Birdstrike Certification Tests of F-35 Canopy and Airframe Structure

Steve D. Owens
F-35 Structures Certification Lead
F-35 Structures Development
Lockheed Martin Aeronautics Company

Eric O. Caldwell
Mechanical Engineer Staff
Aircraft Systems Test Laboratory
Lockheed Martin Aeronautics Company

Mike R. Woodward
Chief Engineer - Structures
F-35 Chief Engineers Office
Lockheed Martin Aeronautics Company

2009 Aircraft Structural Integrity Program (ASIP) Conference
December 1-3, 2009
Jacksonville, FL

Presentation Outline

- **Birdstrike Assessment Approach**
- **Canopy Design & Requirements**
- **Canopy Bird Impact & Removal System Test Results**
- **F-35B STOVL Lift Fan Inlet Door Bird Impact Test Results**
- **Inlet Duct Structure - Strength Analysis & Test Plan**

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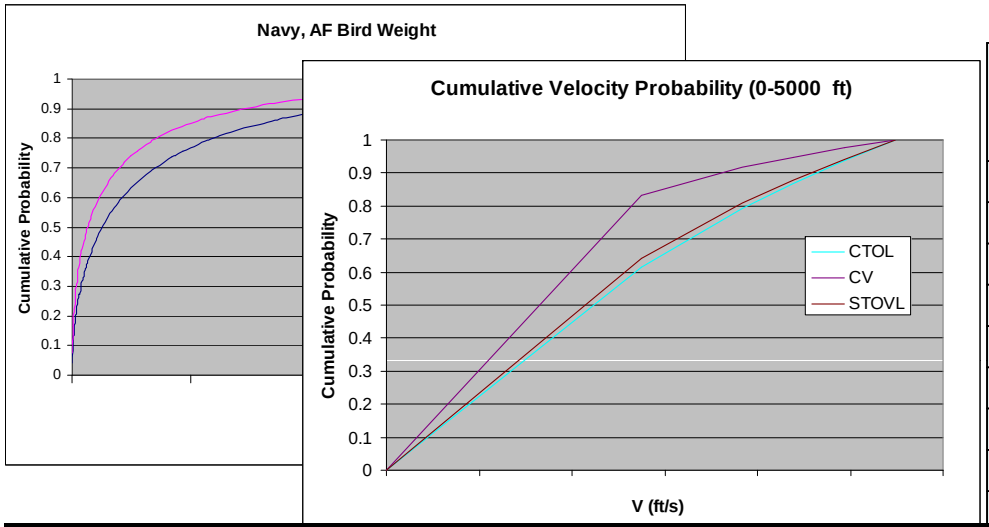
Aircraft Vulnerability to Bird Impact was Assessed in Preliminary Design



1 X 10 $^{-7}$ Event / Flt Hr

Aircraft Component	Vuln. Area (sq ft)	Bird Weight (lb)	Crit Vel. (kts)	Norm Bird Weight (lb)	Norm Vel. (kts)
HORIZONTAL TAIL LE	0.6	1	316	4	158
VERTICAL TAIL LE	2.4	1	449	4	225
INLET DUCT	3.3	1.5	393	4	240
CANOPY-CTOL/CV-AFT	1.1	1.5	451	4	276
CANOPY-STOVL-AFT	1.3	2	459	4	324
CANOPY-WINDSCREEN	5.0	2.5	448	4	354
RADOME					
LIFT FAN INLET D					
INTAKE FAIRINGS	10.0	4.5	505	4	536
		6	520	4	637

