NASA/TM–2013-217995/Volume II
NESC-RP-12-00822

Probing Aircraft Flight Test Hazard Mitigation for the Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) Research Team

Appendices

Michael J. Kelly/NESC
Langley Research Center, Hampton, Virginia

May 2013

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23681-2199

May 2013

Acknowledgments

Nielsen Engineering and Research, Inc., contractors Mr. Stanley C. Perkins, Jr., and Mr. Omar Quijano conducted aerodynamic analyses in support of this assessment.

Michael Sean Walsh provided excellent graphic artist support.

The following team members were significant contributors to the contents of this document.

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Volume II

Appendices

Probing Aircraft Flight Test Hazard Mitigation for the Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) Research Team

April 18, 2013

Volume II. Appendices

Appendix A. Initial Evaluation

Initial Evaluation:

Independent Assessment of the Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) Probing Aircraft Flight Test Hazard Mitigation

Walt Engelund – LaRC NCE

757.864.4486

w.c.engelund@nasa.gov

July 12, 2012

Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Identification

W. Engelund

July 12, 2012

Request Number: T-12-00822

Request Title: Independent Assessment of the Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) Probing Aircraft Flight Test Hazard Mitigation

Request Initiator: Mr. Brian Beaton

Request Date: July 9, 2012

Affected Center/Program/Project: LaRC, DFRC, GRC

Resolution Need Date: Sept 2012

Request Description:

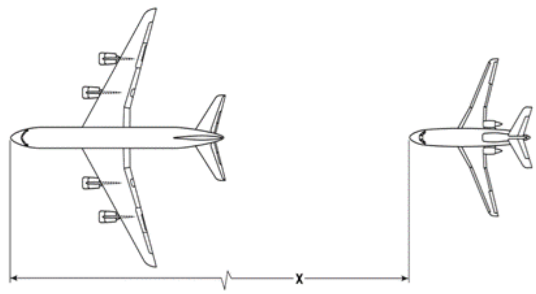
The Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) flight experiment, part of ARMD's Fundamental Aeronautics Program - Subsonic Fixed Wing Project, seeks to obtain in-situ airborne emission measurements from a DC-8 aircraft burning alternative fuels. This will be accomplished by flying a specially instrumented NASA HU-25 Falcon aircraft in the wake of a NASA DC-8 aircraft, in formation at distances from 100 meters to 10 kilometers aft of the predecessor aircraft, to measure its emissions and contrail characteristics as it burns JP-8 and a 50:50 blend of JP-8/Biofuel. Several potential hazards exist, two of which are the probing HU-25 Falcon aircraft may experience structural failure and/or engine out due to heavy turbulence and distorted flowfields in the wake of the large DC-8 aircraft. The ACCESS project is seeking NESC assistance to independently assess these two hazards and potential mitigations to ensure safety of flight.

This briefing is for status only and does not represent complete engineering data analysis

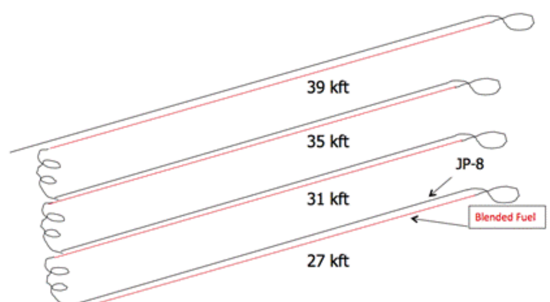
2

Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

ACCESS Flight Test Concept of Operations	W. Engelund
	July 12, 2012



Coordinated DC-8 and Chase Aircraft Flight Formation



Coordinated DC-8 and Chase Aircraft Flight Paths

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Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Initial Safety Hazards	W. Engelund
	July 12, 2012

Engine out due to ingestion of distorted flow

- Description
  - Ingestion of distorted flow in the wake of the heavy lead aircraft could cause engine distress up to and including flameout on the probing aircraft with potentially limited ability to restart.
- Effects
  - Mission success, loss of / damage to asset, personnel
- Possible Mitigations
  - Determine / examine engine distorted flow tolerance
  - Determine / examine wake distortion in the area to be probed
  - Determine and account for engine restart envelope
  - Evaluate probing aircraft state instrumentation capabilities
  - Use the above to determine safe operating limits and plan for recovery altitude for abnormal aircraft attitudes
  - Evaluate crew safety / egress

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Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Initial Safety Hazards	W. Engelund
	July 12, 2012

Aircraft Structural Failure

- Description
  - The probing aircraft will see significantly different flow conditions in the wake of the heavy lead aircraft than in normal planned operation resulting in a risk of overloading or failure of aircraft structural components.
- Effects
  - Mission success, loss of / damage to asset, personnel
- Possible Mitigations
  - Determine wake flow conditions for area to be probed
  - Compare certification loads for probing aircraft to expected loading from above and determine safe operating envelope
  - Examine additional instrumentation for structural health
  - Evaluate crew safety / egress
  - Utilize a build-up test approach to include envelope expansion testing.

Justification and Recommendation	W. Engelund
	July 12, 2012

Risk:

- **Will this activity enhance the overall safety of the programs/projects or the potential for mission success? [include NESC Risk Matrix if appropriate]**
  - *Potentially, yes. The project has specifically requested that the NESC provide an independent review and assessment of flight safety hazards and potential mitigation options.*
- **Will this activity reduce technical risks within the projects?**
  - *Potentially, yes. Same as above.*
- **Is there deviation from accepted specifications, standards, or practices?**
  - *No.*
- **What is the impact of the issue to NASA (safety, health, cost, science returns, and/or public visibility perspectives)?**
  - *The ACCESS flight test will provide a high value data set to ARMD, NASA, and our stakeholders to help assess the potential of alternative biofuels to reduce the impact of aviation on air quality and climate. Flight safety is a critical to the success of the program.*

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Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Justification and Recommendation (cont.)	W. Engelund
	July 12, 2012

Project Engagement

- **Does the program/project recognize the issue? What actions are they taking?**
  - *Yes. The project has multiple partners (LaRC, DFRC) who have conducted initial assessments of the potential hazards, and are currently proposing and pursuing several solution options to address and mitigate them.*
- **What priority have they assigned to it?**
  - *High.*
- **Does the program/project have the resources ($, skills) to resolve the issue?**
  - *TBD. The project is currently pursuing multiple options to address and mitigate the identified hazards. They are seeking independent NESC assessment to help determine the most appropriate course of action. Depending on the outcome they may or may not have the required budget or skills to mitigate the hazards and may require additional NESC support.*
- **Will this activity lead to cost savings or cost avoidances?**
  - *TBD.*
- **Are there dissenting opinions?**
  - *No, in the sense that no project decisions have been made yet on full mitigation strategy. However there are differing opinions over the need to acquire flight test data using separate F-18 aircraft to fully characterize the wake flow and understand the potential effects on the HU-25 Falcon.*
- **Is it program/project milestone critical?**
  - *Yes.*

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Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Justification and Recommendation	W. Engelund
	July 12, 2012

Given the nature of this request, the fact it involves safety of flight, and ultimately could help ARMD enable the ability to acquire a high value data set that would serve the aviation and climate communities, the recommendation is to pursue this request as an independent NESC assessment.

It is recommended that the NESC assemble an independent team of experts, who would first consult with the ACCESS flight test team to fully understand the potential hazard issues, history, and the project's multiple proposed approaches to address them. The NESC team should then conduct its own independent assessment and provide to the project a list of recommended mitigation options.

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Initial Evaluation Temp
NESC-PR-006-TP-01, March 8, 2012

Appendix B. ACCESS System Requirements Review (June 2012)

1: Information in this presentation material is no longer "Pre-Decisional." All materials and work has been finalized.
2: Because all budget information has been removed from this presentational material, this presentation is no longer considered "For Internal NASA Use Only."

Agenda

Time	Duration	Presenter	Topic of Discussion
8:30 AM	0:10	R. Del Rosario/ R. Wahls	01 Welcome/SFW Background
8:40 AM	0:15	B. Anderson/ B. Beaton	02 ACCESS Background/ Flight Experiment Structure
8:55 AM	0:05	B. Beaton	03 SRR Overview/Success Criteria
9:00 AM	0:05	B. Beaton	04 ACCESS Flight Experiment Need and Goals
9:05 AM	0:40	B. Beaton	05 System Requirements
9:45 AM	0:10	B. Beaton	06 Data & Communication Requirements
9:55 AM	0:20	B. Anderson	07 Concept of Operations
10:15 AM	**0:15**	**Break**	**Break**
10:30 AM	0:30	B. Beaton/ B. Anderson	08 Operational Requirements
11:00 AM	0:15	B. Beaton/ B. Anderson	09 Modifications to Aircraft/ System Interfaces
11:15 AM	0:10	B. Beaton	10 ACCESS Management Review/ Safety & Airworthiness Review Process
11:25 AM	0:05	Questions	
11:30 AM	**1:00**	**Lunch**/B. Beaton	11 Initial Safety Hazards
11:45 AM	0:15	B. Beaton	12 Initial Risks
12:00 PM	0:15	B. Beaton	13 Schedule
12:15 PM	0:15	B. Beaton	14 Preliminary Costs
12:30 PM	0:30	Review Board	15 Summary

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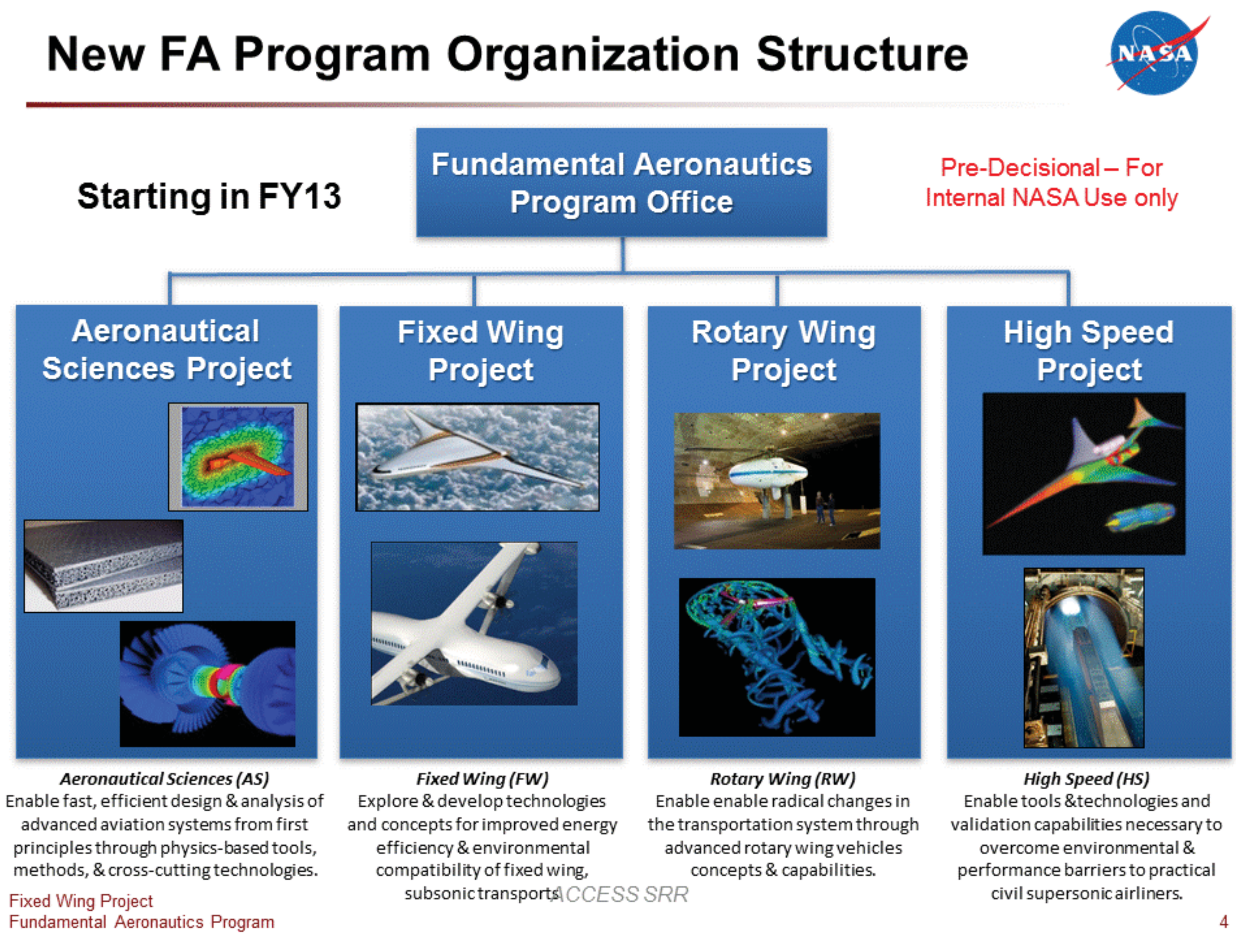
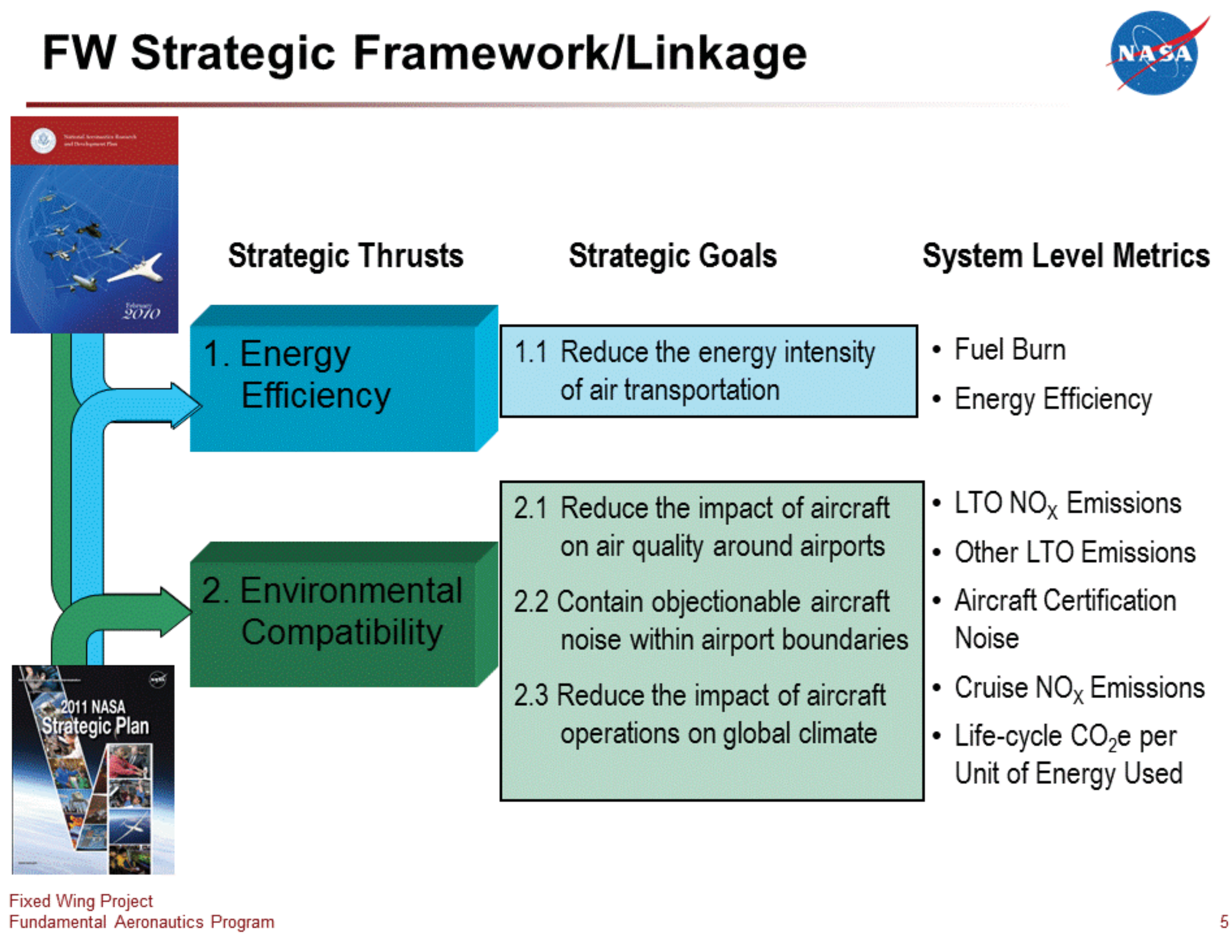
01 Welcome/SFW Background



New FA Program Organization Structure
Starting in FY13
Fundamental Aeronautics Program Office
Pre-Decisional – For Internal NASA Use only
Aeronautical Sciences Project
Fixed Wing Project
Rotary Wing Project
High Speed Project
Aeronautical Sciences (AS)
Enable fast, efficient design & analysis of advanced aviation systems from first principles through physics-based tools, methods, & cross-cutting technologies.
Fixed Wing (FW)
Explore & develop technologies and concepts for improved energy efficiency & environmental compatibility of fixed wing, subsonic transports
Rotary Wing (RW)
Enable enable radical changes in the transportation system through advanced rotary wing vehicles concepts & capabilities.
High Speed (HS)
Enable tools &technologies and validation capabilities necessary to overcome environmental & performance barriers to practical civil supersonic airliners.
Fixed Wing Project
Fundamental Aeronautics Program
ACCESS SRR
4


FW Strategic Framework/Linkage
Strategic Thrusts
Strategic Goals
System Level Metrics
1. Energy Efficiency
1.1 Reduce the energy intensity of air transportation
• Fuel Burn
• Energy Efficiency
2. Environmental Compatibility
2.1 Reduce the impact of aircraft on air quality around airports
2.2 Contain objectionable aircraft noise within airport boundaries
2.3 Reduce the impact of aircraft operations on global climate
• LTO NO_X Emissions
• Other LTO Emissions
• Aircraft Certification Noise
• Cruise NO_X Emissions
• Life-cycle CO_2e per Unit of Energy Used
2011 NASA Strategic Plan
2010
Fixed Wing Project
Fundamental Aeronautics Program
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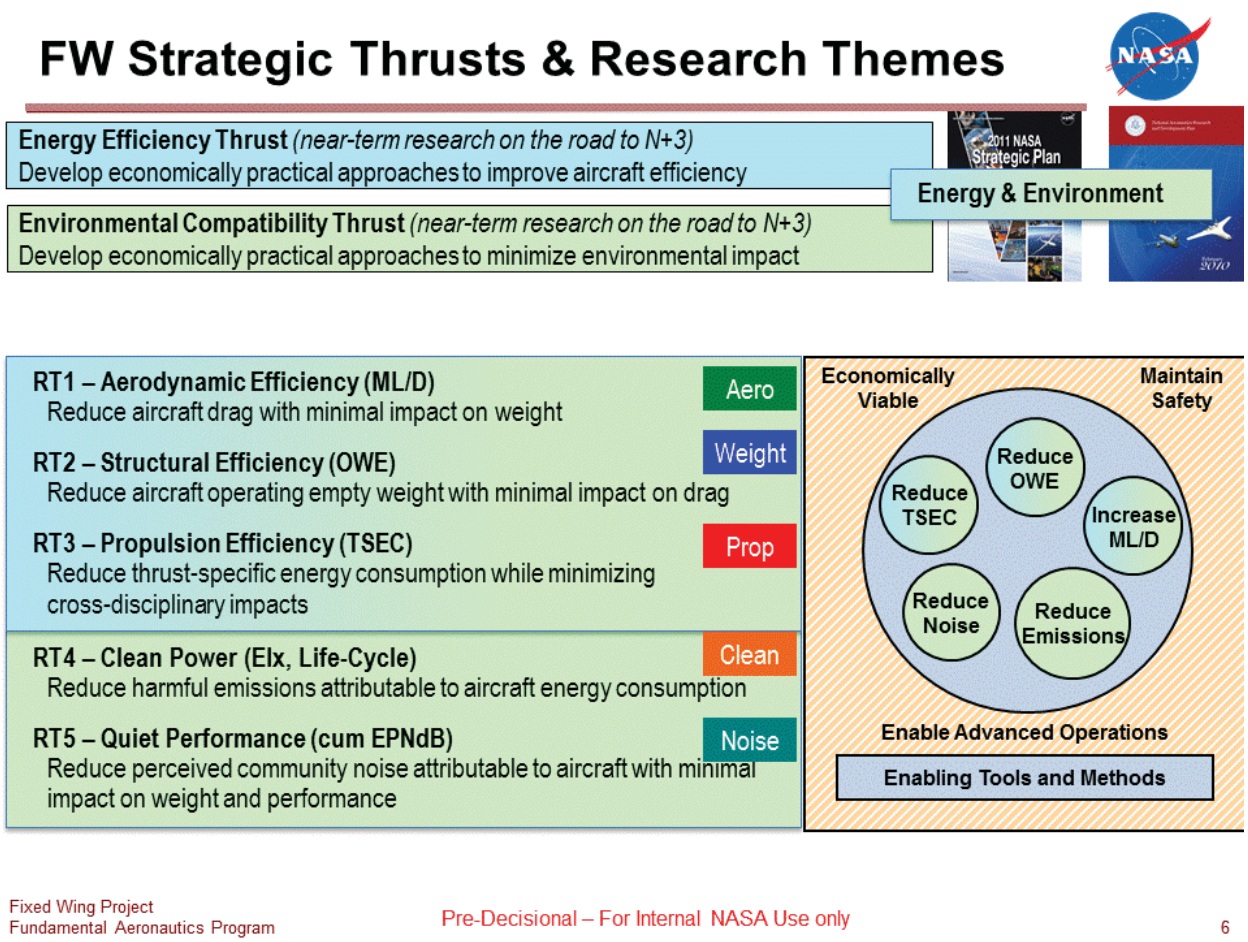

