OpenVSP
Inertia Calculation Capability

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NASA Langley Research Center

OpenVSP Workshop
NASA Ames Research Center
August 23-25, 2016
Motivation
Tool Set Interfaces
Inertia Calculation Verifications
Test Case
Considerations
Conceptual analysis process for LEAPS inertia calculations

- Input - Geometry - OpenVSP
- Input - Mass statement - FLOPS
- Output - Vehicle level inertias

Previous workshops

SBIR

Motivation

<table>
<thead>
<tr>
<th>MASS AND BALANCE SUMMARY</th>
<th>POUNDS</th>
<th>KG</th>
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<tbody>
<tr>
<td>HINGES</td>
<td>10.40</td>
<td>4.713</td>
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<td>HORIZ TAIL</td>
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<td>VERT TAIL</td>
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<td>5.998</td>
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<td>POSTS</td>
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<td>PROPELLOR TWIN</td>
<td>( 7.97)</td>
<td>( 3.62)</td>
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<td>TOWABLE CONTROLS</td>
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<td>FURNITURE AND EQUIPMENT</td>
<td>9.09</td>
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<td>0.11</td>
<td>0.050</td>
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<tr>
<td>SYSTEMS AND EQUIPMENT TOTAL</td>
<td>( 14.64)</td>
<td>( 6.66)</td>
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</tbody>
</table>

WEIGHT

- EMPTY: 54.77
- OPERATING WEIGHT: 90.14
- ZERO FUEL WEIGHT: 76.49
- MEBF (GROSS) WEIGHT: 100.00

Conceptual Analysis Process for LEAPS Inertia Calculations

- Input - Geometry - OpenVSP
- Input - Mass Statement - FLOPS
- Output - Vehicle Level Inertias

Previous Workshops

SBIR

NASA SBIR/STTR Technologies

Motivation

8/19/2016

McMillin
Tool Set Interfaces
Tools
- Component General Tab
- Blank Component Mass Tab
- Analysis Menu
  - Comp Geom
  - Mass Properties

Mass Properties Tool Set
Inertia Calculation
Verifications
Comparison to Analytic Solids and Shells

- All shells and solids checked were accurate to at least three decimal places
Comparison of Wing to CAD Computation

- **Solid Wing From OpenVSP Transferred to FreeCAD (OCC) via IGES (mm)**
  - **VSP**
    - Volume 8.4471
    - Center of Mass (2.9477, 0.0, 0.0)
    - Inertia Matrix
      - (111.377, 0, 0)
      - (0, 12.184, 0)
      - (0, 0, 123.466)
  - **FreeCAD**
    - Volume 8.5253
    - Center of Mass (2.9378, 0.0, 0.0)
    - Inertia Matrix
      - (111.980, 0, 0)
      - (0, 12.318, 0)
      - (0, 0, 124.201)
Test Case
Test Case: CeRAS

- Investigate OpenVSP enabled mass properties capability for LEAPS Inertias
- CeRAS/CPACS (XML) file has no inertia data
- Need VSP model, IGES is provided
“Inertia Calculation for Preliminary Design” - 1979 AFRL Document

Procedure

- Define Geometry using basic shapes
- Allocate mass, assign densities
  - Components, distributed, point, volumes
- Calculate component inertias about reference axis
  - Eight shape based inertia calculations
- Sum and translate inertias to vehicle cg
  - Parallel Axis Theorem in a spreadsheet

Several comparisons with existing aircraft, one detailed example for a C5-A!
**Inputs**
- Mass statement
- Geometry
- Vehicle and component level inertias for comparison

**Table 6. C-5A Weight Statement**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
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<tbody>
<tr>
<td>Wing Group - Center Section</td>
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<td>- Interplane Panel</td>
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<td>- Outer Panel</td>
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<td>- Secondary Structure</td>
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<td>- Aft Stabilizing Loop, EOA Balance Weights</td>
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<td>Flaps - Stabilizing Edge</td>
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<td>Slats - Leading Edge</td>
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<td>Spoilers</td>
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<td>Tail Group</td>
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<td>Stabilizer - Basic Structure</td>
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<td>- Elevation Trim, EOA Balance Weights</td>
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<td>Fin - Basic Structure</td>
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<td>Rudder</td>
<td>217.5</td>
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<td>Body Group (Including Manufacturing Variations of -07.2)</td>
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<tr>
<td>Fuselage - Basic Structure</td>
<td>6126.8</td>
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<tr>
<td>Gear Pod (including NLG and NLG Doors)</td>
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<tr>
<td>Cargo Floor (including Tracway Wings &amp; Receivers)</td>
<td>7706.7</td>
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<td>Weapons and Falcons Line System</td>
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<td>AFT L/Hp (including Pressure Cover + Tails)</td>
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# C5-A Model – Geometry