Notional Data

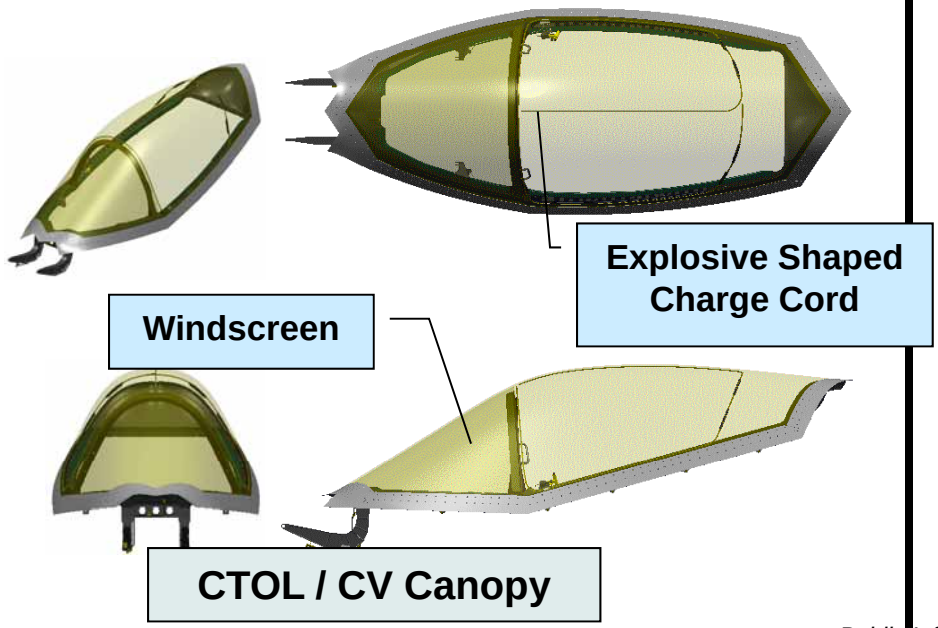
Flight Hour Data			# Events resulting in LOA				LOA Rate/Flt Hr (*10-7)			
AC Type	Reporting Period	Fleet Hours	Total	Canopy	Engine	Structure	Total	Canopy	Engine	Structure
AV-8B	1980-2005	850								
F-18	1980-2005	4								
F-16	1985-2005	7								
F-15	1985-2005	4193								

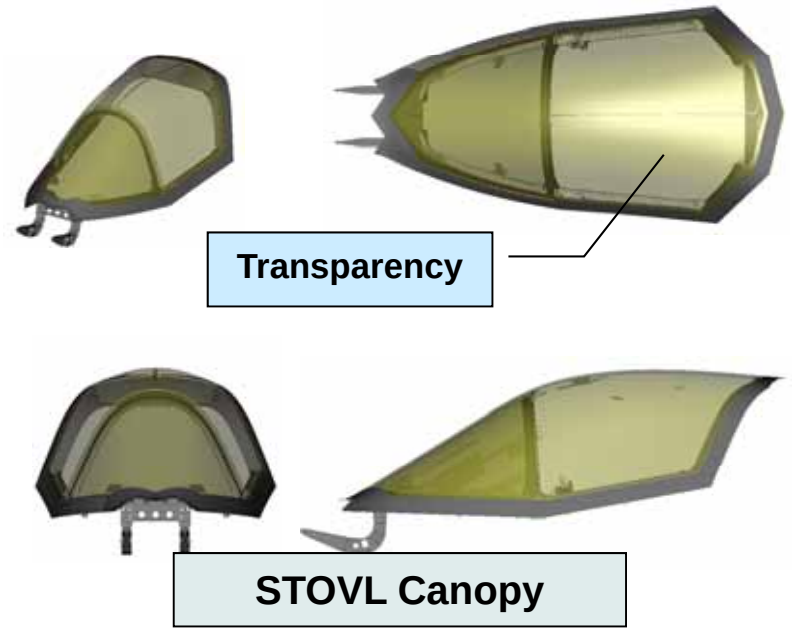
Probability = f(Bird Weight, AV Flight Envelope, Bird Population Density, Threat Area, Time)

- **Bird Strike Defined as a Probabilistic Based Design Criteria**
- **Historical Military Bird Strike Incidence Databases Used to Support System Safety Assessments Considering Structural 'Similarity'**
- **Assessment Led to Focus on <u>Canopy</u>, <u>STOVL Lift Fan Inlet Door</u>, and <u>Engine Inlet Duct</u> Structure for Mitigation & Verification Testing**

F-35 Canopy Design Description

- **Transparency is Single Piece Formed & Stretched Acrylic**
- **Thick Windscreen is Fwd of the Bowframe & Transitions to Thinner Transparency Section Aft**
- **CTOL & CV Canopy Designs are Common & Windscreen Design is Tri-variant Common**
- **Flexible Linear Shape Charge Bonded to IML to Facilitate Pilot Escape**





