146 design variables
  - [2] → 225 design variables
  - [3] → 125 design variables
- Multi-modality
  - [3] → HWB with 8 local minima, transonic wing with 7
- Expensive CFD function evaluations
  - Can be overcome with state-of-the-art adjoint design methods → gradient-based
  - Could use multiple restart to deal local minima

How can VSP be used in conjunction with adjoint design methods?


Modeling & Simulation
Mathematical Problem Statement

Find: \( x^* = \arg \min_x C_D (x) \)

Subject to: \( x_L \leq x \leq x_U \)
\( h_1 = C_{L_{Target}} - C_L (x) = 0 \)
\( h_i = 0 \quad \forall \quad i = 2, \ldots, k \)
\( g_j \leq 0 \quad \forall \quad j = 1, \ldots, m \)
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---

Find: \( x^* = \arg\min_x r_1 (C_D(x) - C_{D_{\text{Target}}}) \)

\[ + r_2 (C_L(x) - C_{L_{\text{Target}}})^2 \]

Subject To: \( x_L \leq x \leq x_U \)

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\end{align*}
\]

Find: \( x^* = \arg \min_x r_1 (C_D(x) - C_{D_{Target}}) + r_2 (C_L(x) - C_{L_{Target}})^2 \)

Subject To: \( x_L \leq x \leq x_U \)
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\begin{align*}
  h_i &= 0 \quad \forall \quad i = 2, \ldots, k \\
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Mathematical Problem Statement

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M&S Environment

VSP Environment
- Parametric Geometry
- External Analysis
- Flow Solver
- Adjoint Solver
- Optimizer

CART3D Design Framework
M&S Environment

VSP Environment
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M&S Environment

### M&S Environment

#### VSP Environment

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#### CART3D Design Framework

```
<Constraint ID="g_6" Expr="tmax_6-0.116000" Bound="Lower"
Sensitivity="Required" VSPname="minThickness_6"/>
<Analysis ID="tmax_6" Sensitivity="Required"/>
</Analysis>
<Constraint ID="g_7" Expr="tmax_7-0.113000" Bound="Lower"
Sensitivity="Required" VSPname="minThickness_7"/>
<Analysis ID="tmax_7" Sensitivity="Required"/>
</Analysis>
<Tessellate ID="wing" Sensitivity="Required"/>
</Model>
```
M&S Environment

VSP Environment

Parametric Geometry

External Analysis

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CART3D Design Framework

<?xml version="1.0" encoding="ISO-8859-1"?>
<Model ID="wing" Modeler="vsp" Wrapper="vsp_wrapper.csh">
<Variable ID="x_8" Value="0.2420" Min="0.1936" Max="0.2904" VSPname="wingKulfan_Sect_1_Au_0"/>
<Variable ID="x_9" Value="0.1040" Min="0.0832" Max="0.1248" VSPname="wingKulfan_Sect_1_Au_1"/>

<Constraint ID="g_6" Expr="tmax_6-0.116000" Bound="Lower" Sensitivity="Required" VSPname="minThickness_6"/>
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VSP Environment

Parametric Geometry

External Analysis

Flow Solver

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CART3D Design Framework
#!/bin/csh -f

# vsp_wrapper.csh

# Set file names
set xmlFile = model.input
set vspFile = model

# Generate *.tri file
vsp -batch $vspFile.vsp -xddm $xmlFile.xml -tri

# Intersect
intersect -i $vspFile.tri -o $vspFile.tri -T

# Error check
if ( $status ) then
    echo 'vsp -batch $vspFile -tri failed' >> FAILED
goto ERROR
endif
exit 0
ERROR:
exit 1
vsp_wrapper.csh

#!/bin/csh -f

# vsp_wrapper.csh

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set xmlFile = model.input
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endif
exit 0
ERROR:
exit 1

VSP_make.cpp

• Acts as surrogate for -xddm command
• Re-writes *.vsp from scratch
• Writes airfoil thickness to XDDM file
• Had to do it for CST method