FW Strategic Thrusts & Research Themes
Energy Efficiency Thrust (near-term research on the road to N+3)
Develop economically practical approaches to improve aircraft efficiency
Environmental Compatibility Thrust (near-term research on the road to N+3)
Develop economically practical approaches to minimize environmental impact
2011 NASA Strategic Plan
Energy & Environment
RT1 – Aerodynamic Efficiency (ML/D)
Reduce aircraft drag with minimal impact on weight
Aero
RT2 – Structural Efficiency (OWE)
Reduce aircraft operating empty weight with minimal impact on drag
Weight
RT3 – Propulsion Efficiency (TSEC)
Reduce thrust-specific energy consumption while minimizing cross-disciplinary impacts
Prop
RT4 – Clean Power (Elx, Life-Cycle)
Reduce harmful emissions attributable to aircraft energy consumption
Clean
RT5 – Quiet Performance (cum EPNdB)
Reduce perceived community noise attributable to aircraft with minimal impact on weight and performance
Noise
Economically Viable
Maintain Safety
Reduce OWE
Reduce TSEC
Increase ML/D
Reduce Noise
Reduce Emissions
Enable Advanced Operations
Enabling Tools and Methods
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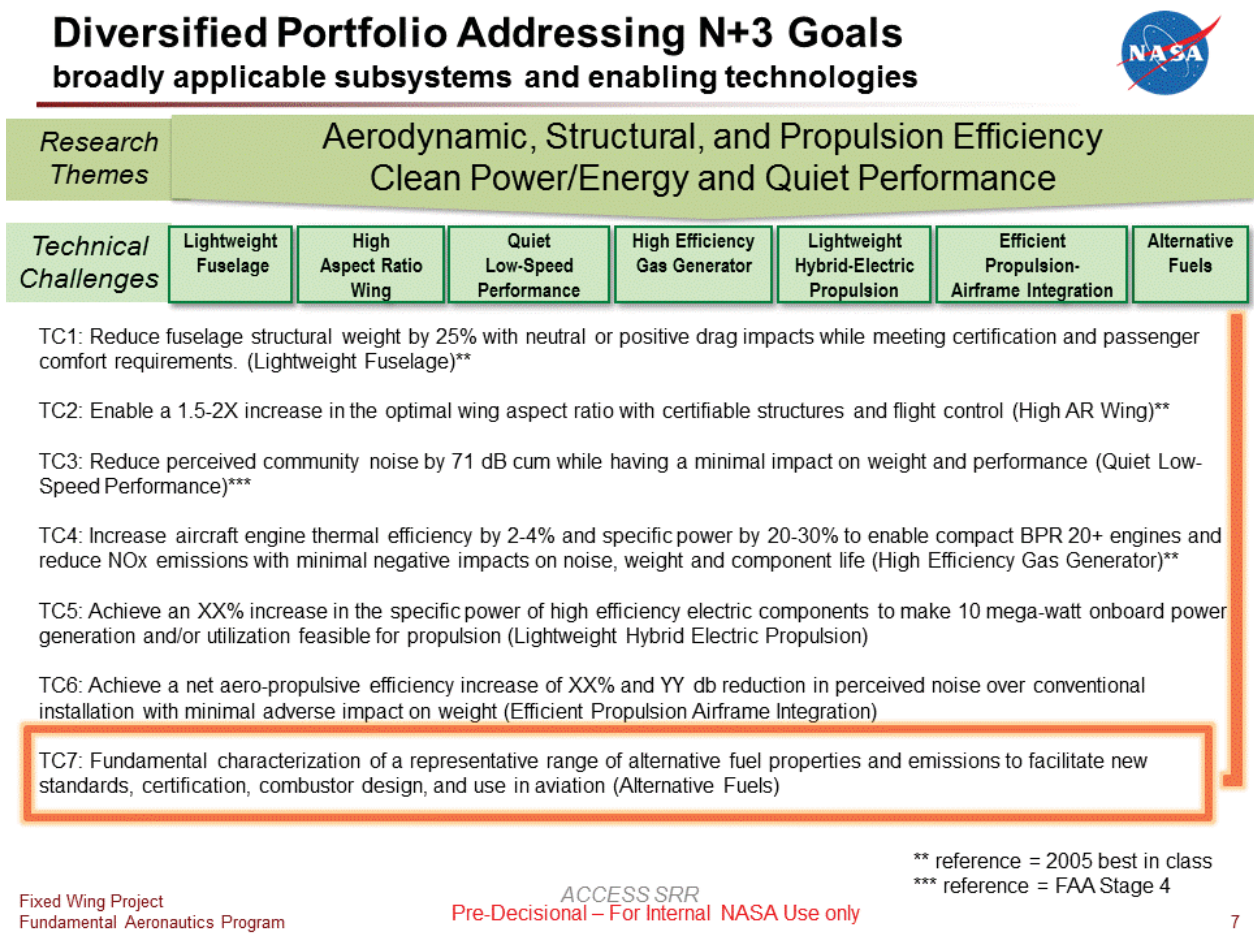

Diversified Portfolio Addressing N+3 Goals
broadly applicable subsystems and enabling technologies
Research Themes
Aerodynamic, Structural, and Propulsion Efficiency
Clean Power/Energy and Quiet Performance
Technical Challenges
Lightweight Fuselage
High Aspect Ratio Wing
Quiet Low-Speed Performance
High Efficiency Gas Generator
Lightweight Hybrid-Electric Propulsion
Efficient Propulsion-Airframe Integration
Alternative Fuels
TC1: Reduce fuselage structural weight by 25% with neutral or positive drag impacts while meeting certification and passenger comfort requirements. (Lightweight Fuselage)**
TC2: Enable a 1.5-2X increase in the optimal wing aspect ratio with certifiable structures and flight control (High AR Wing)**
TC3: Reduce perceived community noise by 71 dB cum while having a minimal impact on weight and performance (Quiet Low-Speed Performance)***
TC4: Increase aircraft engine thermal efficiency by 2-4% and specific power by 20-30% to enable compact BPR 20+ engines and reduce NOx emissions with minimal negative impacts on noise, weight and component life (High Efficiency Gas Generator)**
TC5: Achieve an XX% increase in the specific power of high efficiency electric components to make 10 mega-watt onboard power generation and/or utilization feasible for propulsion (Lightweight Hybrid Electric Propulsion)
TC6: Achieve a net aero-propulsive efficiency increase of XX% and YY db reduction in perceived noise over conventional installation with minimal adverse impact on weight (Efficient Propulsion Airframe Integration)
TC7: Fundamental characterization of a representative range of alternative fuel properties and emissions to facilitate new standards, certification, combustor design, and use in aviation (Alternative Fuels)
** reference = 2005 best in class
*** reference = FAA Stage 4
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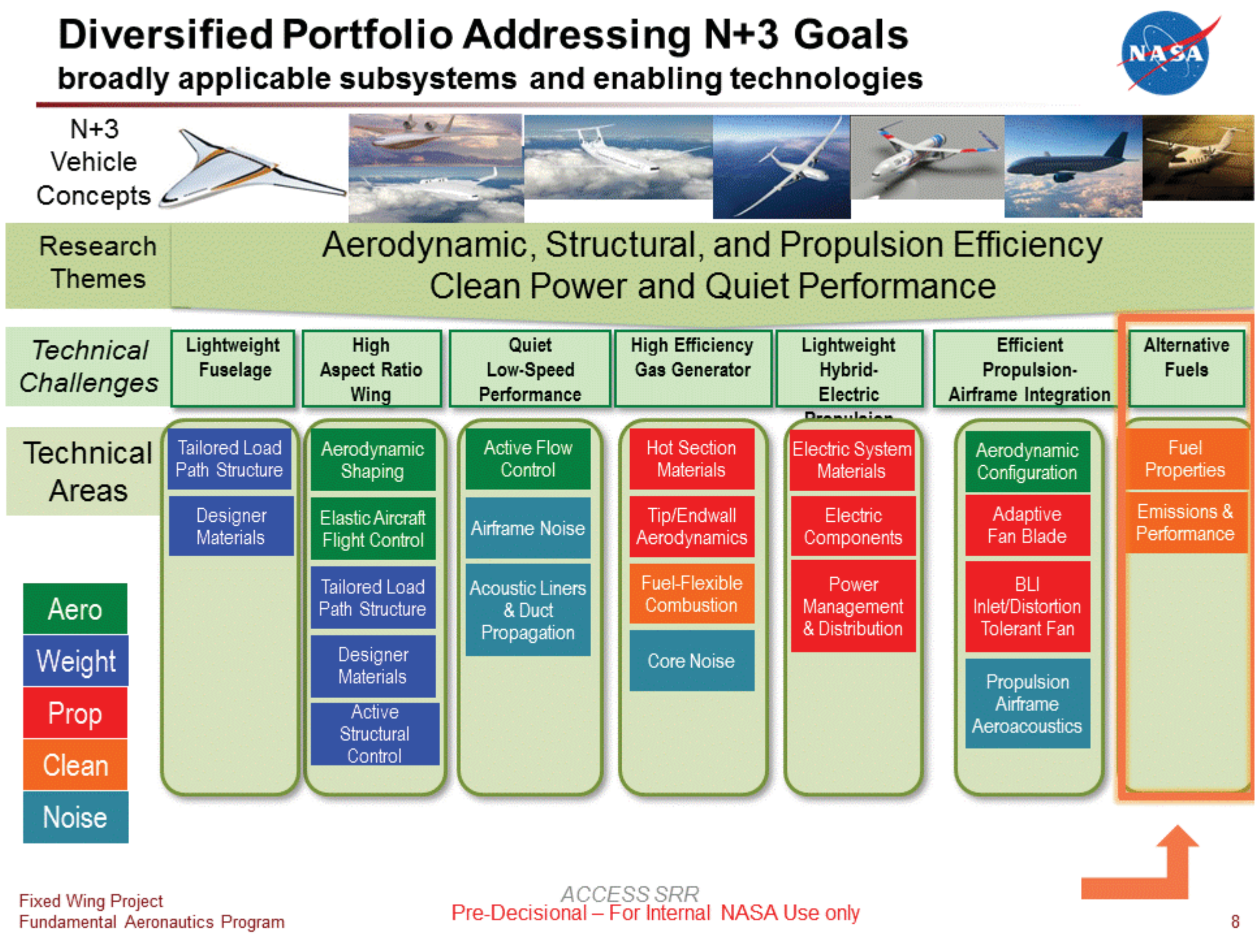

Diversified Portfolio Addressing N+3 Goals
broadly applicable subsystems and enabling technologies
N+3 Vehicle Concepts
Research Themes
Aerodynamic, Structural, and Propulsion Efficiency
Clean Power and Quiet Performance
Technical Challenges
Lightweight Fuselage
High Aspect Ratio Wing
Quiet Low-Speed Performance
High Efficiency Gas Generator
Lightweight Hybrid-Electric
Efficient Propulsion-Airframe Integration
Alternative Fuels
Technical Areas
Tailored Load Path Structure
Designer Materials
Aerodynamic Shaping
Elastic Aircraft Flight Control
Tailored Load Path Structure
Designer Materials
Active Structural Control
Active Flow Control
Airframe Noise
Acoustic Liners & Duct Propagation
Hot Section Materials
Tip/Endwall Aerodynamics
Fuel-Flexible Combustion
Core Noise
Electric System Materials
Electric Components
Power Management & Distribution
Aerodynamic Configuration
Adaptive Fan Blade
BLI Inlet/Distortion Tolerant Fan
Propulsion Airframe Aeroacoustics
Fuel Properties
Emissions & Performance
Aero
Weight
Prop
Clean
Noise
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Alternative Fuels

characterization of alternative fuels

Objectives

Drag Weight TSFC **Clean** Noise

Investigate potential of Alternative Fuels to reduce the impact of aviation on air quality and climate.

Technical Areas & Approaches

Fuel Property Characterization

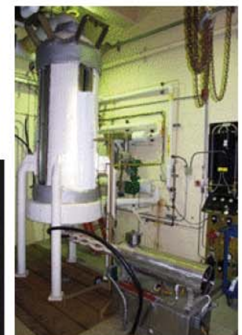
- Thermal stability, chemical kinetics, ignition energy

Emission & Performance Characterization

- Emissions Testing of advanced combustor concepts and in-use gas-turbine engines with alternative fuels and fuel blends
- Laboratory Scale Alternative Fuel Effects on contrails, exhaust plume chemistry, particulates, at simulated altitude conditions
- Flight Testing of alternative fuels with detailed plume sampling to measure emissions and study exhaust plume chemistry and fuel effects on contrail formation

Benefit/Pay-off

- Dramatic reductions in the impact of aviation on the environment
  - Reduced particulate and gaseous emissions
  - Reductions or elimination of contrails
  - Reductions in CO_2



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Fixed Wing Project Key Deliverables

SFW prior to FY13, FW in FY13 going forward

AAFEX/ACCESS Project Milestones

AAFEX:

- FY09 2Q AAFEX 1 Ground Test Complete
- FY10 4Q AAFEX 1 Data Analysis Summary
- FY11 2Q AAFEX 2 Ground Test Complete
- FY12 4Q AAFEX 2 Data Analysis Summary

ACCESS:

- FY13 2Q ACCESS 1 Initial Flight Test of HEFA fuels
- FY13 4Q ACCESS 1 Data Analysis Complete
- FY14 2Q ACCESS 2 Flight Test of HEFA fuels
- FY14 Zero Sulfur/Control Flight Test

FY15 4Q Alternative Fuel Emissions Characterization in Flight (industry, military, regulatory/standard-setting orgs)

- Characterizes gaseous and particulate emissions of hydroprocessed esters and fatty acids (HEFA) blended jet fuels in flight as potential carbon dioxide (CO2) reducing aviation fuel using data from ACCESS 1 and ACCESS 2 flight tests in ACCESS 2 flight tests in FY13 and FY14.

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02 ACCESS Background/ Flight Experiment Structure

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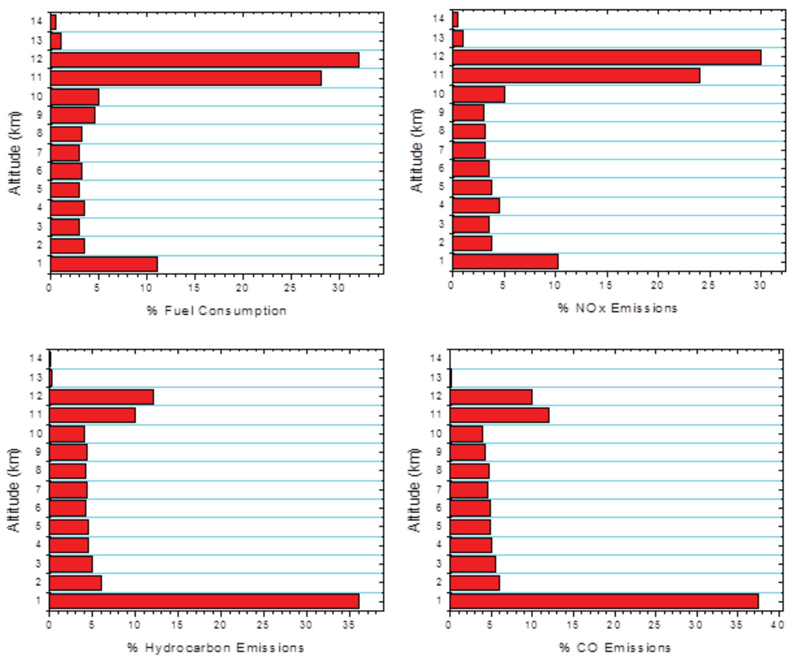
Motivation for Flight Experiment



- Almost 90% of Jet fuel burned during flight
- NOx emissions peak at cruise altitudes, can effect ozone budget in Upper Trop/Lower Stratosphere
- Particle and water vapor emitted at cruise can effect cirrus cloud occurrence and radiative properties

- Ground-based emissions impact local air quality
- Cruise emissions impact climate via O_3 and Cloud Effects

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Ground-based Measurements Can Not Satisfy Science Requirements

- Because of differing ambient temperatures and pressures, cruise-level power settings are very poorly simulated in ground tests; altitude test cell operations are expensive and can't reproduce atmospheric mixing processes
- Emission parameters are very temperature dependent--ground-level tests cannot replicate the cold, dry conditions present at flight altitudes
- Emission impacts on contrails cannot be assessed at ground level
- Except for number EI observations, there are very little data available to relate ground-based PM emission parameters to cruise altitude emissions; data for black carbon mass/number emissions are particularly lacking and potentially important for climate assessments
- Very little data available to relate aircraft PM emissions to contrail formation and characteristics—still some uncertainty as to whether exhaust PM and fuel sulfur plays a primary role in ice formation or if background aerosol sufficient in most cases to seed nucleation

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Motivation Specific to Alternative Fuels

Ground-based tests indicate that alternative fuels:

- Greatly reduce aircraft black carbon number and mass emissions at all power settings
- Reduce secondary aerosol formation
- Generate smaller black carbon particles, which are largely insoluble

Modeling studies suggest:

- Homogeneous nucleation is slow, particles needed to seed contrail ice formation
- Ice is slow to form on insoluble particles, can potentially suppress contrails by reducing black carbon number & size and eliminating sulfur from fuels

Altitude chamber tests indicate that:

- Exhaust PM essential for formation of ice particles in near-field region
- Ice nucleation rates depend on PM number, size and solubility
- Ice onset can be delayed by modifying soot surface properties

Big Questions:

- Do alt fuels similarly reduce PM emissions at altitude?
- Do reduced PM numbers, size, and solubility effect contrail formation or properties?

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Previous Airborne Emissions Tests

NASA

- Subsonic Assessment Near-Field Interactions (SNIF-1), Summer 1995
  - Sabreliner chased NASA B737, P-3B, and C-130 over east coast
- Subsonic Assessment Near-Field Interactions (SNIF-2), Winter 1996
  - Sabreliner sampled MD80, B757, B747 in east coast flight corridors
- Subsonic Assessment Cloud and Contrail Effects Special Study (SUCCESS), Spring 1996
  - Sabreliner chased NASA DC-8 and B757
- Subsonic Assessment Near-Field Interactions (SNIF-3), Summer 1997
  - Sabreliner sampled ANG F-16s over Vermont and New Jersey

German Aerospace Agency (DLR)

- SULFUR flight series, mid 1990's , Falcon 20 chasing ATTAS, A310, A340, B707, B747, B737, DC8, DC10
- Pollution from aircraft emissions in the North Atlantic (Polinat), Falcon 20, late 1990's
- CONCERT—Falcon 20, various aircraft, 2009-2011
- **Lufthansa flight experiment, Falcon 20 chasing A380 with bio fuel, Spring 2012**

NRC Canada

- Wake/Vortex Dynamics Measurements—T33 chasing commercial and military AC
- Alt Fuel effects—T33 chasing military AC burning biofuel

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ACCESS Approach Demonstrated During SNIF/SUCCESS Flight Series

- Selected T-39 Sabreliner based on proximity, cost and availability
- Modified airframe with aerosol and gas inlets and venturi port on roof, 5-hole pressure port system on nose, and pylons for cloud probes
- Payload included sensors for CO2, SO2, and aerosols

- Flight plans included self-sampling T-39 emissions and contrails at cruise, sampling commercial AC emissions 5 miles in trail and near-field sampling behind other NASA Aircraft
- Successfully conducted more than 30 flights over 3 year period

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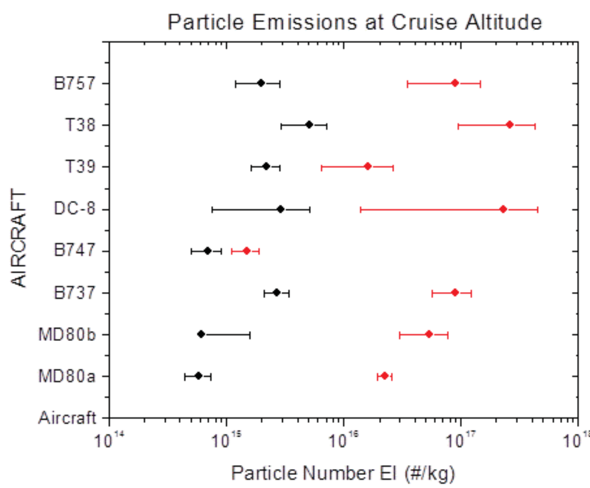
SNIF-2, Winter/Spring 1996

Flew Instrumented T-39 within flight corridors and behind NASA DC-8; measured particles, H_2SO_4 and wake vortex motion

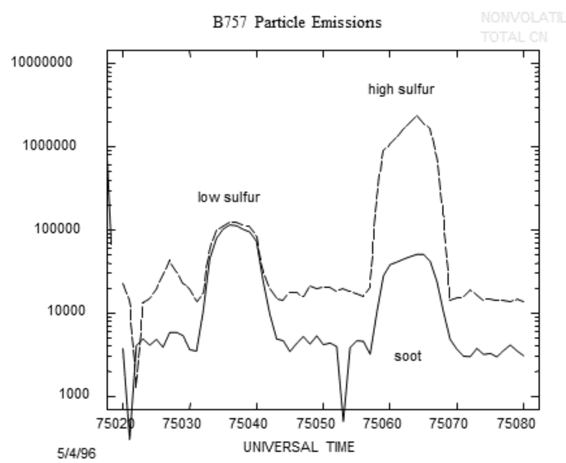
Made detailed measurements behind > 8 commercial airliners plus extensive near-field measurements behind NASA DC-8, starting from a refueling position and dropping back to 10 km to observe plume evolution.