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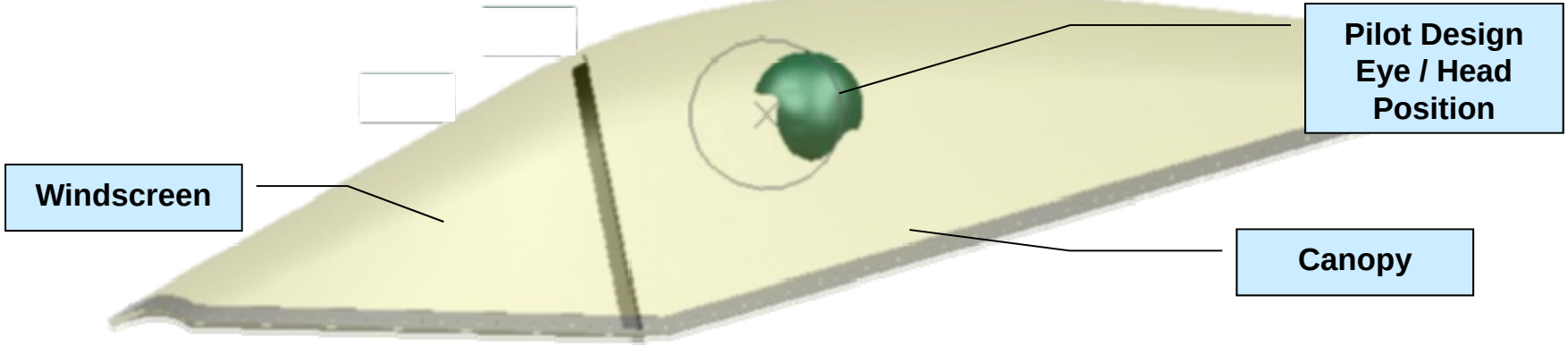
Canopy Bird Impact Design Criteria

- **Canopy Design & Test Success Criteria:**
  - ***Canopy System Must Withstand Impact of a 4 lb Bird at 480 Kt on the Reinforced Windscreen & 350 Kt on the Canopy Crown Without:***
    - ***Breaking or Deflecting so as to Strike the Pilot When Seated in the Design Eye "High" Position,***
    - ***Damage To The Canopy That Would Cause Incapacitating Injury To The Pilot, or***
    - ***Damage That Would Preclude Safe Operation of, or Emergency Egress From the Aircraft***



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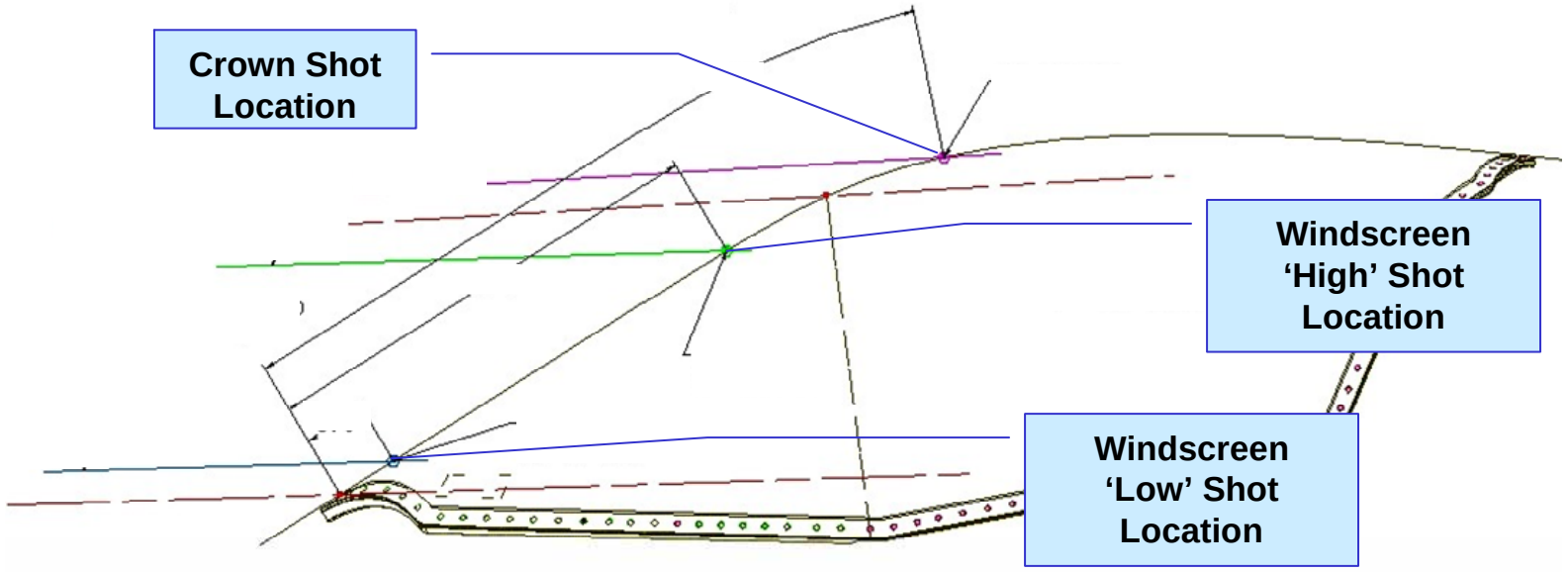
Canopy Bird Impact Test Approach

