Safe Separation Analysis of the Internal GBU-32 JDAM from JSF

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Fort Worth, TX
JCS Threshold Weapon Requirements

Internal Weapons

GBU-38 JDAM 500-lb (MK-82 Warhead)
GBU-32 JDAM 1,000-lb (MK-83/BLU-110 Warhead)
GBU-31 JDAM 2,000-lb (BLU-109 Warhead)
GBU-31 JDAM 2,000-lb (MK-84 Warhead)
GBU-12 Paveway II 500-lb LGB (MK-82 Warhead)
UK 500# PGB

External Weapons

CBU-103 / 104 / 105 WCMD
CBU-87 / 89 Cluster Munition
AGM-154 A/C JSOW Glide Bomb
JDAM PGK (BLU-109 & MK-82)
Phase I SDB

AGM-158 JASSM
426-Gallon Wing Tank

AMRAAM C
AIM-132 ASRAAM
Brimstone
MK-76
BDU-48 / MK-58
Missionized Gun Pod (CV / STOVL)
AIM-120B
UK 500# PGB
GBU-12 Paveway II 500-lb LGB (MK-82 Warhead)

MK-82 BLU-111 500-lb LDGP
MK-82 BLU-111 BU-49 Ballute 500-lb HDGP
MK-83 BLU-110 LDGP 1,000-lb LDGP
MK-83 BSU-85 HDGP
MK-84 2,000-lb LD/HDPG
GBU-31 JDAM 2,000-lb (MK-84 / BLU-109 Warhead)
MK-84 BSU-50 Ballute 2,000-lb HDGP
AGM-65 Maverick (If 1760 compliant)
AIM-9X Sidewinder
AIM-132 ASRAAM
AGM-88 HARM (If 1760 compliant)

GBU-10 Paveway II 2,000-lb LGB (MK-84 Warhead)
GBU-16 Paveway II 1,000-lb LGB (MK-83 Warhead)
GBU-24/B Paveway III 2,000-lb LGB (MK-84 / BLU-109 Warhead)

MXU-64B/CNU-88 Baggage Pod

DISTRIBUTION STATEMENT A: Approved for public release; distribution is unlimited
Weapons Stations

- Over 18,000 Lbs Ordnance Capacity
- Nonpyrotechnic Suspension and Release
F-35 JSF Store Separation Analysis

Objective:
Demonstration of the process used by the F-35 JSF Store Separation team to analyze the pre-flight safe separation of the GBU-32 JDAM.

Topics:
– Store Separation 3 Step Process
– Flowfield Studies: New Grid Collection Methods
– In-Bay Aerodynamic Loads Modeling
  – Innovative Techniques for Database Building, Validation, and Flight Clearance Envelope Generation
– Applying MSC.Adams & VI-AirCraft to Store Separation Applications
JSF Store Separation 3-Step Process

**Step 1: Validation**

1. Grid Data
   - GEMD Database
   - Grid Data = CTS Aero?
   - 6DOF (ADAMS)
     - = CTS Traj?
       - Y: GEMD+ 6DOF OK
       - N: Miss Distance

**Step 2: Flight Envelope**

- 6DOF (M,Alt) → Miss Distance → Flight Clearance Envelope

**Step 3: Parameter Uncertainty**

- Monte Carlo → 6DOF → Miss Distance → Probability of Clearance
Flowfield Grid Studies

**Standard Grid:** *Extensive grid used for flowfield analysis*

- Tilt and Slant Sweeps
- Z Sweep to 25ft or WT limits
- Combined pitch and yaw displacements

**Snowman Grid:** *New Grid design for improved accuracy and test efficiency*

- Large Snowman
  ~170 Points (ZC and YC, combined pitch and yaw)
- Central Snowman
  ~18 Points (ZC, combined pitch and yaw)
Flowfield Grid Studies

Sta.8 1KJDAM, Transonic Low Altitude Case

Majority of cases have **Minimal** Effects on Trajectories near the AC

Snowman grids transition to a nominal z-sweep between 5-6 ft
In-Bay Aerodynamic Loads Modeling

• **Vacuum**
  – In-bay aero set to zero from carriage to park

• **Interp to Zero**
  – In-bay aero interpolated from park loads to zero at carriage (similar to CTS)

• **Interp to Carriage**
  – In-bay aero interpolated from park loads to carriage loads