SUCCESS, Spring 1996

NASA LaRC B757 was flown with 70 ppmS fuel in left wing tank and 700 ppmS in right. Exhaust was sampled from T-39 at 50 m to 5 km

Tests were repeated on 2 flights and involved over 100 B757 near-field plume penetrations by the Sabreliner starting form a refueling position beneath the lead aircraft. Flights were generally conducted in ATC space.



Project objectives and flight plans exactly like those of ACCESS

ACCESS Phase I Activities

1. Modify Falcon 20 with aerosol inlets, sample exhaust ports, wing pylons, and atmospheric state sensors
2. Conduct check flights and coordinated flights with other aircraft to validate/calibrate sensor package
3. Conduct limited flights within east coast flight corridors to survey emissions from a wide range of commercial aircraft
4. Transit to Palmdale, surveying aircraft emissions enroute
5. Conduct ground-based measurements and coordinated flights with NASA DC-8 to measure its emissions and contrail characteristics as it burns JP-8 and a 50:50 blend of JP-8/Biofuel
6. Transit from Palmdale home, again surveying aircraft emissions and contrail characteristics where possible

General Questions to be Addressed

- How do alternative fuels effect the number and physical characteristics of soot emissions?
- How do alt fuels effect NOx, CO and THC emissions?
- How do fuel properties effect downstream volatile aerosol formation?
- How do alt fuels effect the formation temperature and initial characteristics of contrails?
- Are there links between exhaust PM number/properties and contrail ice number and properties?
- Can contrail formation be suppressed by burning sulfur-free alt fuel in a modern low-PM emitting engine?
- How do cruise altitude PM, NOx, and THC EI values relate to ground-based measurements?

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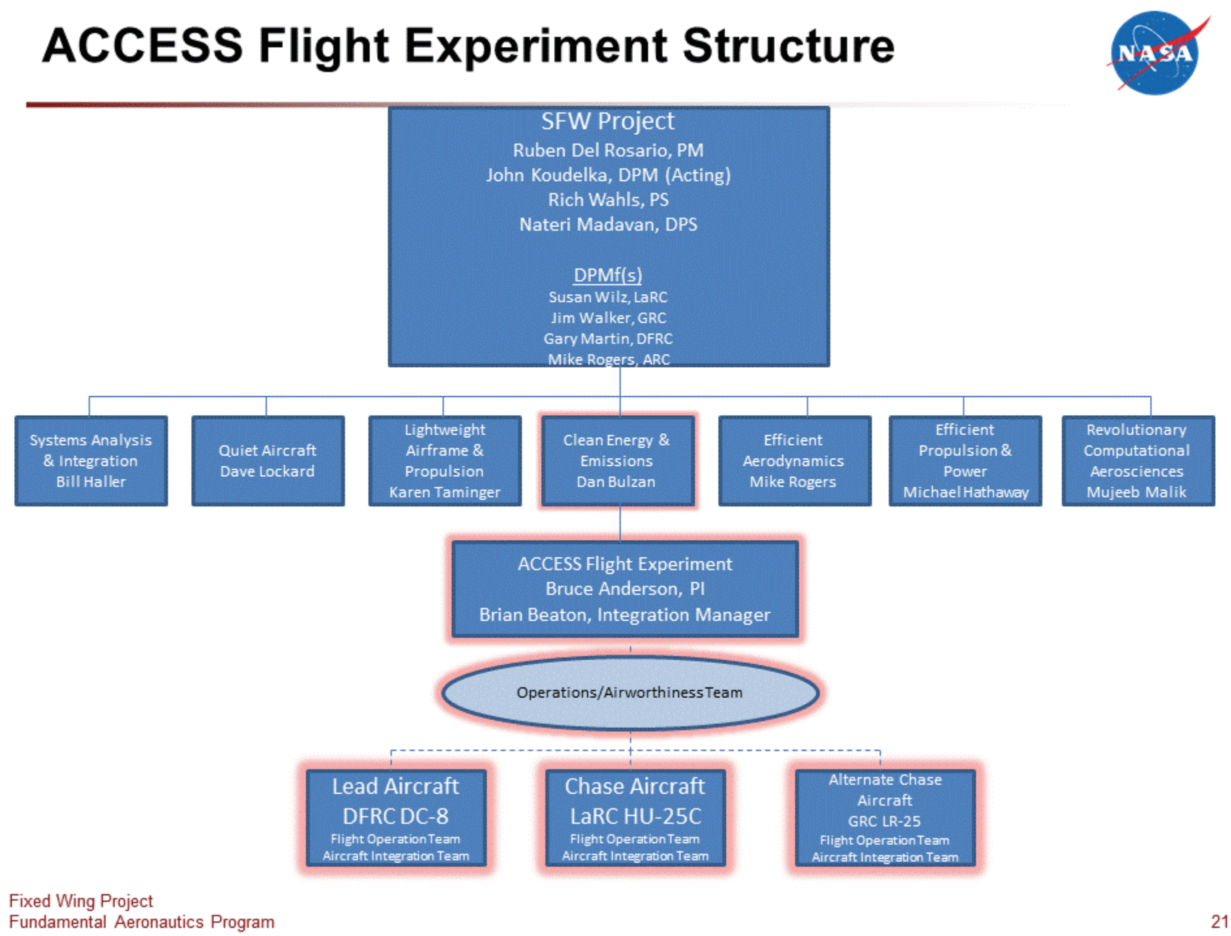
ACCESS Flight Experiment Structure
SFW Project
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John Koudelka, DPM (Acting)
Rich Wahls, PS
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Clean Energy & Emissions
Dan Bulzan
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DFRC DC-8
Flight Operation Team
Aircraft Integration Team
Chase Aircraft
LaRC HU-25C
Flight Operation Team
Aircraft Integration Team
Alternate Chase Aircraft
GRC LR-25
Flight Operation Team
Aircraft Integration Team
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03 SRR Overview/Success Criteria

SRR Overview

- Introduction
  - The SRR focuses on the maturity of the ACCESS flight experiment requirements.
- Objectives
  - The SRR evaluates the ACCESS flight experiment requirements for clarity, achievability, consistency, understanding, responsiveness to the sponsor commitments, and appropriateness to fulfill the program needs. This review also identifies requirement flow-down to the subsystems.

SRR Success Criteria

The review board members are able to conclude that:

a. The requirements are responsive to the program's objectives, and properly represent program constraints.

b. The maturity of the requirements, together with existence of a realistic plan to complete requirements definition and flow-down, gives confidence that the process will complete in a timely manner to support the design activity.

c. The project utilizes a sound requirements process for development, allocation, and control of requirements throughout all levels.

d. The performance capabilities represented in the requirements appear to be achievable.

e. Requirements traceability is established that facilitates communication of requirement changes to the affected areas.

f. Interfaces with supporting systems and among project systems have been identified, and preliminary plans and schedules exist for documenting the interfaces.

g. Preliminary approaches by which to verify and validate requirements have been identified down to the system level.

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SRR Success Criteria

The review board members are able to conclude that:

h. Definition of the project's requirements architecture is complete to one level below the project systems.
i. Requirements that are key to accomplishing the program and technology development objectives have been defined.
j. The project properly recognizes the requirements that are drivers on the implementation.
k. Major risks have been identified and technically assessed, and viable mitigation strategies have been defined.
l. The cost and schedule are valid in view of the system requirements and architectural concepts.

04 ACCESS Flight Experiment Need and Goals

ACCESS Flight Experiment Need and Goals

ID	Need and Goals
AN1	NASA needs to characterize fuel effects on aircraft particle and gas phase emissions at cruise altitudes.
AG1	Examine the evolution (growth, changes in composition/microphysical properties) of exhaust and contrail particles as plumes age and become mixed with background air.
AG2	Investigate the role of black carbon concentrations and properties and fuel sulfur in regulating contrail formation and the microphysical properties of the ice particles.
AG3	Survey black carbon and gas-phase emissions and contrail properties from commercial aircraft at cruise in air-traffic corridors
AG4	Obtain comparable measurements of aircraft emissions on the ground to allow extrapolating data from previous ground-based experiments to cruise altitude conditions.

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05 System Requirements

System Requirements

(ASR-01) The chase aircraft instrumentation shall measure predecessor aircraft exhaust plume gas and particle concentrations onboard.

- Rationale: Almost 70 percent of all jet fuel is burned in the 25K ft -40K ft altitude range. Collecting data in this cruise altitude range will help to gain an understanding of aircraft emissions and contrail formation and the benefit that might be gained by switching to alternative aviation fuels. Collecting data will facilitate an assessment of aviation impacts on atmospheric composition and climate.
- Verification: Test
- Traceability: [AN1, AG1-4]
- Note: Mount Aerosol/Gas Inlet Probe (on top of cabin ahead of chase aircraft engines) Mounting sensor on top of the aircraft will not create a loss of lift needed for steady sampling operations. HIMIL Probe from NCAR

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System Requirements

(ASR-02) The chase aircraft instrumentation shall measure contrail ice particles *at the same fuselage station on top of the cabin near the aerosol inlet* to correlate ice particles with soot particles.

- Rationale: Collecting measurements at the same location on the airframe will help define the relationship between aircraft particle emissions and the number and size of ice particles formed in the downstream contrail.
- Verification: Test
- Traceability: [AN1, AG1-3]
- Note: *PI will provide DMT probe or Cloud Droplet Probe (CDP) and aerosol inlet.*

System Requirements

(ASR-03) The chase aircraft instrumentation shall measure the water-vapor content of the atmosphere in the free stream and in the exhaust plume at altitude.

- Rationale: Highly accurate water vapor measurements are needed to understand the role of background conditions in the formation, microphysical properties and lifetimes of aircraft contrails.
- Verification: Test
- Traceability: [AN1, AG1-3]
- Note: Window-mounted Diode Laser Hygrometer (DLH). Replace cabin window with optical-quality window and mounting brackets

System Requirements

(ASR-04) The chase aircraft instrumentation shall measure the Angle of Attack of the chase aircraft. Desired: measure side slip of chase aircraft to enable modeling of 3-D winds.

- Rationale: Collecting this data will help understand wake plume dynamics and exhaust-plume dispersion.
- Verification: Test
- Traceability: [AN1, AG1-3]
- Note: Mount Angle of Attack Sensor on side of aircraft. *PI will provide standard Rosemount 858Y probe along with differential pressure transducers.*

System Requirements

(ASR-05) The chase aircraft instrumentation shall measure the ambient frost point temperature at altitude.

- Rationale: Collecting ambient data in this cruise altitude will help to understand effects of background condition on contrail formation and exhaust chemical evolution.
- Verification: Test
- Traceability: [AN1, AG1-3]
- Note: Mount small inlet for humidity/dewpoint sensor on aircraft fuselage. *PI will provide inlet and Edgetech 137 humidity sensor.*

System Requirements

(ASR-06) The chase aircraft instrumentation shall measure the temperature of the ambient and the exhaust plume at altitude.

- Rationale: Collecting data at cruise altitudes will help to understand effects of background conditions on contrail formation and exhaust chemical evolution.
- Verification: Test
- Traceability: [AN1, AG1-3]
- Note: Mount fast-response Rosemount temperature sensor. *PI will provide sensor head and electronics.*

System Requirements

(ASR-07) The chase aircraft shall vent instrumentation exhaust to the outside of the fuselage of the chase aircraft.

- Rationale: Instrumentation exhaust must be vented overboard to prevent contaminating cabin air with potentially toxic chemicals.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Mount exhaust port on belly or window blank.

System Requirements

(ASR-08) The chase aircraft instrumentation shall provide an alternative means to record static, dynamic pressure output and mach number of the chase aircraft.

- Rationale: Need to understand the position of the chase aircraft WRT the predecessor aircraft and to understand the wake plume dynamics.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: Provide tap into aircraft static pressure output for press alt reading. *Can either install additional pressure sensor on static line or provide digital readout of existing sensor.*

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System Requirements

(ASR-09) The chase aircraft instrumentation shall provide an alternative means to view and record chase aircraft position relative to the predecessor position (Differential GPS/INS) in real-time. Desires: longitudinal, lateral, and altitudinal separation.

- Rationale: Need to understand the position of the chase aircraft WRT the predecessor aircraft to determine wake plume age and understand the dynamical features
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: *Can use LaRC Crossbow 440 unit if necessary.*

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System Requirements

(ASR-10) The chase aircraft instrumentation shall provide an alternative means to record the chase aircraft pitch, roll, yaw and accelerations at 20 Hz frequency.

- Rationale: Information needed to understand the wake plume dynamics.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: *Can use LaRC Crossbow 440 for crude wind calculations; Applanix-type INU system preferred for more precise winds*

System Requirements

(ASR-11) The chase aircraft shall provide video capability looking forward from the chase aircraft windscreen during the flight experiment.

- Rationale: Needed to record contrail formation times and for establishing aircraft separation distances.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: Mount video cameras in forward windscreen. *LaRC will provide cameras and digital recording capability.*

System Requirements

(ASR-12) The chase aircraft shall provide electrical power 28VDC for instrumentation.

- Rationale: Voltage is standard on aircraft and is necessary for the instrumentation payload.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

System Requirements

(ASR-13) The chase aircraft shall provide electrical power 120VAC@60 Hz for instrumentation.

- Rationale: Voltage is necessary for the instrumentation payload power supplies.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

System Requirements

(ASR-14) The chase aircraft shall provide 5 kW of power for the instrumentation payload.

- Rationale: Power is necessary for the instrumentation payload.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: 2 kW @ 28VDC and 3 kW @120VAC

System Requirements

(ASR-15) The chase aircraft shall provide instrument racks to accommodate 160 vertical inches for the instrumentation payload.

- Rationale: Physical space is necessary for the instrumentation payload.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Assumes equipment: 24-inches deep by 19-inches wide.

System Requirements

(ASR-16) The chase aircraft shall provide 1500 lb capacity for the instrumentation payload.

- Rationale: Capacity is necessary for the instrumentation payload.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

ACCESS System Requirements-17

(ASR-17) The chase aircraft shall provide access to instrumentation racks during flight to permit calibration, adjustments, and to read the research equipment.

- Rationale: This information is needed to understand when the chase aircraft is encountering the exhaust plume and for quality control for measurements.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

ACCESS System Requirements-TBD

(ASR-TBD) Desires hard-points on wings on chase aircraft for mounting cloud particle instruments.

- Rationale: This hardware is needed for phase 2.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: This is for a secondary phase for the flight experiment but the instruments that get attached to these hard-points will be for measuring contrail evolution into cirrus clouds.

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06 Data & Communication Requirements

Data & Communication Requirements

(ADR-01) The computer shall record instrumentation data on board the chase aircraft.

- Rationale: Data is required for post flight analysis to meet the objectives.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

Data & Communication Requirements

(ACR-01) The pilots shall communicate between the predecessor and the chase aircraft.

- Rationale: Direct communication is required for coordination of close formation maneuvers.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]

Data & Communication Requirements

(ADR-02) The computers shall display and record pressure, altitude, and navigational parameters on board the predecessor and the chase aircraft.

- Rationale: Data is required for post flight analysis to meet the objectives.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Record only required for predecessor aircraft.

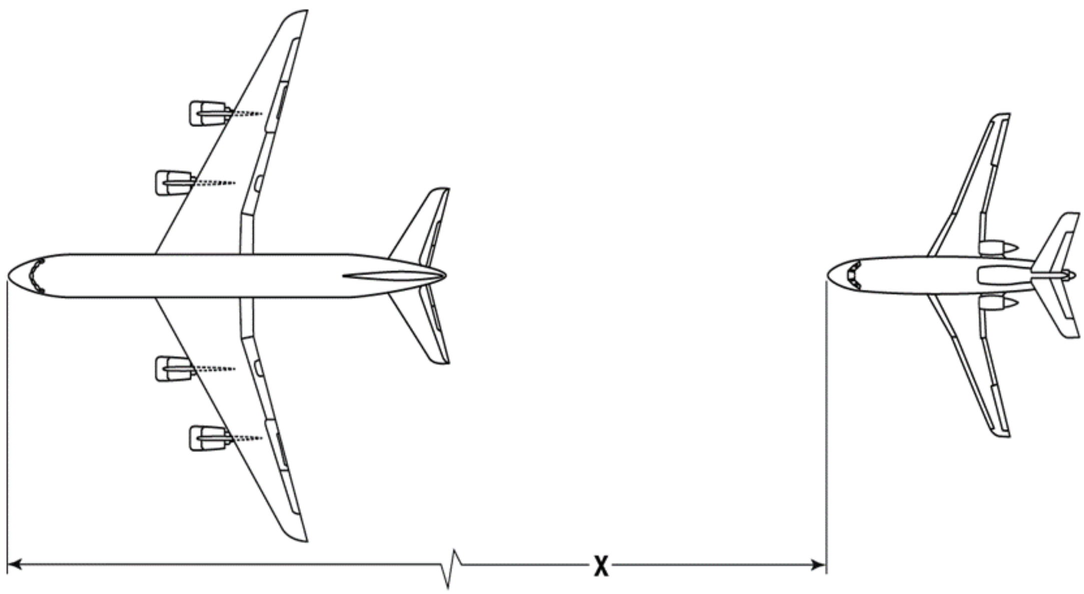
Data & Communication Requirements

(ADR-03) The computers shall display and record differential separation GPS positions on board the predecessor and the chase aircraft.

- Rationale: Data is required for post flight analysis to meet the objectives as well as real time for coordination of aircraft spacing.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Record only required for predecessor aircraft.