- ***Windscreen*** **Tests - 'High' & 'Low' Shots at 480 Kt with 4 lb Bird**
- ***Canopy Crown*** **Tests**
  - ***Shoot STOVL & CTOL/CV Variant Canopies Using 4 lb / 350 Kt Bird***
  - ***Subsequent Firing of Transparency Removal System to Validate Proper Functionality & Fly-away of the Transparency***



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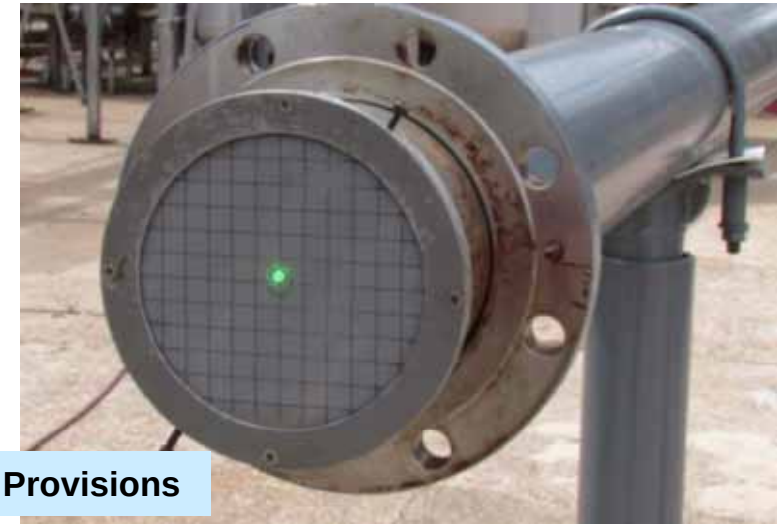
Bird Impact Test Facility & Setup

View Looking into the Business End of the Cannon

Speed 'Trap' to Measure Projectile Velocity



Bore Sighting Provisions

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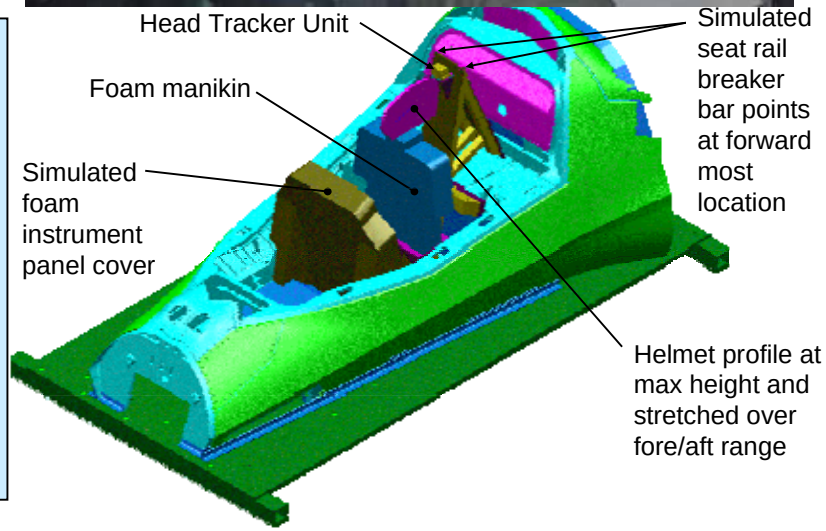
Accurate Representation of Boundary Conditions Maintained for Canopy Tests

- **Representative Forward Fuselage**
  - ➢**Include Canopy Frame & Latches**
  - ➢**Include Pressurized Canopy Seal**
- **Positioned at Aircraft Cruise Angle of Attack**
- **Set-up Simulated Features in Close Proximity to the Canopy Crown**
- **Projectile is a Euthanized Chicken**



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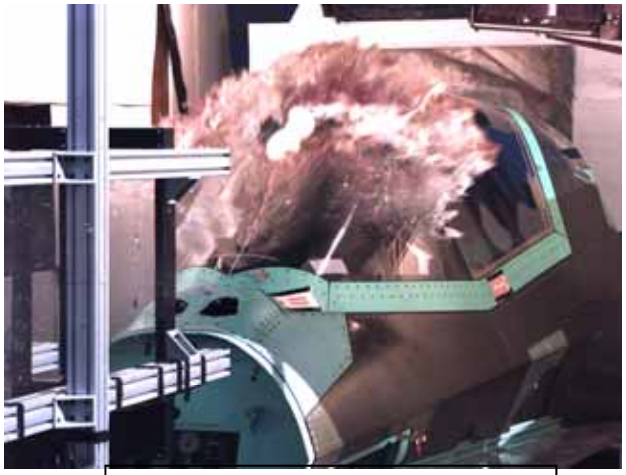
F-35 STOVL Windscreen Bird Impact Test