• **In-Bay Loads**
  – In-bay aero obtained from an attached loads database

Data taken at various vertical positions and pitch displacements
In-Bay Aerodynamic Loads Modeling

Sta.8 1KJDAM, Transonic Low Altitude Case

**DX (in)**

**DY (in)**

**Roll (deg)**

**Pitch (deg)**

**Yaw (deg)**
In-Bay Aerodynamic Loads Modeling

- Recommendations
  - Use attached loads data, if available
  - Interpolate from park loads to zero
- Leverage modeling/simulation to reduce cost
- No additional attached loads WT testing planned

Minimal Effects on Trajectories, Miss Distance Plots, and Clearance Envelopes
JSF Store Separation 3-Step Process

Step 1: Validation

Grid Data

GEMD Database

Grid Data = CTS Aero?

N

Y

Step 2: Flight Envelope

6DOF (M,Alt) → Miss Distance

6DOF (ADAMS)

= CTS Traj?

N

Y

GEMD+ 6DOF OK

Flight Clearance Envelope

Step 3: Parameter Uncertainty

Monte Carlo → 6DOF → Miss Distance

Probability of Clearance
Flight Clearance Envelope

• ASEP High Fidelity Tool
  – ADAMS (Automatic Dynamic Analysis of Mechanical Systems)
  – ASEP (ADAMS Store Separation - customized VI-AirCraft)

• Flight Envelope Simulations
ASEP
Subsystem-based Approach

Subsystems
- Wheel(s)
- LGR
- Brakes
- Hydraulics
- Control Laws
- Engine
- Airframe
- Stores

Assemblies
- Wheel
- LGR Structure (w/o wheels)
- LGR Dynamics (w/ wheels)
- Full Aircraft
- Full Aircraft Stores

Simulations
- Wheel/Tire
- Steady Axle Load
- Drop Retract-Extend
- • Dyn. Tipback
  • Taxi & Shimmy
  • Braking
  • Landing
  • Catapult
  • In-flight
- • StoreMotion
  • Basic In-flight
  • Full maneuver
  • Simulation
  • Basic In-flight
  • Full maneuver
  • Pit ejection
# ASEP Workflow

<table>
<thead>
<tr>
<th>Components</th>
<th>Templates</th>
<th>Subsystems</th>
<th>Assemblies</th>
<th>Tests (Simulations)</th>
<th>Post-Processing</th>
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**Standard User**
- Existing → Existing or New → Existing or New → Existing → Existing or New

**Template Builder**
- Existing → New

**Customizer**
Flexible Parts:
(from NASTRAN / ANSYS)
- Pistons
- Swaybraces

Flexible Connections:
- Airframe attachments
- Releasable lugs
- Swaybrace pads
- Piston/Housing bearings

Friction:
- Piston/Housing bearings
- Swaybrace pads

Freeplay:
- Piston/Housing bearings
## ASEP Workflow

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**ASEP Workflow**

Lockheed Martin Aeronautics Company
Create Assemblies from Subsystems

Library of Subsystems

Stores Subsystem

Stores Subsystem

Airframe Subsystem

Select subsystems during assembly creation process

Store Assembly Only

Full-aircraft Assembly

Lockheed Martin Aeronautics Company
Assembly & Automated Simulation

- Comprised of rigid and/or flexible subsystems
- Ready for automated landing gear and/or store-related simulations
PostProcessing Simulation Results
JDAM Flight Envelope Simulations

- Miss distances are automatically computed in ASEP’s post-processor
- Need to perform 100+ simulations for each flight envelope
  - Repeat the envelope for:
    - Various G’s
    - Various +/- Roll rates
    - Flex/Freeplay, when necessary
    - Various adjacent stores
STOVL
(2) GBU-32 MK-83 JDAM (I) + (2) AIM-120C (I)

Basis for Assessment

• **CTS**: WS-15 data
• **Freestream**: Boeing large (~1/3) scale
• **In-Bay Loads**: WS-15 Attached Loads
• **Flowfield**: WS-15
• **CFD**: na
• **6DOF**: ADAMS (Rigid, no freeplay)
STOVL GBU-32 Envelope
0.5g, All Rigid, No Freeplay, 0°/sec Roll Rate

Flight Clearance Envelope

Trajectory

Miss

Miss Distance
STOVL GBU-32 Envelope
0.5g, All Rigid, No Freeplay, 25°/sec Roll Rate

Trajectory

Flight Clearance Envelope

Miss
Sample Ejector Mech. Differences

- Moving vs. Non-moving swaybraces
- Same ejector piston force, aero database, store, maneuver
Sample Flexible Simulations

- Launcher Rail, Aircraft Wing, BRU Attachments, etc.
JSF Affordability is Key

• Fewer store sep flight test points
• Increased number of aircraft/stores to certify

• Therefore,
  – Increased emphasis on:
    • Modeling & simulation
    • Validation
    • Efficiency
  – Pre-flight analysis is critical!
What’s New & Different?