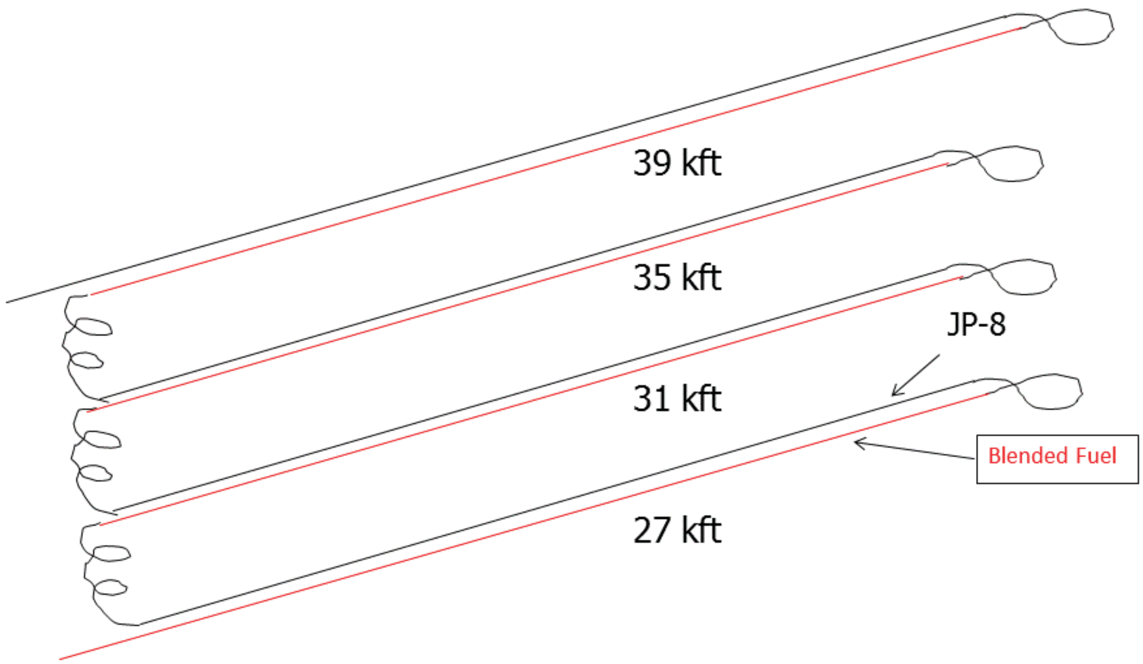
07 Concepts of Operations

Concept of Operations



Coordinated DC-8 and Chase Aircraft Flight Formation

Concept of Operations



Coordinated DC-8 and Chase Aircraft Flight Paths

Fixed Wing Project
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Concept of Operations

Ground Tests & Operations:

- Dedicated JP-8 & blended fuel tests
- Obtain large aliquot of JP-8 + >5,000 gals of alt fuel
- Mix fuels and test properties
- Load 10,000 gals blended fuel + 20,000 gals JP-8 on DC-8
- Taxi DC-8 onto ramp and chock
- Conduct ~1 hr long ground-based emission test w/Chase aircraft parked downwind of DC-8 to sample emissions

Concept of Operations

Flight Operations:

- DC-8 takes off, climbs to ~25kft burning JP-8
- Rendezvous with chase plane and conduct series of race tracks at 27, 31, 35, and 39K ft, alternating between burning alt fuels and JP-8 in all 4 DC-8 engines
- Flight legs 10 to 20 min long
- Conduct test well away from flight corridors
- Select region of large-scale uniformity where contrails will likely form
- Align track with wind, offset out/back legs to prevent sampling old emissions
- Turn DC-8 and chase aircraft in opposite directions, rendezvous at the start of leg
- Chase plane samples at <100 m at start of each leg and falls back to 10 km at end
- DC-8 switches fuels, loiters in turns for chase plane to catch up

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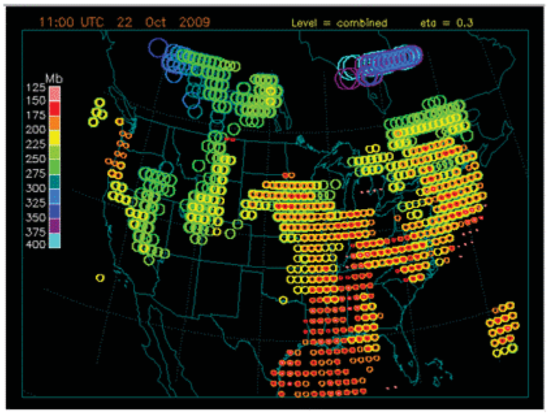
Flight Planning and Data Analysis Tools

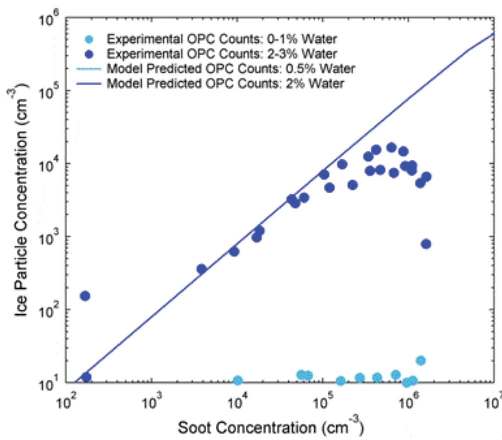


Langley Contrail Forecast Model
(Pat Minnis, PI)

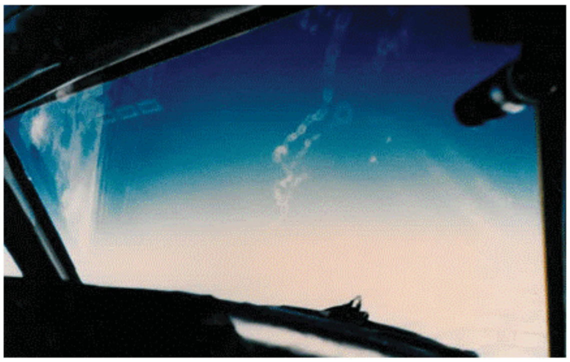
- http://enso.larc.nasa.gov/sass/contrail_forecast/contrail_prediction.html
- Partly developed under ACCRI program
- Predicts contrail formation probability over CONUS at various flight altitudes based on RUC model temperature and humidity forecast data

ARI Contrail Formation and Evolution Model
(Hsi-Wu Wong, PI)

- Predicts contrail particle number and size based on exhaust PM microphysics and ambient conditions
- Provides input to large-eddy simulation models
- Improvement and validation objective of ACCRI project



Flight Corridor Aircraft Emission and Contrail Surveys to Acquire Comparison Data



- Discuss plans with FAA beforehand
- File plans to fly within corridors where contrails likely to form
- Monitor air traffic on TCAS
- Request to fall 5 miles in trail behind commercial airliners
- Get tail #s and fuel flows from pilots, get engine types and histories from FAA web site
- Collect data during two dedicated missions from LaRC within east coast flight corridors
- Collect data during transits to/from Palmdale

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In-Flight Measurement Comparisons for System Validation/Calibration

- NASA P-3B is taking part in the DISCOVER-AQ air quality mission over the California Central Valley during Jan 15-Feb 15 2012
- P-3B will be flying test flights from Wallops in January, then 15 missions based from Palmdale

- Experimenters on P-3B will measure all the parameters being recorded on Falcon 20 with well proven instruments
- Measurement comparison legs will be conducted between the P-3B and Falcon on a single flight, either on east coast or near Palmdale
- Test will involve performing three, 10-minute long, wingtip-to-wingtip flight at altitudes up to P-3B maximum flight level
- Measurement comparison flights conducted on all multi-aircraft missions including current DISCOVER-AQ, DC3, SEAC4RS projects

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Ground-based Measurements to Tie ACCESS Data to Previous Observations

- DC-8 emissions were measured during APEX-1, APEX-3, AAFEX-I, and AAFEX-II
- Ground measurements provide much more detailed information on gas phase and aerosol emissions than possible in flight; ACCESS data can be used to link the two.

- Test will involve parking the Falcon 100 m downwind of the DC-8 in the B-1B run-up area near the DAOF; will also park an instrumented van nearby to draw samples from an inlet probe mounted 30 m behind the DC-8
- With the Falcon engines running to provide power, will run the DC-8 engines at power settings ranging from ground idle to takeoff thrust while burning either JP-8 or JP-8/Biofuel Blend

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08 Operational Requirements

Operational Requirements

(AOR-01) The chase aircraft shall operate in race track patterns at altitudes 30K - 38K ft range at 2K ft intervals and measure existing aircraft emissions.

- Rationale: Accumulate emission profiles from modern aircraft at cruise altitudes for comparison to results from DC-8 flight tests—needed to verify that DC-8 is representative of modern fleet.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: There will be two (2) flights at three (3) hours per test flight. Will loiter around flight corridors and ask ATC to vector aircraft 5 miles in trail behind whatever commercial aircraft happens to fly somewhere nearby.

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Operational Requirements

(AOR-TBD) Desires to operate chase aircraft in wingtip-to-wingtip formation with similarly instrumented research aircraft at altitudes 24K ft range.

- Rationale: Needed for quality assurance of in-flight instrument operation and calibration.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: P-3 aircraft from Wallops is the candidate for this effort.

Operational Requirements

(AOR-02) The predecessor and the chase aircraft shall operate in race track patterns and collect data (See Appendix A) at altitudes 27K, 31K, 35K, and 39K ft range.

- Rationale: Almost 70 percent of all jet fuel is burned in the 25K ft -40K ft altitude range. This is where contrails form. Collecting data in this cruise altitude will facilitate an assessment of aviation impacts on atmospheric composition and climate.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]

Operational Requirements

(AOR-03) The predecessor and the chase aircraft shall deploy at airspeeds of 450 KTAS. (>0.70 mach preferred)

- Rationale: This is the recommend aircraft cruise speed for efficient fuel burn rate for the predecessor aircraft.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]

Operational Requirements

(AOR-04) The flight experiment shall have a cumulative operating time of ten (10) hours at altitude.

- Rationale: Repetitive experiments must be conducted to delineate effects of fuels on emissions and contrails from those associated with variations in background temperature, humidity, and chemical composition.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]
- Note: Shall consider predecessor aircraft fuel burn rate.

Operational Requirements

(AOR-05) The chase aircraft shall operate in formation varying or increasing distances from 100 meters (328 ft) to 10 kilometers aft of the predecessor aircraft.

- Rationale: Measurements are required to capture initial emissions from the exhaust plume and evolution as the plume ages over distance.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]

Operational Requirements

(AOR-06) The chase aircraft shall operate in formation ±150 meters (±400 ft) below/above the predecessor aircraft to insure exhaust penetration with the sensors.

- Rationale: Measurements are required to capture the profile across the exhaust plume.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]

Operational Requirements

(AOR-07) The chase aircraft shall operate in formation ±150 meters (±400 ft) starboard/port of the predecessor aircraft to insure exhaust penetration with the sensors.

- Rationale: Measurements are required to capture the profile across the exhaust plume.
- Verification: Demonstration
- Traceability: [AN1, AG1-3]

Operational Requirements

(AOR-08) The predecessor aircraft shall burn standard JP-8 fuel blends.

- Rationale: This is needed to know what the aircraft conditions are under standard fuel conditions.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Base fuel has to be dedicated for the flight experiment.

Operational Requirements

(AOR-09) The predecessor aircraft shall burn alternative hydro-treated renewable jet fuel blends in a 50:50 ratio volume.

- Rationale: This is needed to know to understand the benefit of burning alternative fuels.
- Verification: Demonstration
- Traceability: [AN1, AG1-4]
- Note: Alternative fuel has to be dedicated for the flight experiment.

Operational Requirements

(AOR-10) The predecessor aircraft shall operate using dedicated JP-8 standard fuel and alternative fuel for the entire flight experiment.

- Rationale: This is needed due to the fact that properties of JP-8 fuel can vary widely.
- Verification: Inspection
- Traceability: [AN1, AG1-4]
- Note: This is needed for ground and for flight testing.

Operational Requirements

(AOR-11) The predecessor and the chase aircraft shall conduct ground measurements using standard fuels for comparison for one hour.

- Rationale: This is needed to know what the aircraft emissions are using standard fuel.
- Verification: Demonstration
- Traceability: [AG-4]
- Note: Base fuel has to be dedicated for the flight experiment.

Operational Requirements

(AOR-12) The predecessor and the chase aircraft shall conduct ground measurements using alternative fuels for comparison for one hour.

- Rationale: This is needed to know what the aircraft emissions are using alternative fuel.
- Verification: Demonstration
- Traceability: [AG-4]
- Note: Base fuel has to be dedicated for the flight experiment.

09 Modifications to Aircraft/ System Interfaces

Modifications to GRC Learjet 25

Learjet Model 25

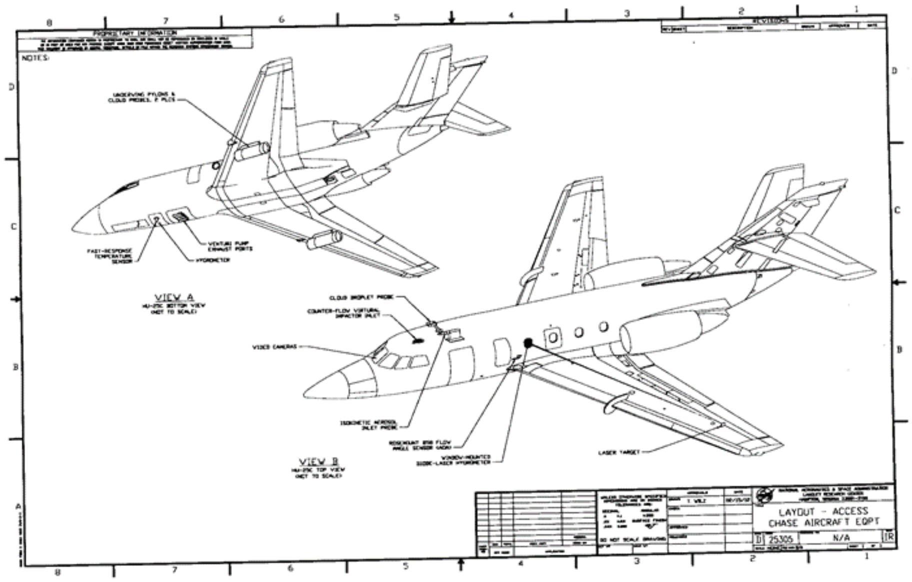
Lear 25 Aircraft Data	
Wingspan	35 ft 8 in (10.84 m)
Length	47 ft 7 in (13.18 m)
Height	12 ft 3 in (3.73 m)
Powerplants	General Electric CJ-610-6, axial-flow turbojet engines

Lear 25 Aircraft Crew / Performance Data	
Pilots	2
Researchers	1-4
Cruise Speed	350 KIAS (.82 MACH)
Range	@ 1,200 Nautical Miles
Ceiling	45,000 ft
Gross Weight	15,000 lb
Useful Load	@ 6,500 lb*

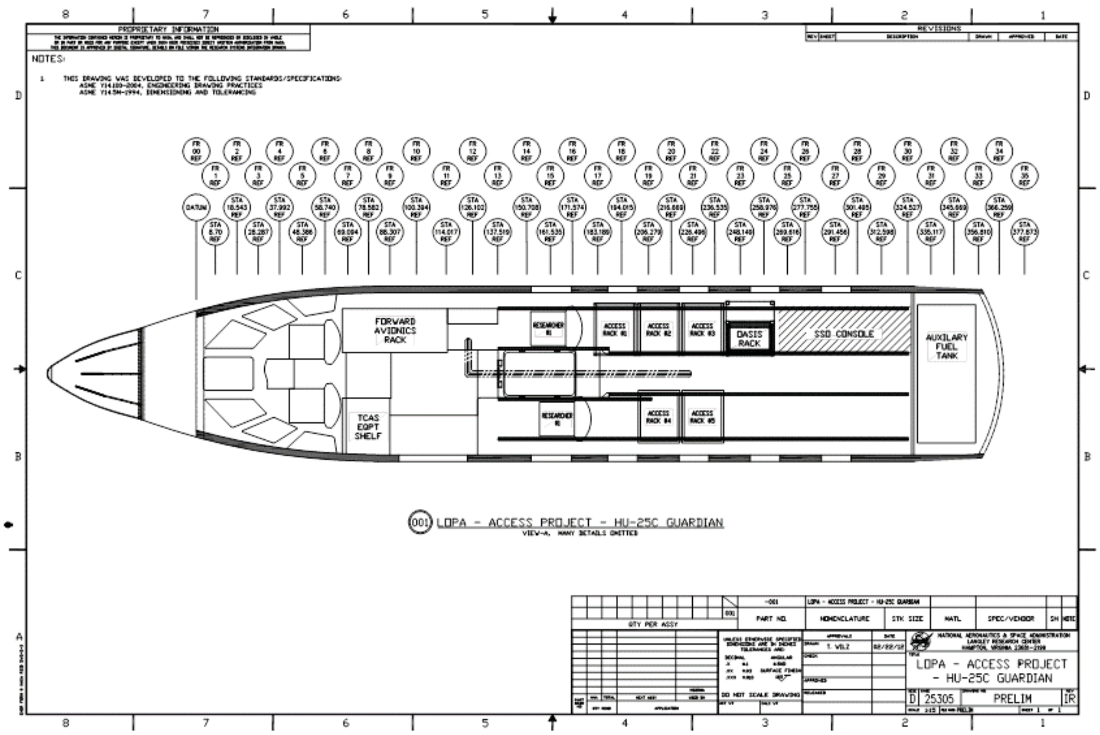
* Fuel/Crew/Research Equipment and other restriction may apply

Modifications to Langley HU-25C

Locations for Sensors



Cabin Layout



Modifications to Aircraft

Instrument	Requirements ID	Aircraft
Aerosol/Gas Inlet Probe (top of aircraft)	(ASR-01)	Falcon, Learjet
Cloud Droplet Probe (top of aircraft near Aerosol/Gas Inlet Probe)	(ASR-02)	Falcon, Learjet
Diode Laser Hygrometer (DLH) (window mounted)	(ASR-03)	Falcon, No for Learjet
Angle of Attack Sensor (Rosemount 858Y) (side of aircraft)	(ASR-04)	Falcon, No for Learjet
Humidity sensor inlet (Dew/Frost Point Hygrometer) (nose)	(ASR-05)	Falcon, Learjet
Fast-response Temperature Sensor (nose)	(ASR-06)	Falcon, Learjet
Venturi Exhaust Ports	(ASR-07)	Falcon, No for Learjet
Aircraft Static Pressure	(ASR-08)	Falcon, Learjet
Aircraft Navigational Parameters (GPS)	(ASR-09)	Falcon, Learjet
Aircraft pitch, roll, yaw and accelerations @ 20Hz	(ASR-10)	Falcon, ? Learjet
Video cameras (forward windscreen)	(ASR-11)	Falcon,? Learjet
Differential GPS between lead and chase aircraft	(ADR-03)	Falcon,? Learjet

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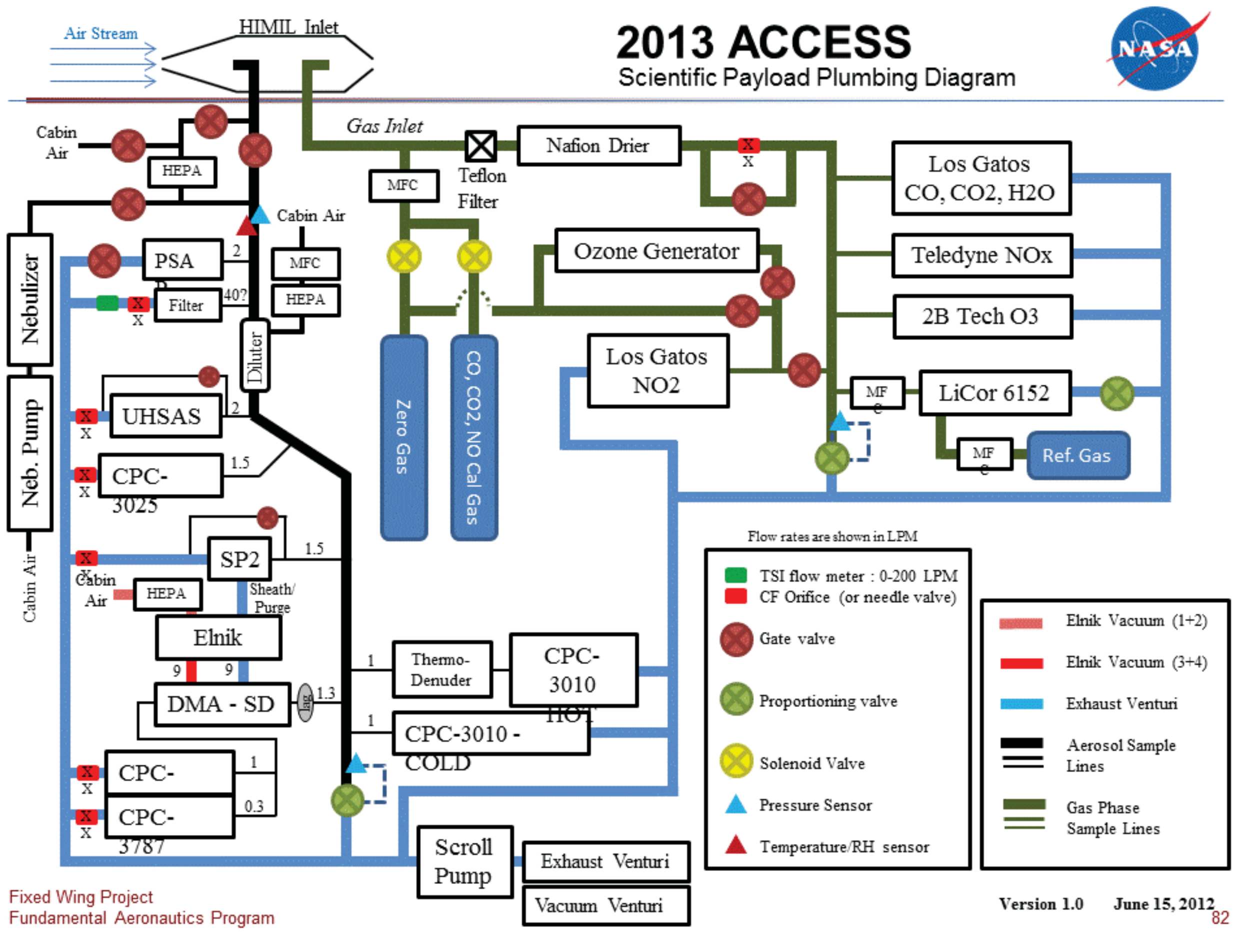
Interfaces

- Interfaces occur between:
  - Aircraft and instruments
  - Predecessor Aircraft and Chase Aircraft
- The types of interfaces are:
  - Airflow (ex. inlet air)
  - Electrical (ex. aircraft power supply)
  - Mechanical (ex. mounting plates)
  - Data (ex. aircraft data)
- Interfaces will be captured in the Interface Control Document (ACCESS-ICD-01)


2013 ACCESS
Scientific Payload Plumbing Diagram
Air Stream
HIMIL Inlet
Gas Inlet
Cabin Air
HEPA
Nebulizer
Neb. Pump
PSA
Filter
MFC
Diluter
UHSAS
CPC-3025
SP2
Sheath/Purge
Elnik
DMA - SD
CPC-
CPC-3787
Teflon Filter
Nafion Drier
Zero Gas
CO, CO2, NO Cal Gas
Ozone Generator
Los Gatos NO2
Los Gatos CO, CO2, H2O
Teledyne NOx
2B Tech O3
LiCor 6152
Ref. Gas
Thermo-Denuder
CPC-3010
CPC-3010 - HOT
CPC-3010 - COLD
Scroll Pump
Exhaust Venturi
Vacuum Venturi
Flow rates are shown in LPM
TSI flow meter : 0-200 LPM
CF Orifice (or needle valve)
Gate valve
Proportioning valve
Solenoid Valve
Pressure Sensor
Temperature/RH sensor
Elnik Vacuum (1+2)
Elnik Vacuum (3+4)
Exhaust Venturi
Aerosol Sample Lines
Gas Phase Sample Lines
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Falcon Instrument Payload