480 Kt – 4 lb Chicken

Canopy Bird Impact Design Requirements were Successfully Verified by Test

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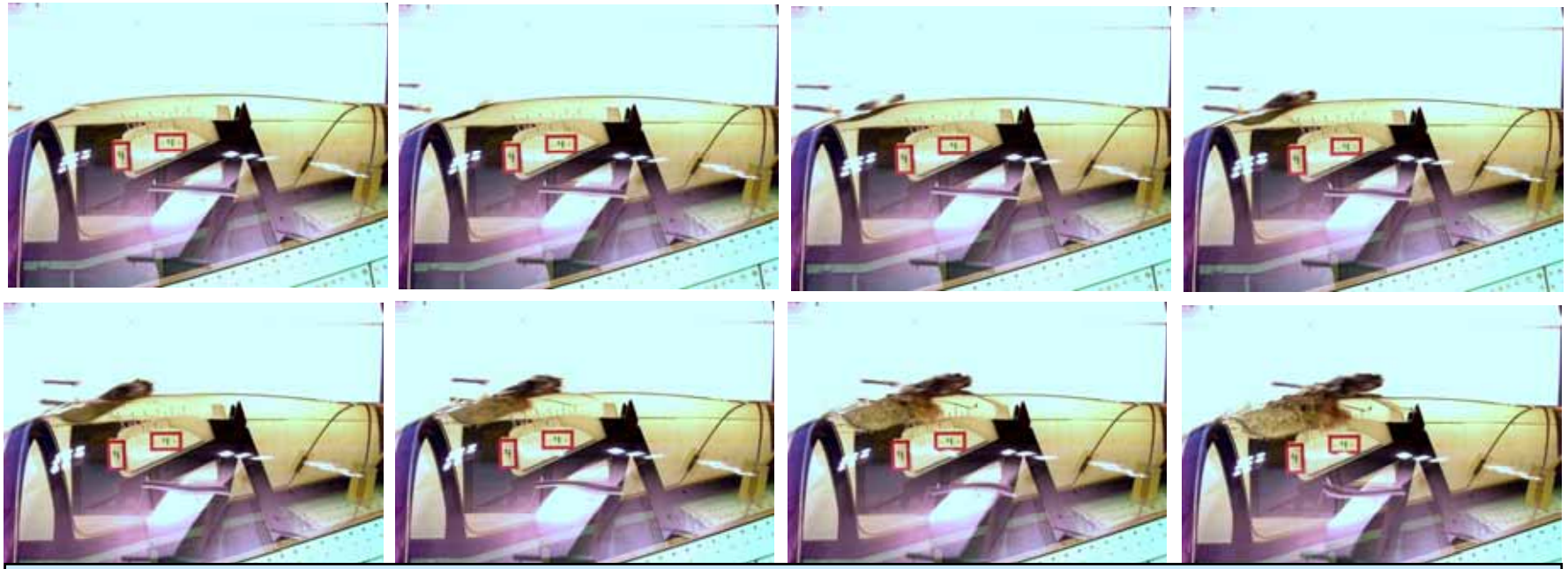
F-35 CTOL Canopy Crown Bird Impact - Design Development Test -



- CTOL 350 Knot Canopy Crown Bird Impact – 4.0 lb Chicken
- 0.0004 Seconds Per Image Displayed; 3 msec Duration
- Preliminary Design Transparency with Reduced Thickness Failed
- Test Success was Achieved for Re-sized Transparency

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Firing the Transparency Removal System

Post Bird Impact Test Firing of the TRS Detonation Cord Successfully Demonstrated Escape System Capability

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Design Criteria for Bird Impact on Airframe Structure

a) **Identify Structure Likely To Be Damaged from a Bird Mass/Speed Derived from a 1 X 10^{-5} Occurrence / Flt Hr to Identify Structure Likely Damaged for Logistics Planning**

Cost of Ownership Related Criteria

b) **Prevent Loss of Aircraft or Pilot Incapacitation Due to Impact from a Bird with Mass/Speed Derived from a 1 X 10^{-7} Occurrence / Flt Hr**

Flight Safety Driven Criteria

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STOVL Lift Fan Inlet Door Selected for Bird Impact Testing