• Flowfield Grid Studies - Uses for the Central Snowman
  – Exploratory studies to capture separation characteristics
  – Candidate as a CFD grid

• In-Bay Aerodynamic Loads Modeling
  – Minimal trajectory and miss distance effects
  – Use aerodynamic model to reduce testing costs

• Innovative Database Building and 6DOF Tool
  – Streamline process for building databases
  – Techniques provide good basis for validating aerodynamic databases and 6DOF analysis

• ASEP 6DOF Tool
  – Automation/speed, different user modes, higher fidelity
  – Quick integration of aero and autopilot modules
QUESTIONS?
Backup
Database Validation Techniques

• Flowfield Grid Studies
• In-Bay Aerodynamic Loads Modeling
• Innovative Tools for Database Building and Validation
  – GEMD (General Exchange of Methods and Data)
  – Automated Database Building Scripts
  – Wind-tunnel CTS* vs. Database Aerodynamics
  – Wind-tunnel CTS* vs. Database Trajectories

* CTS – Captive Trajectory System
Flowfield Grid Studies

**Standard Grid:** Extensive grid used for flowfield analysis

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**Snowman Grid:** New Grid design for improved accuracy and test efficiency

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**Z-Sweep Collection Method**

**Discrete Points Collected like “Pitch-Pause” Method**
Flowfield Grid Studies

• Wind-tunnel test efficiencies
  ~ “X” time units - Standard Grid
  ~ “X”×2 time units - Large Snowman
  ~ “X”÷2 time units - Central Snowman

• Central Snowman Pros/Cons
  + Reasonable comparisons with CTS
    – Discrete data points vs. sweeps
      • Less efficient for comparable amounts of data
      • Relies on linear interpolation in key locations

• Use the Central Snowman grid for exploratory cases and CFD
• Prediction errors used in uncertainty analysis
Flowfield Grid Studies

- Measured points used to:
  - Assess interpolation errors between grid collection methods
  - Incorporate into uncertainty analysis (Step 3 in the Process)

- Consider 3-levels of each parameter, uniformly spaced

  30” from Carriage
    - \( \Delta X_p = -2, 0, 2 \) in
    - \( \Delta Y_p = -2, 0, 2 \) in
    - \( \Delta Z_p = 25, 30, 35 \) in
    - \( \Delta \Psi = -3, 0, 3 \) deg
    - \( \Delta \Theta = -5, 0, 5 \) deg
    - \( \Delta \Phi = -10, 0, 10 \) deg

  48” from Carriage
    - \( \Delta X_p = -5, 0, 5 \) in
    - \( \Delta Y_p = -4, 0, 4 \) in
    - \( \Delta Z_p = 43, 48, 53 \) in
    - \( \Delta \Psi = -5, 0, 5 \) deg
    - \( \Delta \Theta = -10, 0, 10 \) deg
    - \( \Delta \Phi = -20, 0, 20 \) deg

- Full Factorial = \( 3^6 = 729 \) Cases
- Taguchi L18 Array to Select 18 Cases
Flowfield Grid Studies

Sta.8 GBU-32 (1KJDAM)
Error = Measured minus Predicted Data

Snowman vs. Standard Grids produce similar error bands
Some error reduction for Large Snowman

Uncertainty Bands

Step 3: Monte Carlo Uncertainty Analysis
Database Validation Techniques

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Innovative Database Building Tools

Database Scripting Tool (dBST)
Automated Scripts for Generating/Validating Databases

Wind-Tunnel Data Files

Templates of Database Functions

Aerodynamic Database in GEMD
(General Exchange of Methods & Data)

“Black Box” Object

What effects do these differences have on trajectories?
6DOF Analysis and Validation

Sta.8 1KJDAM, Transonic Low Altitude Case

No ejector modeling

CTS motion to EOS

√ Store 6DOF validation

√ Database validation