Parameter	Instrument	Operating Principle	Previous Airborne Use
CO2	LiCor 7000	Non-Dispersive IR	Deployed on DC-8, P-3B, T-39
CO, CO2	CRD Los Gatos	Cavity Ring-down Absorption	DC-8, P-3B
H2O	LaRC -- DLH	Long-path IR	DC-8, P-3B, B-200, Lear, Twin Otter, Global Hawk, GV, GI
	Edgetech 137	Chilled Mirror	P-3B, DC-8, B-200; standard AC instrument
NO	Teledyne T200UP	Chemiluminescence	UMD Cessna
NO2	Los Gatos Research	Cavity Ring-down Absorption	UMD Cessna
O3	2B Technologies	Chemiluminescence	Balloons, NOAA P-3
Ultrafine Aerosol	TSI3025 CPC	Condensation Growth/Optical	DC-8, P-3B, T-39
Fine Aerosol	TSI3010 CPC	Condensation Growth/Optical	DC-8, P-3B, T-39
Nonvolatile Aerosol	TSI3010 CPC	Condensation Growth/Optical	DC-8, P-3B, T-39
Size: 10 to 300 nm	TSI SMPS	Condensation Growth/Optical	DC-8, P-3B, T-39
Size 80 to 1000 nm	DMT Ultra-High Sensitivity Aerosol Spectrometer (UHSAS)	Optical Scattering	DC-8, P-3B
Soot size/mass	DMT Single Particle Soot Photometer (SP2)	Laser Incandescence	DC-8, P-3B
Cloud Particle Size	DMT Cloud Droplet Probe (CDP)	Optical Scattering	DC-8
Cloud Particle Images	DMT Cloud, Aerosol and Precipitation Spectrometer (CAPS)	Optical Scattering/Imaging	DC-8, B-200
Temperature	Rosemount T sensor	hot wire	Standard AC Instrument
Position and accelerations	Applanix INS/GPS	GPS, Accelerometers	Standard AC Instrument
U, V, W	Rosemount 558 probes or Radome Mods	Differential Pressure	Standard

Fixed Wing Project
Fundamental Aeronautics Program

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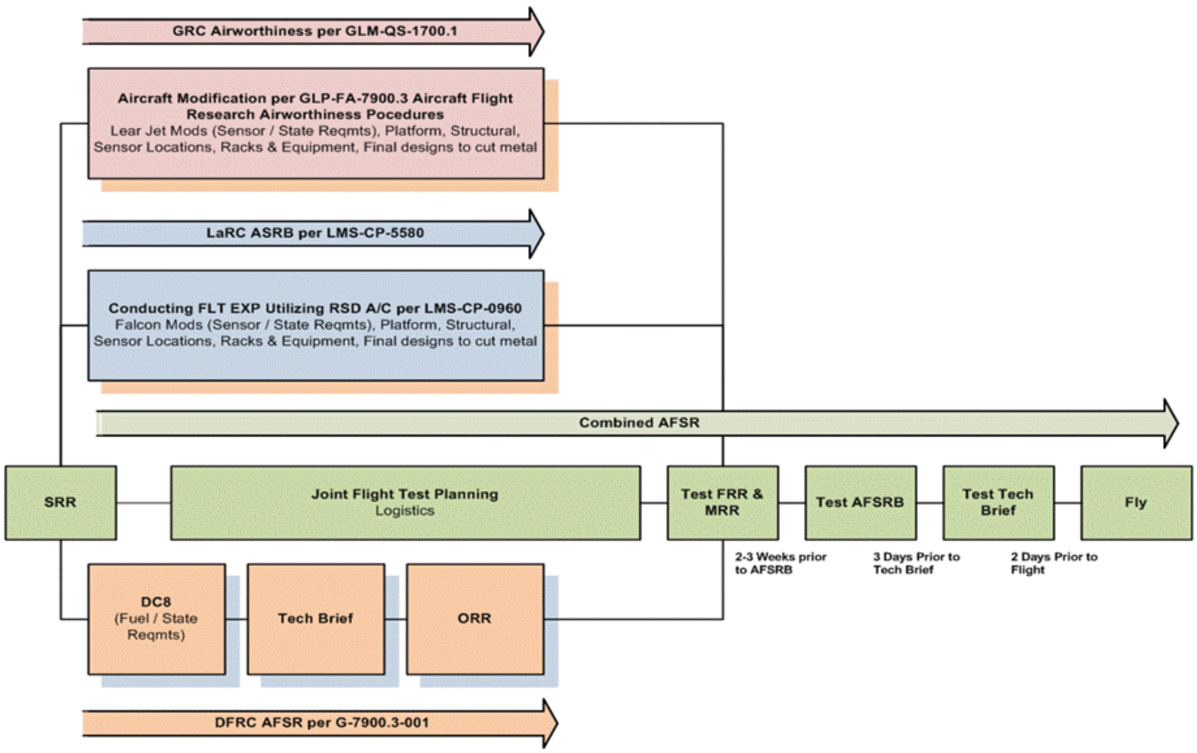
10 ACCESS Management Review/ Safety & Airworthiness Review Process

Flight Experiment Management Review Process

- Shall use the reporting processes of SFW
- Method for reporting to Centers are under development
  - Frequency of reporting
  - Details of reports
- In discussions with ARMD Directors for methods of reporting

Combined Safety and Airworthiness Review Process



Fixed Wing Project
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ACCESS SRR

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Combined Safety and Airworthiness Review Process

- **Aircraft Operations Guidance**
  - LMS-CP-0960, Conducting Flight Experiments Utilizing RSD Aircraft
    - Flight Test Operations and Safety Report (FTOSR)
  - LMS-CP-5580, Airworthiness and Safety Review Board (ASRB)
    - Applicable for all LaRC flight tests
  - GLP-FA-7900.3, Aircraft Flight Research Airworthiness Procedures
    - Applicable for all GRC flight tests
  - DCP-X-009, Airworthiness and Flight Safety Review Process
    - Applicable for all DFRC flight tests

- **Aircraft Maintenance Guidance**
  - LMS-TD-0940 LaRC General Aircraft Maintenance Manual for RSD
    - For all aircraft equipment maintenance procedures and practices

11 Initial Safety Hazards

Initial Safety Hazards

1. Engine out due to ingestion of distorted flow

- **Description**
  - Ingestion of distorted flow in the wake of the heavy lead aircraft could cause engine distress up to and including flameout on the probing aircraft with potentially limited ability to restart.
- **Effects**
  - Mission success, loss of / damage to asset, personnel
- **Possible Mitigations**
  - Determine / examine engine distorted flow tolerance
  - Determine / examine wake distortion in the area to be probed
  - Determine and account for engine restart envelope
  - Evaluate probing aircraft state instrumentation capabilities
  - Use the above to determine safe operating limits and plan for recovery altitude for abnormal aircraft attitudes
  - Evaluate crew safety / egress

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Initial Safety Hazards

2. Aircraft Structural Failure

- Description
  - The probing aircraft will see significantly different flow conditions in the wake of the heavy lead aircraft than in normal planned operation resulting in a risk of overloading or failure of aircraft structural components.
- Effects
  - Mission success, loss of / damage to asset, personnel
- Possible Mitigations
  - Determine wake flow conditions for area to be probed
  - Compare certification loads for probing aircraft to expected loading from above and determine safe operating envelope
  - Examine additional instrumentation for structural health
  - Evaluate crew safety / egress
  - Utilize a build-up test approach to include envelope expansion testing.

Initial Safety Hazards

3. Aircraft Controllability/Operability at Unusual Attitudes

- **Description**
  - The lighter probing aircraft flying in the wake of the heavy lead aircraft will likely encounter significant drastic attitude and rate changes resulting in potential difficulties in fuel system function or controllability for a platform not rated for acrobatics.
- **Effects**
  - Mission success, loss of / damage to asset, personnel
- **Possible Mitigations**
  - Determine wake flow conditions for area to be probed
  - Evaluate aircraft / fuel system capabilities at possible attitudes / rates
  - Evaluate aircraft controllability / recovery capabilities for wake flow (including entry into and exit from the wake)
  - Work with pilots office / TPS graduate to evaluate, define safe entry, maneuver, exit from wake, and recovery based on the above
  - Evaluate crew safety / egress

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12 Initial Risks

Initial Flight Experiment Risks

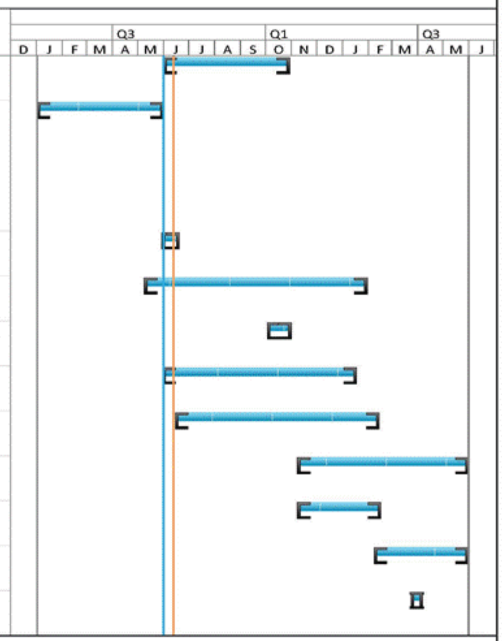
1. Given the advanced age of the DC-8 (1967 aircraft), there is a possibility of maintenance issues which may cause a schedule slip.
2. Given the advanced age of the Guardian HU-25C (1981 aircraft), there is a possibility of maintenance issues which may cause a schedule slip.
3. Given the uncertainty of the ASCENDS Project to allow "piggyback" flights for ACCESS flight experiment, there is a possibility for higher flight costs for using the DC-8 aircraft.
4. Given the uncertainty of the other committed flight projects for the Learjet, there is a possibility for a schedule slip.
5. Given the uncertainty of the schedule for the RVSM Falcon upgrade, there is a possibility for schedule slip.

13 Schedule

R14.2

ACCESS
High Level

ID		Task Name	Duration	Start	Finish
1		Aircraft Maintenence	107 d	6/1/12	10/29/12
6	✓	System Requirements Development	109 d	1/2/12	5/31/12
18		Requirements Documents	15 d	5/30/12	6/20/12
21		Design	192 d	5/9/12	1/30/13
47		Design Reviews	21 d	10/2/12	10/31/12
50		Implementation	167 d	5/31/12	1/17/13
78		Flight Clearance Reviews	175 d	6/15/12	2/13/13
90		Flight Ops	148 d	11/8/12	5/31/13
91		HU - 25C	73 d	11/8/12	2/15/13
98		DC - 8 Schedule	81 d	2/8/13	5/31/13
102		Lear 25 Schedule	10 d	3/24/13	4/7/13

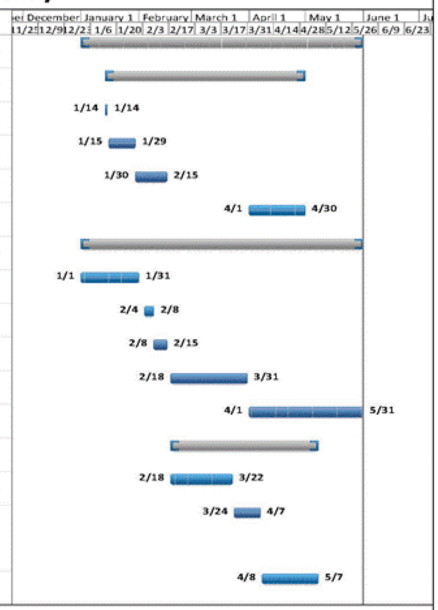


Page 1 J.Cronauer

R14.2

ACCESS MISSION
Aircraft Flight Test Availability

ID	Task Name	Duration	Start	Finish
1	**Aircraft Flight Testing Availability**	**109 d**	**1/1/13**	**5/31/13**
2	**UH - 25C**	**77 d**	**1/14/13**	**4/30/13**
3	Deploy	1 d	1/14/13	1/14/13
4	Research / Cal Flights	14 ed	1/15/13	1/29/13
5	Contingency	13 d	1/30/13	2/15/13
6	Committed Project	22 d	4/1/13	4/30/13
7	**DC - 8**	**109 d**	**1/1/13**	**5/31/13**
8	Aircraft Modifications	23 d	1/1/13	1/31/13
9	Shake - Down Flights	5 d	2/4/13	2/8/13
10	Indiana Flight Tests	7 ed	2/8/13	2/15/13
11	ACCESS Mission	41 ed	2/18/13	3/31/13
12	Contracted Maintenance	45 d	4/1/13	5/31/13
13	**Lear 25**	**57 d**	**2/18/13**	**5/7/13**
14	Committed Project	25 d	2/18/13	3/22/13
15	Available for ACCESS Chase Backup	14 ed	3/24/13	4/7/13
16	Committed Project	22 d	4/8/13	5/7/13



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Fixed Wing Project
Fundamental Aeronautics Program

ACCESS SRR

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15 Summary

SRR Summary

Criteria	Description	Presentation Section Number
a	The requirements are responsive to the program objectives, and properly represent program constraints.	01, 05-08
b	The maturity of the requirements, together with existence of a realistic plan to complete requirements definition and flow-down, gives confidence that the process will complete in a timely manner to support the design activity.	01, 04
c	The project utilizes a sound requirements process for development, allocation, and control of requirements throughout all levels.	01, 04
d	The performance capabilities represented in the requirements appear to be achievable.	07, 08
e	Requirements traceability is established that facilitates communication of requirement changes to the affected areas.	05-09
f	Interfaces with supporting systems and among project systems have been identified, and preliminary plans and schedules exist for documenting the interfaces.	09, 13
g	Preliminary approaches by which to verify and validate requirements have been identified down to the system level.	05-09

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Fundamental Aeronautics Program
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SRR Summary

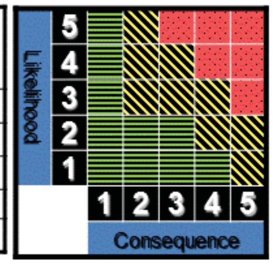
Criteria	Description	Presentation Section Number
h	Definition of the project's requirements architecture is complete to one level below the project systems.	04-09
i	Requirements that are key to accomplishing the program and technology development objectives have been defined.	01, 04
j	The project properly recognizes the requirements that are drivers on the implementation.	01, 05-08
k	Major risks have been identified and technically assessed, and viable mitigation strategies have been defined.	12
l	The cost and schedule are valid in view of the system requirements and architectural concepts.	13, 14

QUESTIONS

BACKUP CHARTS

Risk Ranking Criteria

Likelihood	Safety (Estimated likelihood of safety event occurrence)	Technical (Estimated likelihood of not meeting performance requirements)	Cost/Schedule (Estimated likelihood of not meeting cost or schedule commitment)
5 Very High	$(P_{SE} > 10^{-1})$	$(P_T > 50\%)$	$(P_{CS} > 75\%)$
4 High	$(10^{-2} < P_{SE} \leq 10^{-1})$	$(25\% < P_T \leq 50\%)$	$(50\% < P_{CS} \leq 75\%)$
3 Moderate	$(10^{-3} < P_{SE} \leq 10^{-2})$	$(15\% < P_T \leq 25\%)$	$(25\% < P_{CS} \leq 50\%)$
2 Low	$(10^{-6} < P_{SE} \leq 10^{-3})$	$(2\% < P_T \leq 15\%)$	$(10\% < P_{CS} \leq 25\%)$
1 Very Low	$(P_{SE} \leq 10^{-6})$	$(0.1\% < P_T \leq 2\%)$	$(P_{CS} \leq 10\%)$



Consequence	1 Very Low	2 Low	3 Moderate	4 High	5 Very High
Safety	Negligible or No impact.	Could cause the need for only minor first aid treatment .	May cause minor injury or occupational illness or minor property damage.	May cause severe injury or occupational illness or major property damage.	May cause death or permanently disabling injury or destruction of property.
Technical	No impact to full mission success criteria	Minor impact to full mission success criteria	Moderate impact to full mission success criteria. Minimum mission success criteria is achievable with margin	Major impact to full mission success criteria. Minimum mission success criteria is achievable	Minimum mission success criteria is not achievable
Schedule	Negligible or no schedule impact	Minor impact to schedule milestones; accommodates within reserves; no impact to critical path	Impact to schedule milestones; accommodates within reserves; moderate impact to critical path	Major impact to schedule milestones; major impact to critical path	Cannot meet schedule and program milestones
Cost	<2% increase over allocated and negligible impact on reserve	Between 2% and 5% increase over allocated and can handle with reserve	Between 5% and 7% increase over allocated and can not handle with reserve	Between 7% and 10% increase over allocated, and/or exceeds proper reserves	>10% increase over allocated, and/or can't handle with reserves

- HIGH RISK
- MODERATE RISK
- LOW RISK

SRR Scope — DRAFT

- Research requirements flow down to subsystem and rationale for each requirement;
- Preliminary concept of operations;
- Initial schedule, cost estimate, and workforce requirements
- Draft Safety and Airworthiness Review process mapped out for all centers;
- Identify initial safety hazards;
- Identify initial risks to cost and schedule

Planning Terminology

Term	Description	Examples
Research Theme	Formerly called Technical Challenges – this is how we are organized by tech lead (and this is how we will continue to lead the project after the planning is done).	• AE – Aerodynamic Efficiency (formerly Efficient Aerodynamics) • SE – Structural Efficiency (formerly called LAPS) • QP – Quiet Performance
Technical Challenge	Formerly called Subsystem Concepts – these are common components seen on the various N+3 vehicles.	• Lightweight Fuselage • High Aspect Ratio Wing • Quiet Low Speed Performance (formerly called Quiet Simplified High Lift)
Technical Area	Specific areas of work under the technical challenges, related to the enduring challenges	• Turbulent CF Drag Reduction • Tailored Load Path • Designer Materials • Aerodynamic Shaping • Elastic Aircraft Flight Control • Active Structural Control • Active Flow Control • High-Lift System Noise • Landing Gear Noise
Technical Approach	Specific approaches being researched in SFW; generally related to tasks performed by individual branches/researchers	• Fiber tow placed composites • Curvilinear stiffened metallics • Etc.
Planning Subteams	Groups of researchers, tech leads, and branch heads across different disciplines brought together just for planning purposes	Team 1 incorporates all disciplines associated with the airframe – fuselage & wing

Appendix C. NESC Team Kickoff

NESC Independent Technical Assessment 12-00822

ACCESS Flight Test Hazard Mitigation

KICKOFF MEETING
August 10, 2012

Mike Kelly

Principal Engineer's Office

NASA Engineering & Safety Center

757-864-9331 Desk

757-846-7790 Cell

michael.j.kelly-1@nasa.gov

1

Agenda

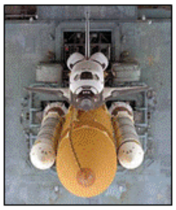
- NESC background (Kelly, 10m)
- Assessment Plan outline (Kelly, 10m)
- Team member self introductions - name, location, expertise (All, 20m)
- Assessment Plan discussion (All, 20m)
- Questions, comments (All, 30m)
- Decide on standing day/time for weekly team tagup & adjourn

2

NESC background & model of operation (1/3)

In 2003, the Columbia Accident Investigation Board (CAIB) observed that NASA's safety organization lacked adequate technical expertise and resources for independent technical reviews of NASA's Programs and Projects.

The NASA Engineering & Safety Center (NESC) was formed as a response to this observation, with a mission to provide the Agency's Programs and Projects with rigorous independent technical perspectives on their most critical technical issues.



NESC is independent

- Centrally managed and funded through the Office of Chief Engineer.
- Unaffiliated with and unbiased by any specific NASA Program or Center.
- Unaffected and unbiased by the Programs our teams evaluate.

3

NESC background & model of operation (2/3)

Office of the Director (7+) – Leadership team located at Langley Research Center (LaRC).

- Director, Deputy Director, MTSO Manager, Systems Engineering Office Manager, Deputy Director for Safety, Chief Astronaut, Chief Scientist, plus administrative.

NESC Chief Engineers (11) – Embedded executives, one at each of NASA's 10 Centers plus one at headquarters, who provide access and insight into Center-based Programs and Projects.

Principal Engineers (7) – Systems thinking project managers who lead assessment teams and advise other assessment team leaders.

Systems Engineers (~15) – Systems engineering and process specialists, who provide system engineering and integration for assessments and other NESC activities.

Management & Technical Support (~20) – Administrative management experts who provide contracting and budgeting solutions for NESC teams and the leadership team.