- **Lift Fan Inlet Door Opens During STOVL Mode Operations**
- **Aircraft Forward Speeds are Relatively Low During STOVL Mode Flight**
- **Selected for Testing Due to Concern that Bird or Door Structural Debris Could be Ingested into the Lift Fan or Become FOD for the Main Engine via the Open Auxiliary Air Intake**

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STOVL Mode Flight Operating Doors

LFI Door is Comprised of Monolithic Carbon Composite Skins Mechanically Attached to Metallic Substructure

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Lift Fan Inlet Door Test Setup

- **Door Angle Set at "Full Open" Position Plus Increment to Account for Aircraft Angle of Attack**
- **Impact Location Centered on the Largest Bay Over the Fan**
- **Test for Score Used a 2 lb Bird Shot @ 140 Kt**
- **Test for Added Knowledge Used a 2 lb Gelatin Simulated 'Bird'**

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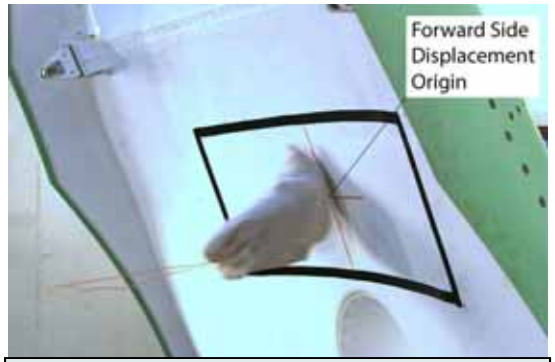
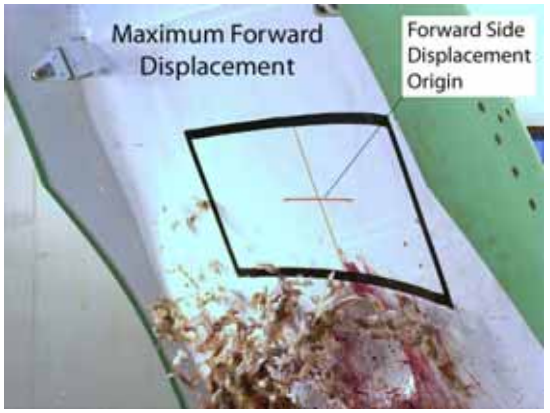
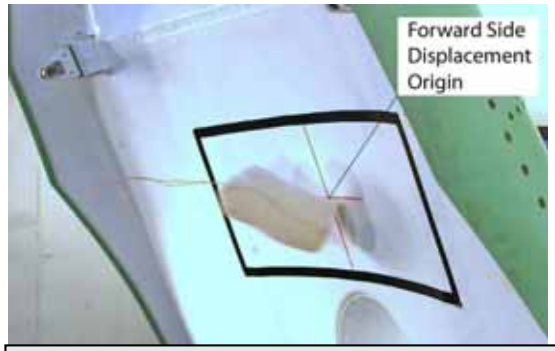
LFI Door Impact Test Results

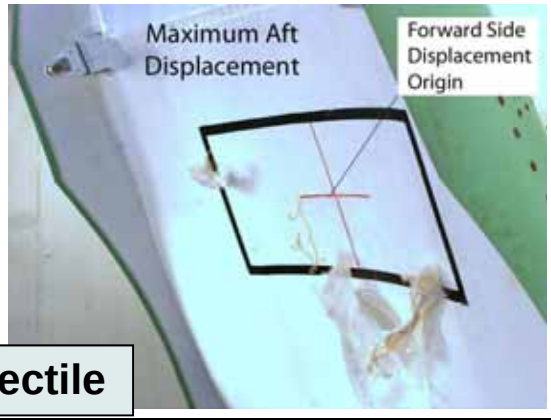
Chicken & Gelatin

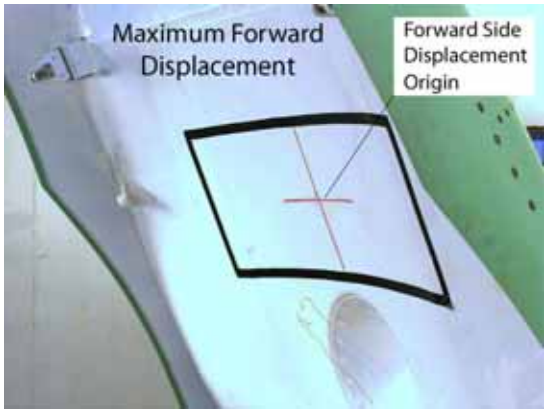




140 Kt / 2.0 lb Chicken







168 Kt / 2.0 lb Gelatin Projectile

- **Door Withstood the Bird Impact without Exhibiting A-scan Detectable Damage at the Impact Location**
- **Second Shot Using Gel Bird Yielded the Same Result**