## Geometry Parameters

**Table 10. C5-A Geometry Definitions for Inertia**

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<th>WING DATA</th>
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<td>b</td>
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<table>
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<td>Z b</td>
<td>ZP 1 - 222</td>
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</table>

8/19/2016

McMillin
35 Weight components - allocated to six groups
- Wing
- Horizontal tail
- Vertical tail
- Fuselage
- Propulsion
- Subsystems
  - Point masses
  - Distributed items
  - Volumes

20 cg location estimation/specifications

Aircraft Weight Allocation Components:
- Horizontal tail structure
- Vertical tail structure
- Fuselage structure
- Main gear
- Nose gear
- Engine Nacelle & Pylons
- Other structure
- Engine
- Aux gearboxes
- Exhaust system
- Cooling & drain
- Lubricating system
- Engine controls
- Oil
- Liquid Nitrogen
- Miscellaneous
- Payload
- Guns
- Starting system
- Auxiliary power unit
- Instruments
- Hydraulics
- Electrical
- Electronics
- Armament
- Air conditioning
- Photographic
- Auxiliary gear
- Other equipment
- Crew
- Wing Pylons
- Ext Wing tanks
- fuselage pylons
- Ext Fuselage tanks
- Fuel

CG Location Groups:
- Main and nose landing gear
- Auxiliary power unit
- Air conditioning
- Auxiliary gear
- Gun
- Crew
- Weapons
- Fuel system (Centroid of fuselage fuel tank)
- Avionics bays
- Radar
- Furnishings & Equipment
- Photographic equipment
- Other equipment
- Liquid nitrogen
- Miscellaneous items
- Fuselage store and tank pylons
- Fuselage external stores and tanks
- Wing store and tank pylons
- Wing external stores and tanks
- Internal Payload
Blank components
Visual cg verification
Volumes included here
Distributed mass allocated to green cylindrical shell

Propulsion modeled as solid cylinders
OWE – fuel level not addressed here

- Wing and Vertical differences due to modeling actual wing versus a trapezoidal slab

- Point mass difference due to treating avionics and furnishings as point masses

- Cg comparison also very favorable

<table>
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My experience

- All component based inertias
- Use of spreadsheet required
- Used ~100 slices (default 10), but is still very fast

1979 Paper process

- Ixx trick for “point mass”
- Avionics/furnishings volumes incorrect?
- Main gear “point masses” (gear down)
- Vertical tail location is moved aft
- Inconsistent selection of origin
- Sign error in equation on page 9

Use this process to reverse engineer Roskam’s radius of gyration data
Considerations
Draw cg not working
Point mass print out not adequate
Shell/Solid interface confusing
Don’t know what priority means – intersected meshes?
Requires scripting to loop through components to create a csv file, API?
Assign mass instead of density, save a step
Stability from version to version could be an issue
Way Forward

♦ **FreeCAD**
  - Requires parts to be solids for inertias
  - Investigate OCC area moments of inertia (surfaces)
  - 3-D printer ready!

♦ **An OpenVSP workbench inside of FreeCAD could provide a very powerful “Best of both worlds” scenario!**
Backup
Mass Properties Tool for Leaps

Flexibility is paramount
- Variety of mass breakdown structures
  - FLOPS
  - CPACS
- Mission phase capability

Recommendation
- Spreadsheet
- Collect mass data from a variety of sources and initialize VSP
- Parallel Axis Transfer and summation of VSP component data for inertia
C5-A Model – Mass Breakdown

Aircraft Weight Allocation Components:
- Horizontal tail structure
- Vertical tail structure
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- Fuselage external stores and tanks
- Wing store and tank pylons
- Wing external stores and tanks
- Internal Payload
Wing, horizontal tail, and vertical tail groups are all common surfaces. To define the shape of the surface the normal planview (one side of wing and horizontal since they're symmetrical) is used. The equations are derived for a trapezoidal panel with the thickness varying linearly from root to tip. If a surface has edge or thickness breaks, it should be separated into inner and outer trapezoidal panels with the inertia of each calculated separately. The thickness is assumed "constant as you go from leading to trailing edge and equal to the maximum for that section."
Early Considerations for Code Development

- Coding style guide
- Configuration control
  - Suite testing
- Database
  - Data dictionary
- Units
- Coordinate Systems

- Inertia presentation at VSP workshop?
Data Products
1. Wing Parameters
2. Mission Conditions
3. Material Properties
4. Vehicle Geometry
5. Vehicle Geometry
6. Aerodynamic Loads
7. Structural Weight

N2 Diagram
- VSP component macro
- VSP to AMMIT Interface
- AMMIT Structural Thickness
- FLOPS Subsystems
- Spreadsheet Mass Prop Calculator Tool

N2 Diagram