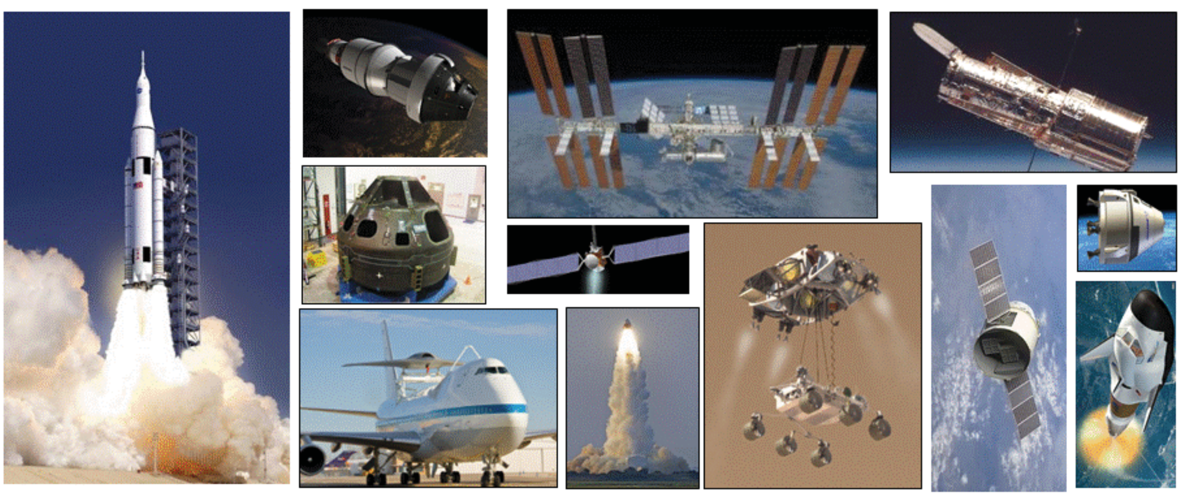
NASA Technical Fellows (15) – Agency technical discipline experts who form and lead Technical Discipline Teams (TDTs).

4

NESC background & model of operation (3/3)

NESC institutionalized the "Tiger Team" approach: NESC assembles diverse, expert technical teams that provide robust technical solutions to the Agency's highest-risk and most complex issues

Primary NESC assessment team deliverables are technical findings and recommendations rigorously traceable to those findings - documented in engineering reports.



ACCESS Flight Test Hazard Mitigation
Assessment Plan Outline

Description:

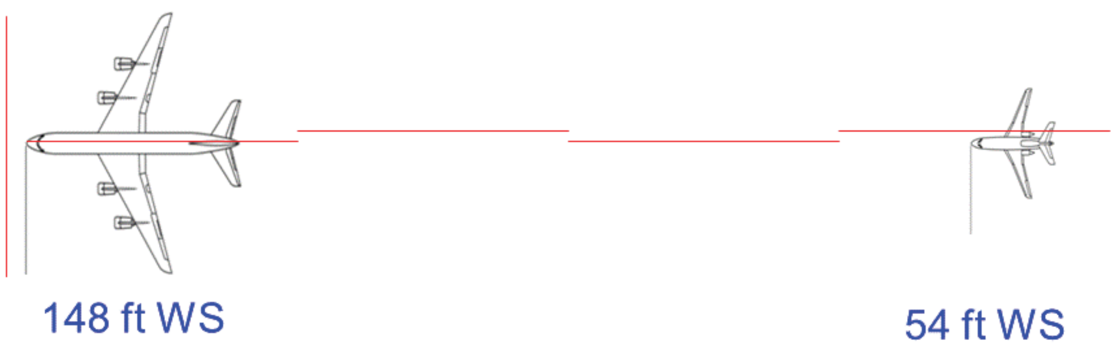
The Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) flight experiment, which is part of the Aeronautics Research Mission Directorate (ARMD) Fundamental Aeronautics Program - Subsonic Fixed Wing Project, seeks to obtain *in situ* airborne emission measurements from a DC-8 aircraft burning alternative fuels.

This will be accomplished by flying a specially instrumented NASA HU-25 Falcon aircraft in the wake of a NASA DC-8 aircraft. The aircraft will be flown at distances from 100 m to 10 km to measure its emissions and contrail characteristics as it burns JP-8 fuel and a 50:50 blend of JP-8 and biofuel.

Three potential hazards have been identified: the probing HU-25 Falcon aircraft may experience structural failure, loss of control, or engine out due to turbulence and distorted flow fields in the wake of the larger DC-8 aircraft. The ACCESS project is seeking NESC assistance to independently assess the structural failure hazard and to identify potential mitigations to ensure flight safety.

This briefing is for status only and does not represent complete engineering data analysis

ACCESS Flight Test Hazard Mitigation
Assessment Plan Outline



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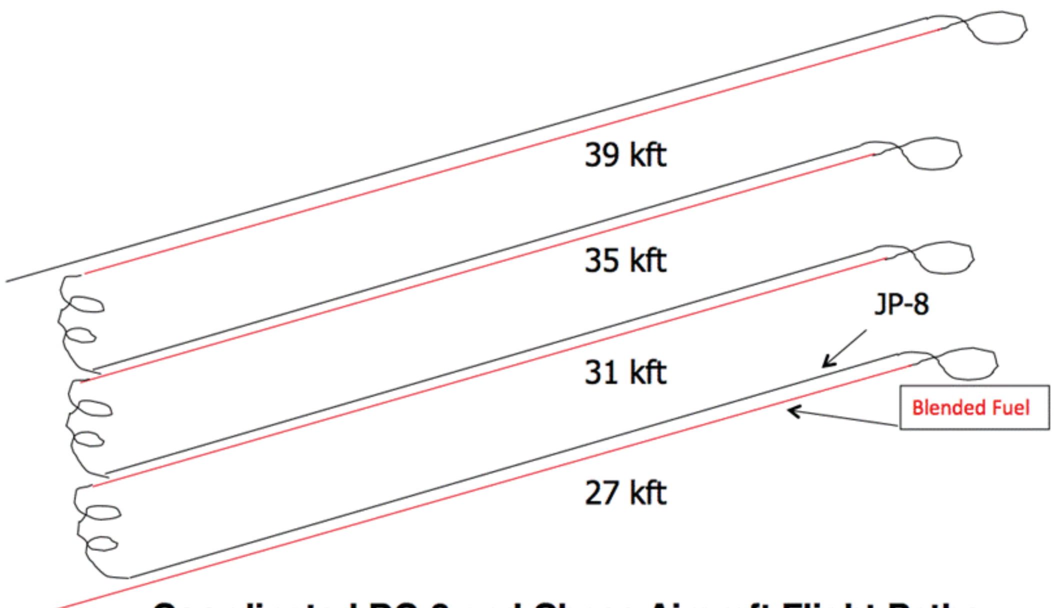
ACCESS Flight Test Hazard Mitigation

Assessment Plan Outline



Coordinated DC-8 and Chase Aircraft Flight Paths

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ACCESS Flight Test Hazard Mitigation

Assessment Plan Outline

Previous Airborne Emissions Tests

NASA

- Subsonic Assessment Near-Field Interactions (SNIF-1), Summer 1995
  - Sabreliner chased NASA B737, P-3B, and C-130 over east coast
- Subsonic Assessment Near-Field Interactions (SNIF-2), Winter 1996
  - Sabreliner sampled MD80, B757, B747 in east coast flight corridors
- Subsonic Assessment Cloud and Contrail Effects Special Study (SUCCESS), Spring 1996
  - Sabreliner chased NASA DC-8 and B757
- Subsonic Assessment Near-Field Interactions (SNIF-3), Summer 1997
  - Sabreliner sampled ANG F-16s over Vermont and New Jersey

German Aerospace Agency (DLR)

- SULFUR flight series, mid 1990's , Falcon 20 chasing ATTAS, A310, A340, B707, B747, B737, DC8, DC10
- Pollution from aircraft emissions in the North Atlantic (Polinat), Falcon 20, late 1990's
- CONCERT—Falcon 20, various aircraft, 2009-2011
- Lufthansa flight experiment, Falcon 20 chasing A380 with bio fuel, Spring 2012

NRC Canada

- Wake/Vortex Dynamics Measurements—T33 chasing commercial and military AC
- Alt Fuel effects—T33 chasing military AC burning biofuel

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ACCESS Flight Test Hazard Mitigation
Introduction of the team

Last Name	First Name	Position/Team Affiliation	Center/ Contractor
Core Team			
Kelly	Michael	NESC Lead	LaRC
Roche	Joe	NESC Deputy Lead	GRC
Pahlavani	Patricia	MTSO Program Analyst	LaRC
Mendenhall	Mike	Vortex Effects	Nielsen Engineering and Research, Inc.
Pandya	Shishir	Aerodynamicist	ARC
TBD*		Applied Aerodynamicist	ARC
TBD*		Wake Data Analysis	KSC
Pototzky	Tony	Loads & Dynamics	LaRC
Modlin	Tom	Loads & Dynamics	Retired JSC
Cruz	Josue	Loads & Dynamics	DFRC
Hartshorn	Fletcher	Loads & Dynamics	Tybine
Clarke	Bob	Test Hazard Mitigation	DFRC
Rose	William	Test Hazard Mitigation & Aero Analysis	Rose Engineering and Research (REAR)
Yechout	Tom	Test Hazard Mitigation	U.S. Air Force Academy
Riter	Steve	Test Hazard Mitigation	Boeing T&E Military Transports
Lilley	Steve	S&MA	GRC
Consultants			
Stewart	Jim	NESC Chief Engineer	DFRC
Bryant	Wayne	Wake Turbulence Expert	Retired FAA Chief Science & Technical Advisor
Administrative Support			
Burgess	Linda	Planning and Control Analyst	LaRC/AMA
Campbell	Jonay	Technical Writer	LaRC/NG
Derby	Terri	Project Coordinator	LaRC/AMA

This briefing is for status only and does not represent complete engineering data analysis

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ACCESS Flight Test Hazard Mitigation
Assessment Plan Discussion

Aircraft Structural Failure

– Description
  • The probing aircraft will see significantly different flow conditions in the wake of the heavy lead aircraft than in normal planned operation resulting in a risk of overloading or failure of aircraft structural components.

– Effects
  • Mission success, loss of / damage to asset, personnel

– Possible Mitigations
  • Determine wake flow conditions for area to be probed
  • Compare certification loads for probing aircraft to expected loading from above and determine safe operating envelope
  • Examine additional instrumentation for structural health
  • Evaluate crew safety / egress
  • Utilize a build-up test approach to include envelope expansion testing.

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ACCESS Flight Test Hazard Mitigation
Assessment Plan Discussion

Our effort has four pieces – but "*what we do specifically*" will be dictated in real time based on what data we can acquire quickly and on *your* collective best judgment.

- Acquire & assess the available DC-8 wake data and put it in a format useful for the loads analysis. Maybe conduct simple first-order aircraft flight response assessment of the Falcon in the DC-8 wake. Challenging: wake information acquisition.

- Acquire falcon design data and perform structural loads assessment (of the vertical and horizontal tails, principally, but possibly also of the wings), using the wake data. Maybe consider loads from upset/recovery too. Challenging: design data acquisition.

- Identify a safe operating envelope, based on the loads results, in terms of minimum Falcon distance aft of the DC-8, and probably with some lateral and vertical dimensions. Consider using demonstrated envelopes from previous similar test campaigns with various lead & chase aircraft.

- Develop recommendations for the ACCESS team that may include Falcon approach procedures, and/or additional Falcon instrumentation, and/or maybe collecting new DC-8 wake data using a completely different chaser aircraft that is specifically tasked to collect wake data (that can be used to improve the wake database specifically to mitigate the Falcon structural failure hazard).

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ACCESS Flight Test Hazard Mitigation
Assessment Plan Discussion

Our effort has ~~four~~ five pieces – but "*what we do specifically*" will be dictated in real time based on what data we can acquire quickly and on *your* collective best judgment.

- Assess the ACCESS team's wake characterization and loads calculations; make findings.
- Acquire & assess the available DC-8 wake data and put it in a format useful for the loads analysis. Maybe conduct simple first-order aircraft flight response assessment of the Falcon in the DC-8 wake. Challenging: wake information acquisition.
- Acquire falcon design data and perform structural loads assessment (of the vertical and horizontal tails, principally, but possibly also of the wings), using the wake data. Maybe consider loads from upset/recovery too. Challenging: design data acquisition.
- Identify a safe operating envelope, based on the loads results, in terms of minimum Falcon distance aft of the DC-8, and probably with some lateral and vertical dimensions. Consider using demonstrated envelopes from previous similar test campaigns with various lead & chase aircraft.
- Develop recommendations for the ACCESS team that may include Falcon approach procedures, and/or additional Falcon instrumentation, and/or maybe collecting new DC-8 wake data using a completely different chaser aircraft that is specifically tasked to collect wake data (that can be used to improve the wake database specifically to mitigate the Falcon structural failure hazard).

This briefing is for status only and does not represent complete engineering data analysis 13

ACCESS Flight Test Hazard Mitigation

ACCESS Project Briefing to "us"

Tue Aug 14 from 3pm – 4pm eastern

- ACCESS Research top level summary
    1. What you're going to do best as can be described today -
        a. Objective
        b. Aircraft
        c. Dwell time, distances, etc
        d. Please DEFER discussion about any test hazard mitigation to another time
    2. What others have done
        a. Summary of NASA test in the 90s (aircraft types and distances etc)
        b. Summary of German tests (aircraft types and distances etc)

- Wake vortex characterization
    1. What's you've done
    2. What you're still doing

- Tail loads assessment
    1. What's you've done
    2. What you're still doing

This briefing is for status only and does not represent complete engineering data analysis

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ACCESS Flight Test Hazard Mitigation

Questions & Answers?

Pick a day and time for weekly team tagup

8/10 Kickoff

AUGUST						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

9/21 Assessment complete

SEPTEMBER						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

10/19 Report Complete

OCTOBER						
S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

This briefing is for status only and does not represent complete engineering data analysis

Appendix D. ACCESS Project Analyses Inbriefing: Proctor, Vicroy, and Pagnotta Analyses

Model for Wind Distribution in the Wake of a DC-8

Fred Proctor
NASA Langley, CSAOB
2 July 2012

Phone: x-46697
Email: fred.h.proctor@nasa.gov

Input parameters DC-8

- Wing Span, $S = 45.237\ m$
- Weight 280,000 *lbs*
  - Mass, M= 127,000 *Kg*
- Airspeed, $V_a = 200\ m/s$ (390 *kts*)
- Acceleration due to earth's gravity, $g = 9.8\ m\ s^{-2}$
- Altitude, z =10,000 *m* (30,480 *ft*)
  - Air density, $\rho = 0.41\ kg\ m^{-3}$
- Assuming elliptically loaded wing:
  - vortex separation, $b = \pi S/4 = 35.5\ m$
  - initial circulation, $\Gamma_o = M g/ (b \rho V_a) = 428\ m^2 s^{-1}$
  - initial vortex descent velocity, $V_o = \Gamma_o/(2 \pi b) = 1.92\ m/s$
  - time scale, $T^* = (t V_o)/b = t/18.52 s$
  - distance behind aircraft, $X = V_a b T^*/V_o$

Assumptions

- Wake generated in cruise by DC-8
- Elliptically loaded wing
- Roll-up has taken place (X > 40 S)
- Wake is represented by two-dimensional vortex pair
- Vortex tangential velocity profile represented by Burnham-Hallock Model (see NASA TM-2004-213018)
- Core radius, r_c, is ~1% of span (AIAA paper 2003-3811)
- Vortex separation and core radius remain constant
- Axial (along-track) flow neglected
- Atmospheric conditions are suitable for long-lasting wakes (low turbulence, neutral stratification, no wind shear)
  - Linear rate of decay based on CFD simulations of phase-1 decay (see next slide); valid between 1.8 *km* < X < 18.5 *km*

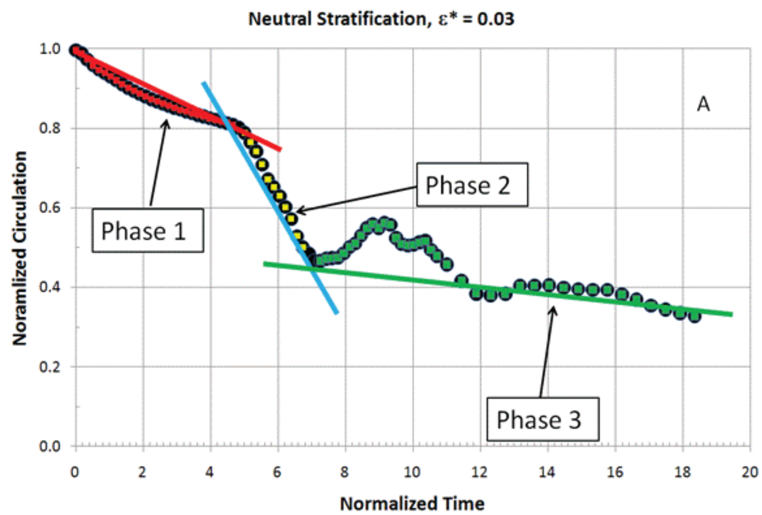
Example of Three Phased Decay

(from Proctor et al 2010, AIAA paper 2010-7991

Phase 1: Weak decay -- vortices quasi-2D
$\Gamma(T^*) = \Gamma_o(1 - T^*/23)$

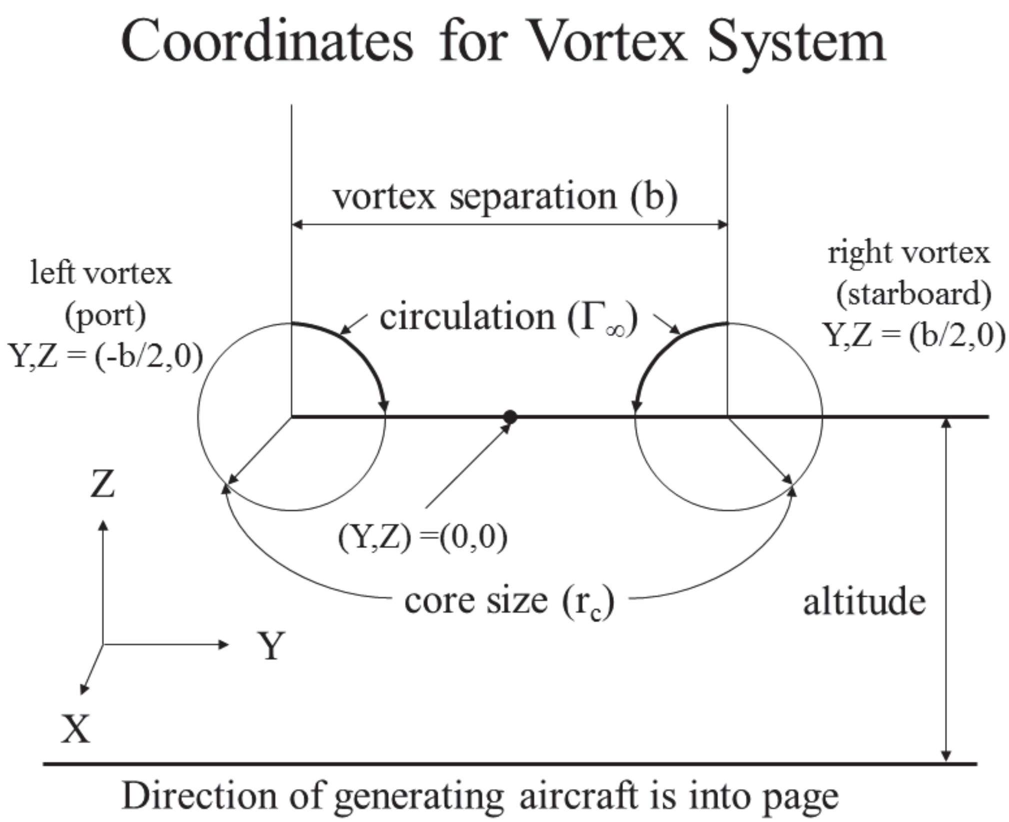
Phase 2: Rapid decay – Vortex linking stage

Phase 3: Gradual decay – ring vortex stage



Normalized circulation vs nondimensional time. From TASS simulation with weak environmental turbulence *and neutral stratification*

4


Coordinates for Vortex System
vortex separation (b)
left vortex
(port)
Y,Z = (-b/2,0)
circulation (Γ∞)
right vortex
(starboard)
Y,Z = (b/2,0)
Z
(Y,Z) =(0,0)
core size (rc)
altitude
Y
X
Direction of generating aircraft is into page

Equations for Vortex System Velocity

for 1.8 *km* < X < 18.5 *km*

$$\vec{V}(X,Y,Z) = v\hat{j} + w\hat{k}$$

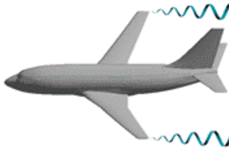
$$\vec{V} = \frac{\Gamma(X)}{2\pi}\left\{\frac{Z}{[(Y+b/2)^2+Z^2+r_c^2]} - \frac{Z}{[(Y-b/2)^2+Z^2+r_c^2]}\right\}\hat{j} - \frac{\Gamma(X)}{2\pi}\left\{\frac{(Y+b/2)}{[(Y+b/2)^2+Z^2+r_c^2]} - \frac{(Y-b/2)}{[(Y-b/2)^2+Z^2+r_c^2]}\right\}\hat{k}$$