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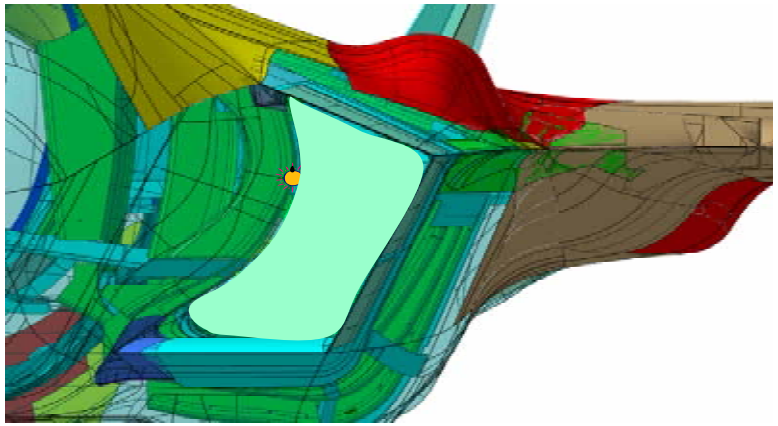
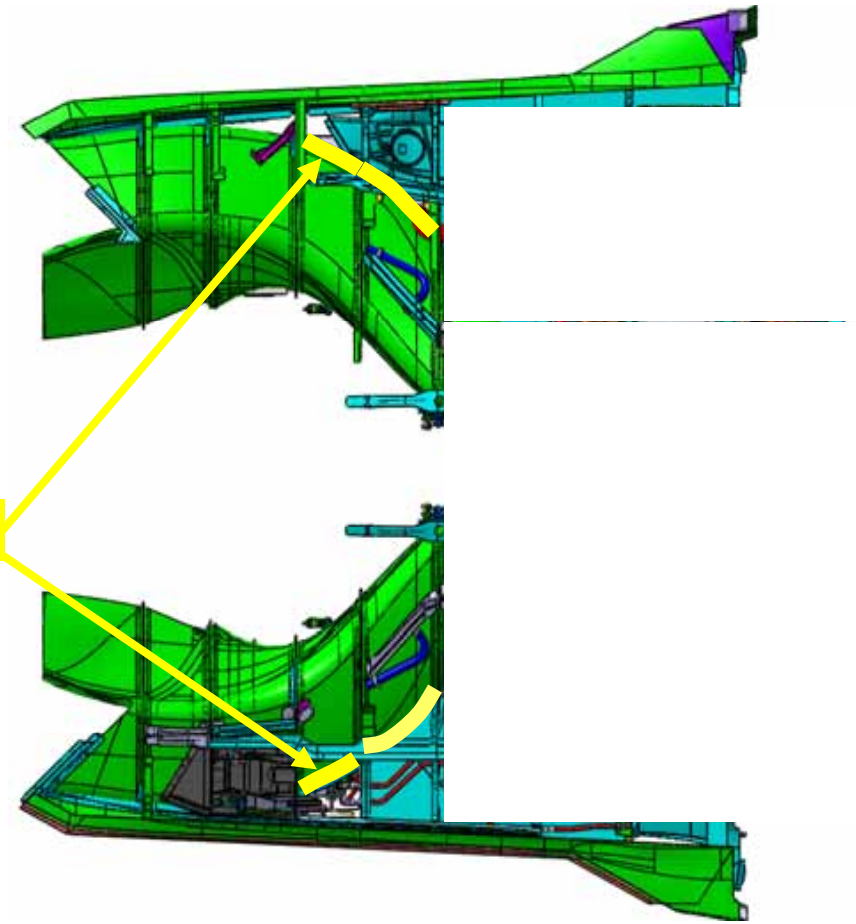
Engine Inlet Duct Structure Assessed During Design

- ***Inlet Duct Structure***
  - ***Composite Inlet Duct Skins are Mechanically Fastened to Metallic Substructure***
  - ***Vulnerability Analysis Considered Bounding Subsystem Installations***