Introduction
M&S
Powered Nacelle
Conclusion
Appendix

\[ A_{ur} \quad \forall \quad r = 1, \ldots, 9 \]

\[ A_{lr} \quad \forall \quad r = 1, \ldots, 9 \]

\[
\left( \frac{y}{c} \right)^i = C \left( \frac{x}{c} \right) \sum_{r=0}^{n=10} A_r^i K_{r,n} S_{r,n} \left( \frac{x}{c} \right) + \frac{x}{c} \Delta^i, \quad \in \mathbb{R} \quad \forall \quad i = 1, \ldots, 7
\]

where:
\[ C \left( \frac{x}{c} \right) = \sqrt{\frac{x}{c}} \left( 1 - \frac{x}{c} \right) \]

\[ K_{r,n} = \frac{n!}{r!(n-r)!} \]

\[ S_{r,n} \left( \frac{x}{c} \right) = \left( \frac{x}{c} \right)^r \left( 1 - \frac{x}{c} \right)^{n-r} \]

\[ \Delta^i = \left( \frac{y}{c} \right)^i \tau_E \]

Wish List

• Include CST methodology as an option for airfoil definition
• Make sure VSP updates <Analysis> with new airfoil thickness in XDDM file
Example: Isolated Powered Nacelle
DUCT/ENGINE

Pros
- Simple
- Rotated airfoil
- Water-tight
- 1-1 connectivity

Cons
- Symmetric only
- Can’t distinguish internal/external surfaces

VSP → TRI
### FUSE2

**Pros**
- Asymmetric
- Internal/external surfaces can be distinguished

**Cons**
- No 1-1 connectivity

**FUSE2**

<table>
<thead>
<tr>
<th>VSP</th>
<th>COMPGEOM</th>
<th>nacelle disappears</th>
</tr>
</thead>
<tbody>
<tr>
<td>VSP</td>
<td>TRI</td>
<td>not watertight</td>
</tr>
<tr>
<td>VSP</td>
<td>STL</td>
<td>TRI</td>
</tr>
</tbody>
</table>
The TUBE Element

It’s a sealed surface that wraps around itself*

VSP → TRI

*See Jon Gladin’s afternoon presentation
# Nacelle Models in VSP

<table>
<thead>
<tr>
<th>Pros</th>
<th>DUCT/ENGINE</th>
<th>FUSE2</th>
<th>TUBE*</th>
</tr>
</thead>
</table>
| • Simple  
• Rotated airfoil  
• Water-tight  
• 1-1 connectivity | • Asymmetric  
• Internal/external surfaces can be distinguished | • Asymmetric  
• 1-1 connectivity | *Coming |
| Cons | • Symmetric only  
• Can’t distinguish internal/external surfaces | • No 1-1 connectivity | • See next slides  
• Can’t distinguish internal/external surfaces |
Powered nacelle shape optimization is possible if:

- CFL number is low (e.g. CFL = 0.5)
- Multi-grid is set to V-cycles (i.e. MG_cycle_type = 1)
- 3-level multi-grid (i.e. mg_fc = mg_ad = 3)
Issue #1: TE Parameters

Suggested Solution
Start at TE where sharp angles are desired, end at LE where blunt angles are desired.
Issue #2: One Surface

**Current**

**Desired**

- Surface need to be broken with `breakTris`
- Then they need to be promoted to GMP tags
- Robustness issues

**Suggested Solution**

- Separate surfaces natively in VSP
- Output *.tri with different component numbers
Issue #3: center-body

Description of Issue
- CART3D returns input.not_robust.cntl on some design iterations
- This only seems to occur when center-body is included
- Could possibly be due to 1-1 mesh connectivity when breaking triangles upon design changes
Conclusion
• VSP can be used for adjoint design methods

• Wish list:
  • Include CST methodology for airfoils
  • Write airfoil thickness to <analysis> in XDDM
  • Surface identification for powered runs
  • Reverse order of sections in TUBE