Where: $\Gamma(X) = \Gamma_o(1 - X/c)$, $\Gamma_o = 428\ m^2/s$, $r_c = 0.5\ m$, $b = 35.5\ m$, and $c = 85{,}190\ m$.

v is the cross-track component of horizontal velocity and w is the vertical component of velocity

Y,Z = (0,0) at midpoint between vortex pair and the vortex centers are located at Y,Z = (±b/2, 0).
X is coordinate along flight path (increasing with distance behind aircraft position, X = 0)


HU-25 Wake Induced
Tail Loads Estimate
D. Vicroy
8/14/2012
332:15:18:30



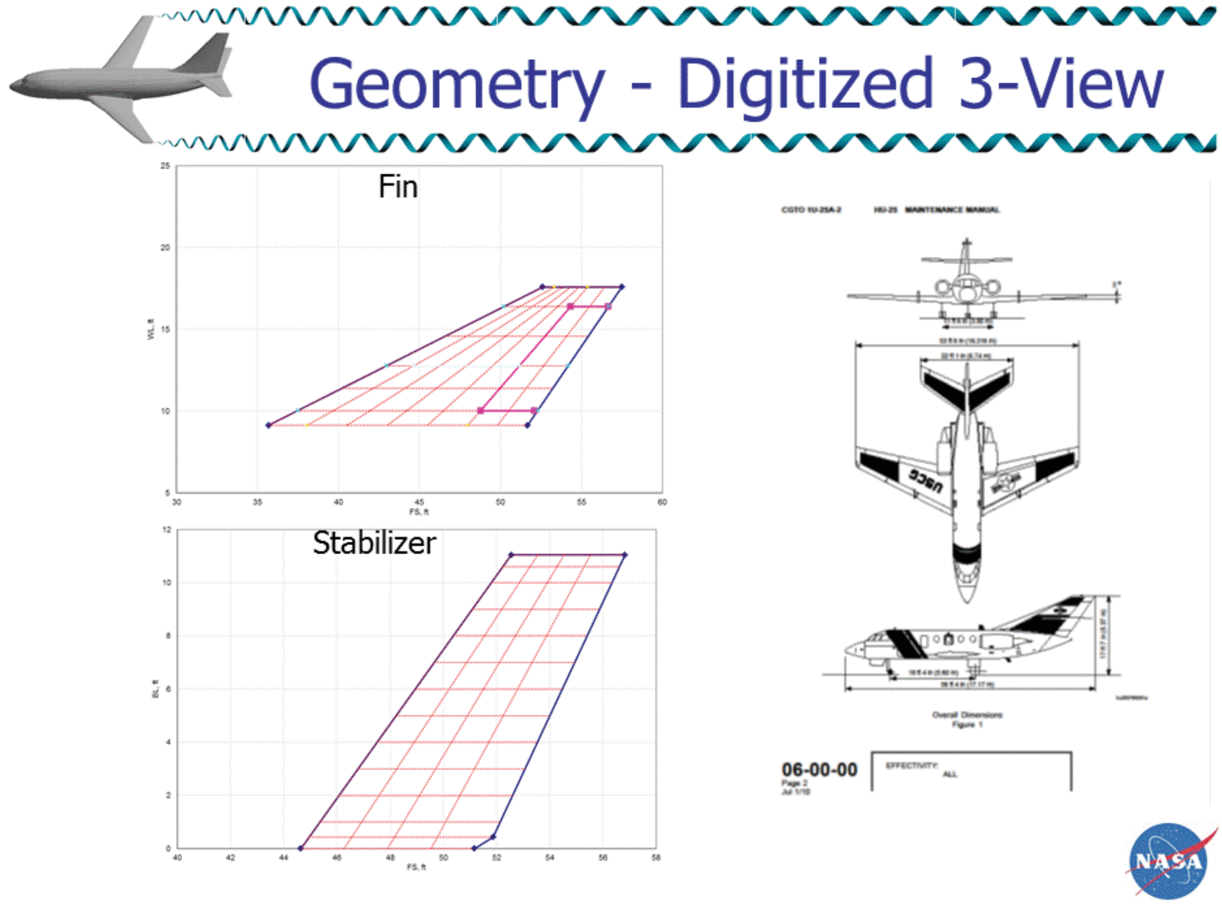
Some Historical Background

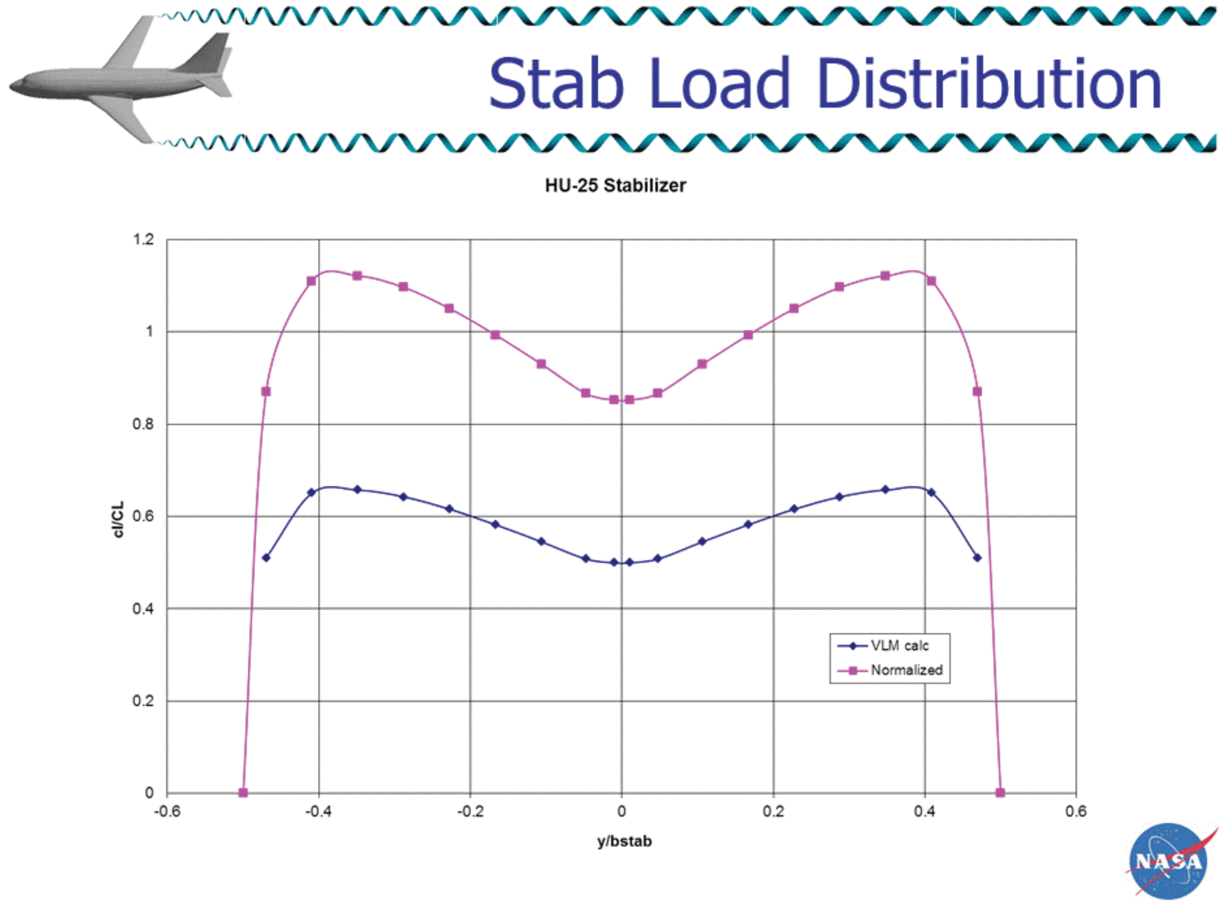
- Big wake hazard interest in 70's with introduction of B-747
- NASA AVOSS research in the 90's for improved airport capacity
- European Wake-net program in 2000's

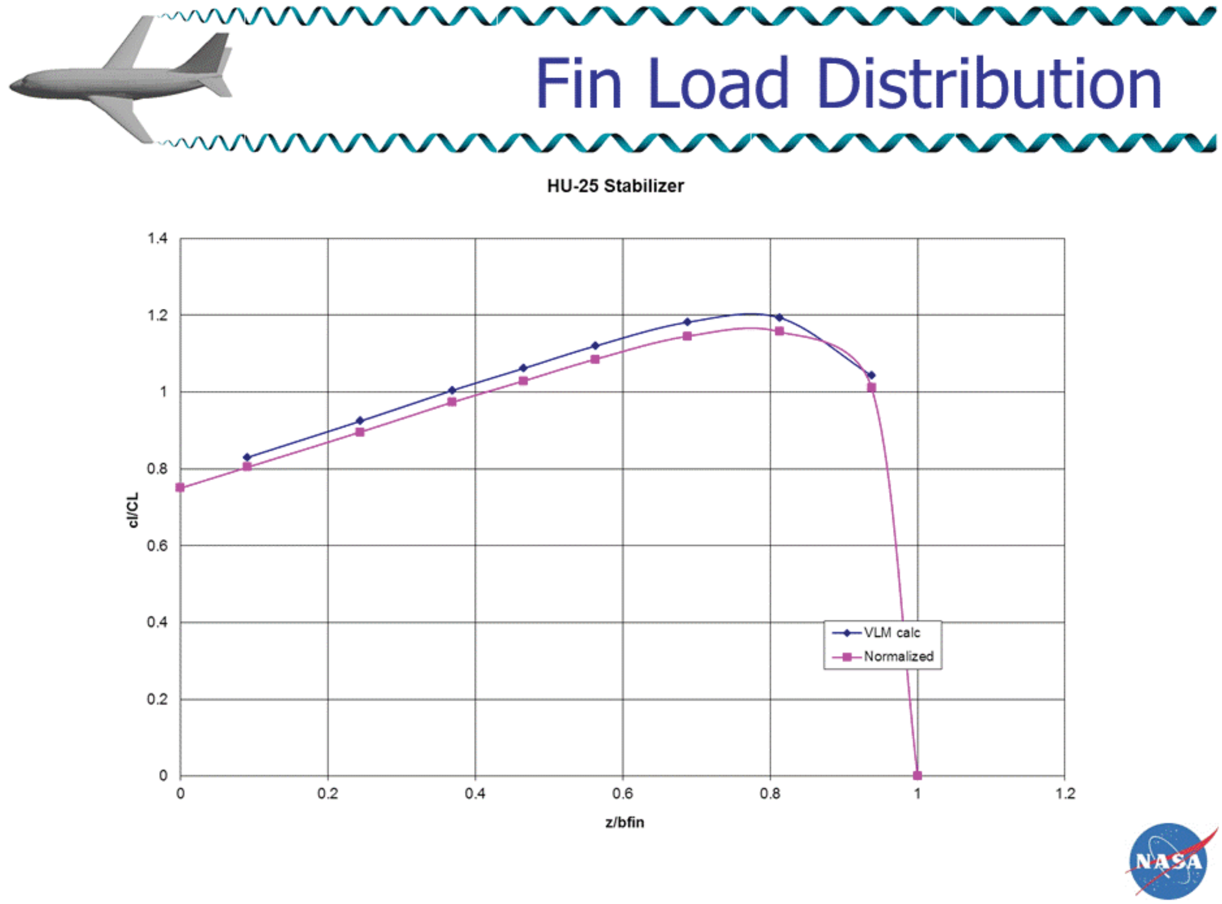
Found "tuned" strip theory to be the preferred method to predict wake induced upset.

Wake load estimate process

- Digitize tail geometry from 3-view drawings
- Compute uniform span load distribution for stab and fin using vortex-lattice method
- Use normalized span load for strip theory wake induced distributed load


Geometry - Digitized 3-View
Fin
Stabilizer
06-00-00


Stab Load Distribution
HU-25 Stabilizer
cl/CL
y/bstab
VLM calc
Normalized
1.2
1
0.8
0.6
0.4
0.2
0
-0.6
-0.4
-0.2
0
0.2
0.4
0.6


Fin Load Distribution
HU-25 Stabilizer
cl/CL
z/bfin
VLM calc
Normalized
0
0.2
0.4
0.6
0.8
1
1.2
1.4

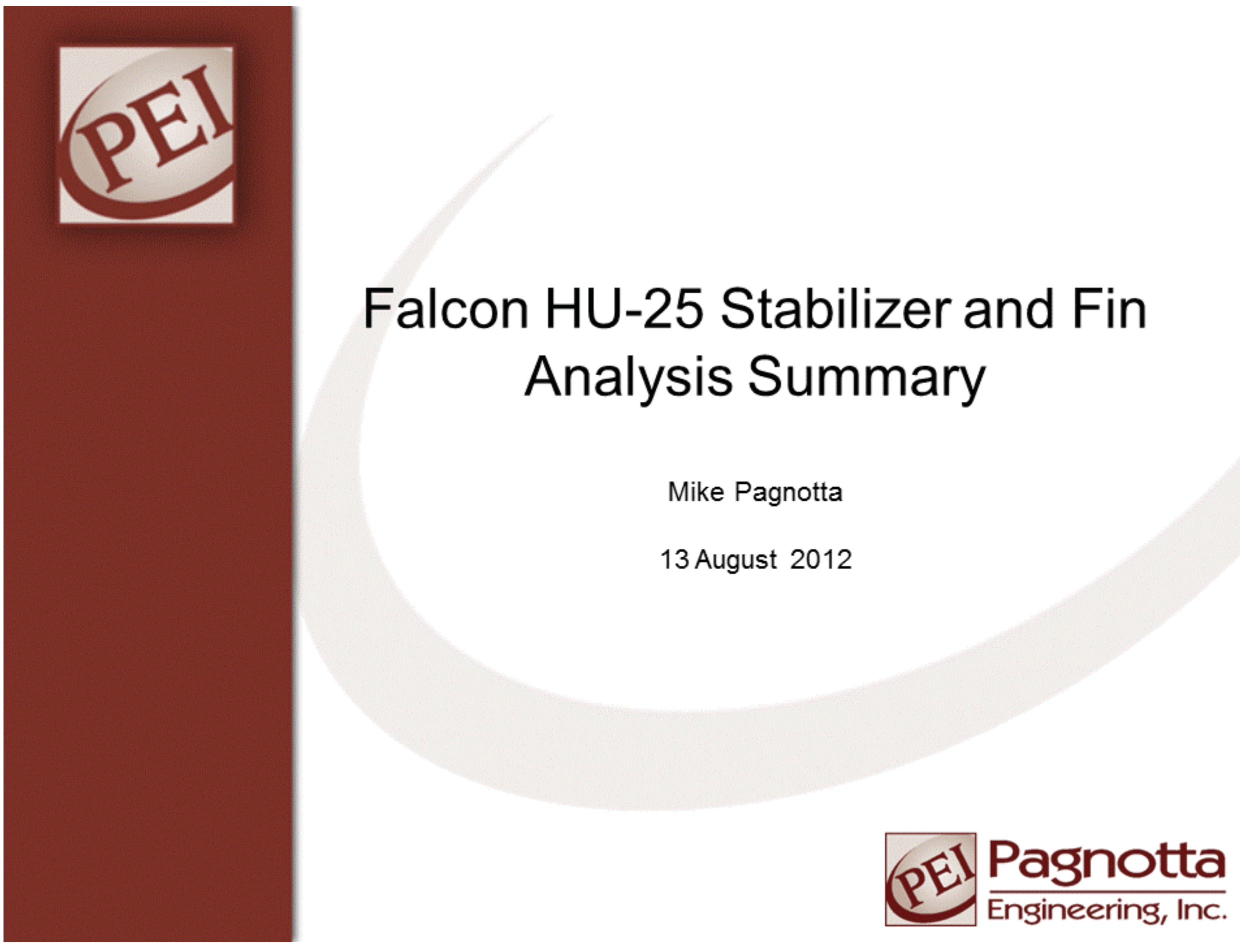
Strip Theory Calculation

Total force normal to surface plane $F_n = \sum_{i=1}^{j} 2\pi \alpha_i k_i c_i d_i$

where:
- j = number of strips
- α_i = strip angle of attack
- k_i = normalized strip load factor
- c_i = strip chord length
- d_i = strip width

Normal of each strip assumed to be at strip c/4 location

Written permission to include the following presentation materials in this publication was received from Mike Pagnotta on May 28, 2013.



Objective

- Determine if vortex loads on stabilizer (horizontal tail) and fin (vertical tail) potentially control the design of those components

- Evaluate stabilizer and fin structures for vortex loads plus level flight loads
  - Can be a detailed evaluation on a complete stabilizer/fin/tail cone if geometry and hardware information is available
  - Can be a simple calculation of resultant loads and moments at key interfaces if tail information is lacking

- Determine stabilizer and fin structural integrity due to maximum flight loads
  - Requires analysis report
  - Can perform simple calculations of resultant loads at key interfaces as planned for the vortex loads provided weight and c.g. information can be obtained

Overall objective is to determine if the planned flight path as chase plane for the DC-8 will generate forces and stresses that could potentially endanger the aircraft structural integrity

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Date: 7/29/12 Slide 2

Assumptions Used in the Loads Comparison

- FS, BL, and WL locations in supplied vortex loads spreadsheet are valid
- Spanwise distribution for flight loads for the stabilizer, as well as height-wise distribution for fin and rudder, are the same as used for the vortex loads ("k" column in the "VtxLoadCalc" tab per Dan Vicroy of NASA LaRC
- Rudder load strips are at the same WL as the upper fin strips (rudder loads distributed along strips 19-23)
- Rudder center of pressure is 24 in. aft of the fin ¼ chord
- It is reasonable to consider level (n=1) flight loads on the stabilizer in combination with the maximum vortex loads. It may or may not be conservative to consider gust loads in addition to vortex plus level flight. Therefore, the stabilizer comparison was made with varying amounts of the maximum gust load (25%, 50%, and 100%).

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Vortex Load Case 1 Data and Interface Locations

Vortex load calculation

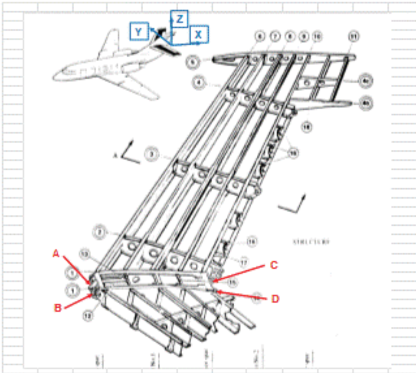
Cruise conditions

Mach	0.7		V, fps	704.9948
Alt	27000	t	q, psf	245.4961

Wake model parameters

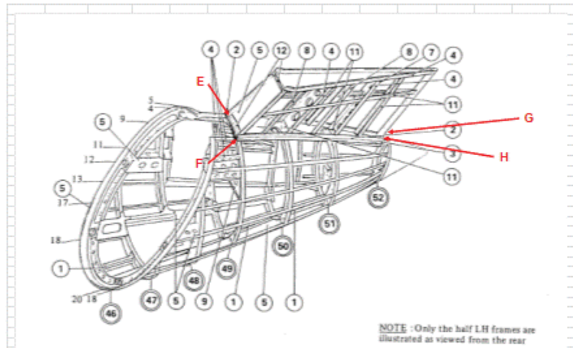
Gam_0	4606.926	t^2/s	Gam	4498.764	ft^2/s
rc	1.64	t			
b	116.47	t			
c	279494	t			
Xw	6562	t			
Yw	58.235	t			
Zw	12.7708	t			

The HU-25C tail is centered on the vortex. The aircraft is 2 km behind the lead (DC-8) aircraft.



Location	FS	BL	WL
A	540	5	150
B	540	-5	150
C	616	4	150
D	616	-4	150

Stabilizer	FS	BL	WL
Centroid	578	0	150



Location	FS	BL	WL
E	447	5	120
F	447	-5	120
G	628	2	120
H	628	-2	120

Fin	FS	BL	WL
Centroid	536.5	0	120

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Date: 8/13/12 Slide 4

Stabilizer Loads and Moments Comparison Summary

Vortex Load Case 1

COMPARISON OF STABILIZER VORTEX TO FLIGHT LOADS		
Design Loads per side	**Maximum Load (lbf)**	**Ratio to max Flight**
Worst Case Flight	-10043	1.000
Vortex Only	-15270	1.521
Vortex Plus Level Flight	-18511	1.843
Vortex Plus Level Flight Plus 25% Gust	-20212	2.013
Vortex Plus Level Flight Plus 50% Gust	-21912	2.182
Vortex Plus Level Flight Plus 100% Gust	-25313	2.521

COMPARISON OF STABILIZER VORTEX TO FLIGHT MOMENTS AT STABILIZER INTERFACE CENTROID		
Design Loads per side	**Maximum MX (in-lbf)**	**Ratio to max Flight**
Worst Case Flight	-635268	1.000
Vortex Only	-881942	1.388
Vortex Plus Level Flight	-1086961	1.711
Vortex Plus Level Flight Plus 25% Gust	-1194523	1.880
Vortex Plus Level Flight Plus 50% Gust	-1302085	2.050
Vortex Plus Level Flight Plus 100% Gust	-1517209	2.388

Note that comparison is for one side of the stabilizer (moments summed at BL 0). The total vortex loads are significantly lower than flight loads when considering both sides. However, the load on one side is a more accurate of the effect on the internal stabilizer structure. Attachments loads are lower for flight as compared to vortex loads.