View Looking Aft @ LHS Inlet Duct



View Looking Down

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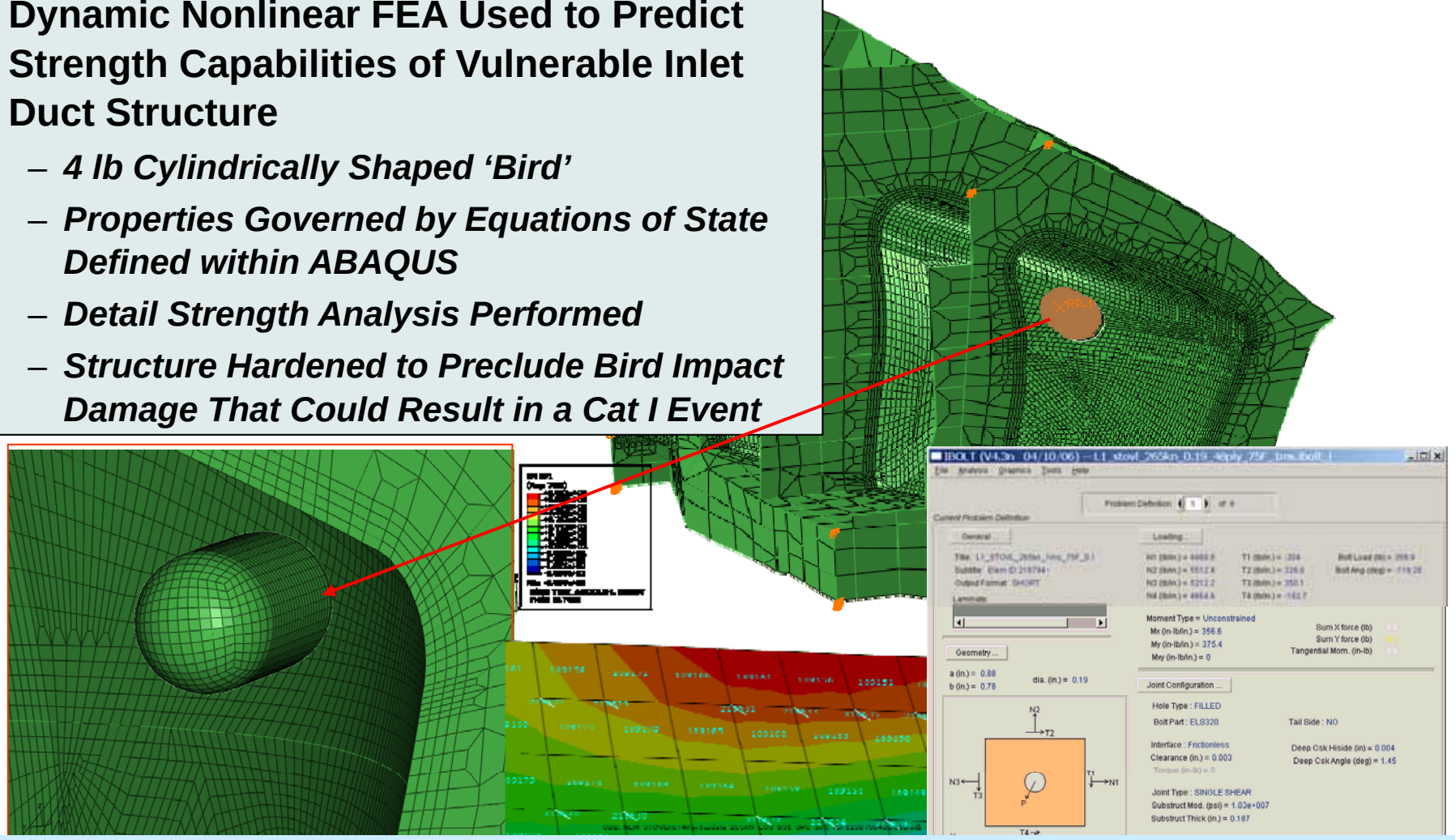
Dynamic FEA of Inlet Duct Structure Conducted During Design Development

- **Dynamic Nonlinear FEA Used to Predict Strength Capabilities of Vulnerable Inlet Duct Structure**
  - ***4 lb Cylindrically Shaped 'Bird'***
  - ***Properties Governed by Equations of State Defined within ABAQUS***
  - ***Detail Strength Analysis Performed***
  - ***Structure Hardened to Preclude Bird Impact Damage That Could Result in a Cat I Event***



Dynamic Nonlinear FEA Used During Design to Size Structure

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Conclusions

- **F-35 Airframe Structure & Canopy Meets Stringent Bird Impact Design Criteria as Validated by Structural Analysis & Representative Testing**

- **Minor Changes in Transparency Nominal Design Thickness Resulted in Significant Changes in Resistance to Bird Impact Induced Deflection & Damage**

- **Early Bird Impact Vulnerability Assessments & Application of Dynamic FEA During Preliminary Structural Design Led to Improvements that Enhance Air Vehicle Safety**

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Questions