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Date: 8/13/12 Slide 5

Fin and Rudder Loads and Moment Comparison Summary

Vortex Load Case 1

COMPARISON OF FIN VORTEX TO GUST LOADS		
Design Loads	Maximum Load (lbf)	Ratio to max Flight
Gust Only	-4737	1.000
Vortex Only	-895	0.189
Vortex Plus 25% Gust	-2079	0.439
Vortex Plus 50% Gust	-3263	0.689
Vortex Plus 100% Gust	-5632	1.189

COMPARISON OF FIN VORTEX TO GUST PLUS RUDDER LOADS		
Design Loads	Maximum Load (lbf)	Ratio to max Flight
Gust Plus Rudder	-8406	1.000
Vortex Only	-895	0.106
Vortex Plus 25% Gust Plus Rudder	-2996	0.356
Vortex Plus 50% Gust Plus Rudder	-5098	0.606
Vortex Plus 100% Gust Plus Rudder	-9301	1.106

COMPARISON OF FIN VORTEX TO FIN GUST PLUS RUDDER MOMENTS AT FIN STUB INTERFACE CENTROID		
Design Loads	Maximum MX (in-lbf)	Ratio to max Flight
Gust Only	-212259	1.000
Vortex Only	-563109	2.653

COMPARISON OF FIN VORTEX TO FIN GUST MOMENTS AT FIN STUB INTERFACE CENTROID		
Design Loads	Maximum MX (in-lbf)	Ratio to max Flight
Gust Plus Rudder	-432039	1.000
Vortex Only	-563109	1.303

COMPARISON OF FIN VORTEX TO FIN GUST PLUS RUDDER MOMENTS AT FIN STUB INTERFACE CENTROID		
Design Loads	Maximum MZ (in-lbf)	Ratio to max Flight
Gust Only	152582	1.000
Vortex Only	979046	6.417

COMPARISON OF FIN VORTEX TO FIN GUST MOMENTS AT FIN STUB INTERFACE CENTROID		
Design Loads	Maximum MZ (in-lbf)	Ratio to max Flight
Gust Plus Rudder	451349	1.000
Vortex Only	979046	2.169

Not certain if maximum fin flight gust loads can occur simultaneously with maximum rudder flight maneuver gust loads. Therefore, comparison with the vortex loads made to fin flight gust load only and fin flight gust plus rudder flight maneuver loads.

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Date: 8/13/12 Slide 6

Conclusions

- For load case 1, Stabilizer vortex loads and interface moments are well in excess of maximum flight loads and moments
  - Forces are from 52.1% to 152.1% higher
  - Moments are from 38.8% to 138.8% higher
  - Note that the higher end of the exceedance is unrealistic. The maximum exceedance assumes that 100% of flight gust exists with the vortex loads.
- For load case 1, Fin vortex loads are generally lower than fin flight loads
  - Unless 100% gust is considered, unrealistic
- For load case 1, Fin vortex interface moments are well in excess of fin rudder flight loads, greater even if fin flight plus rudder maneuver moments are combined (most conservative case for flight)
- Slight decrease in vortex loads for case 2, no appreciable change in above conclusions

Unless the margins of safety for the stabilizer, fin, and rudder are known, vortex loads could adversely affect the structural integrity of the aircraft

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Date: 8/13/12 Slide 7

Appendix E. Tabulated Vortex-Induced Aerodynamic Coefficients and Component Loads

An independent analysis of the vortex induced aerodynamic loads on the Falcon 20 in the wake of the DC-8 was described in the main report. A selected set of results are presented in Section 7.2 for the most conservative DC-8 vortex induced effects on the Falcon 20, but many additional results for less conservative vortex characteristics were considered by the NESC team. The complete set of results from the analysis is shown in this appendix.

The following characteristics of the DC-8 apply to these results:

Weight: 280,000 lb
Altitude: 25,000 ft
Mach number: 0.7
Trailing vortex decay: none
Trailing vortex core: 1%, 2%, and 3.5% of DC-8 wing span

The digitized fuselage, wing, horizontal tail planform, and vertical tail planform used to model the Falcon for the aerodynamic analyses are shown in Figures E-1 through E-5.

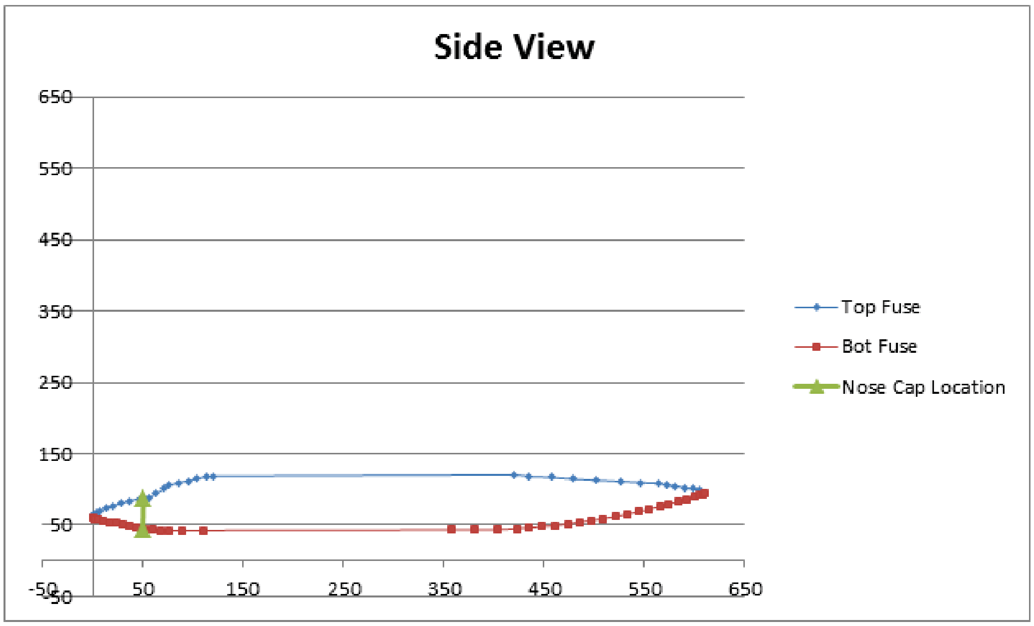


Figure E-1. Digitized Falcon Fuselage Side View Model

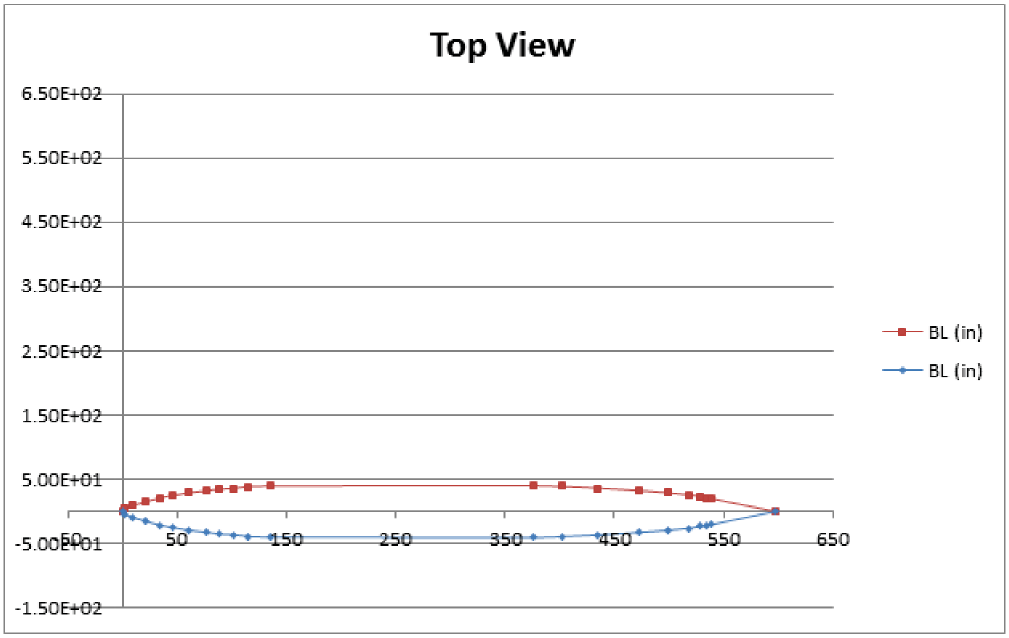


Figure E-2. Digitized Falcon Fuselage Top View Model

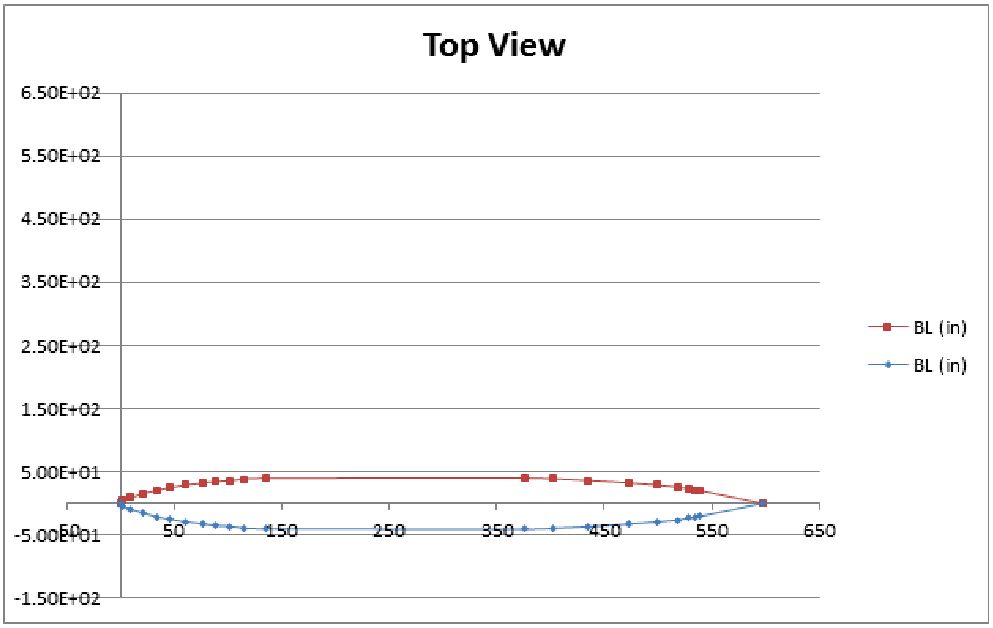


Figure E-3. Digitized Falcon Fuselage Top View Model

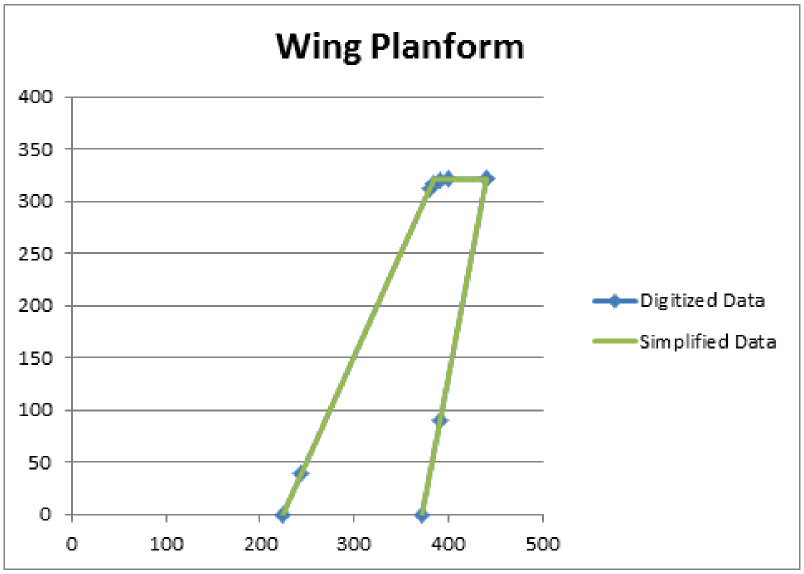


Figure E-4. Digitized Falcon Wing Planform Model

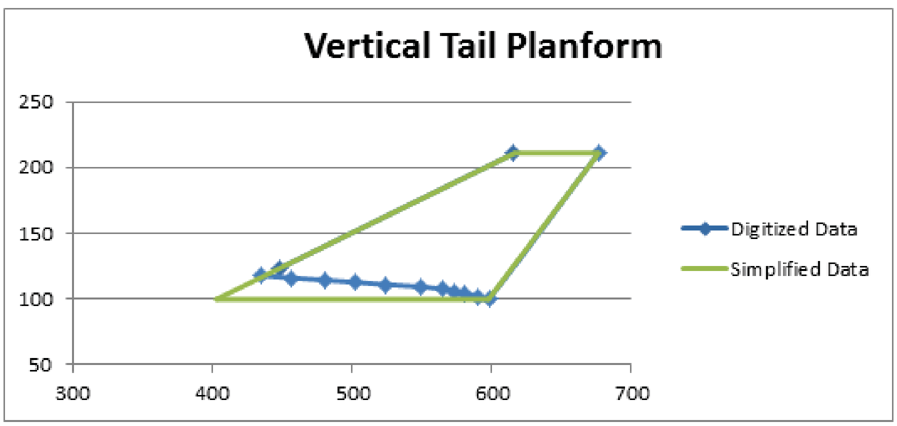


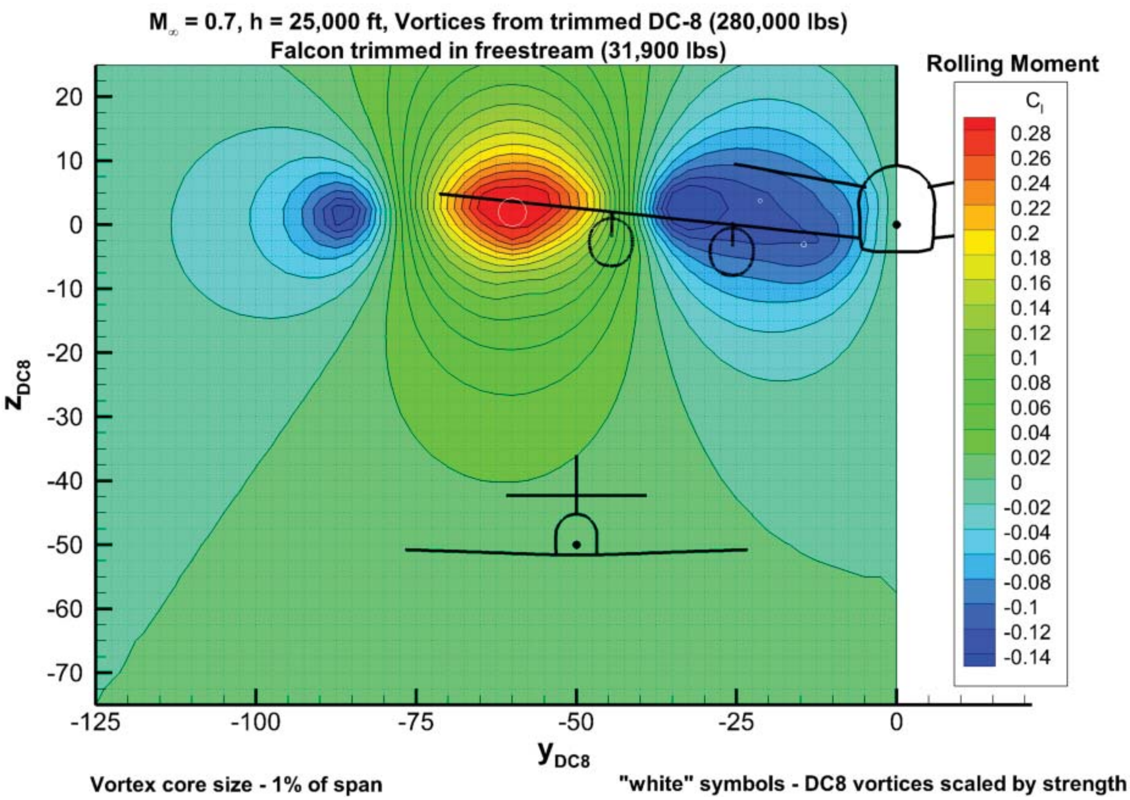
Figure E-5. Digitized Falcon Vertical Tail Planform Model

The NEAR STRLNCH and MISDL prediction methods were applied with the DC-8 modeled as the parent aircraft and the Falcon 20 modeled as the launched store. The Falcon 20, in its heavy configuration of 31,900 lb, was trimmed under free-stream flight conditions. It was then placed in a matrix of locations behind the DC-8, with each location defined by the (Y, Z) coordinates in the DC-8 system. Note in the following figures that the Y coordinates are negative on the port side of the DC-8. At each location in the DC-8 flow field, including all vorticity associated with the wing and tail loading, the Falcon 20 aerodynamic characteristics were computed without changing the trim configuration; therefore, the aerodynamic forces and moments shown are those induced by the DC-8 flow field.

In the color contour maps shown below, the Falcon 20 nose placed at a point (Y, Z) in the DC-8 flow field will produce the aerodynamic characteristic on the aircraft defined by the color bar at the right of each map. Note that the primary DC-8 vortex location (Y = –60, Z = 2) is shown as a white circle in each figure.

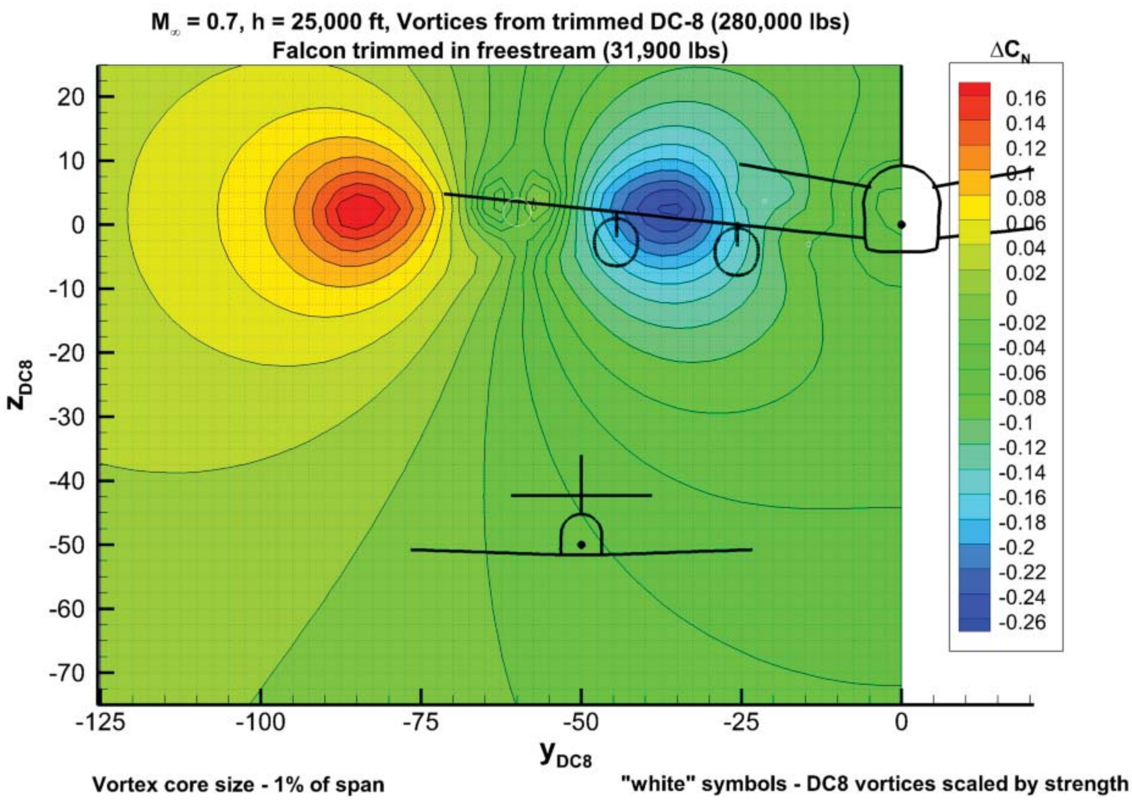
Each set of contour maps for a specific flight condition requires more than 2,000 simulations, so the volume of the results considered by the NESC team is too large to include in tabular form. Each of the data sets used to make the contour maps shown in this appendix is available in digital format if specific results are required.

The first contours shown are for the DC-8 trailing vortex with a core radius of 1 percent of the wing span (Figures E-6(a) through E-6(k). For each case, the Falcon 20 vortex induced rolling moment, normal force, pitching moment, side force, and yawing moment coefficients are shown. The component normal force and root bending moment coefficients are shown for the vertical tail and the right and left horizontal tails.



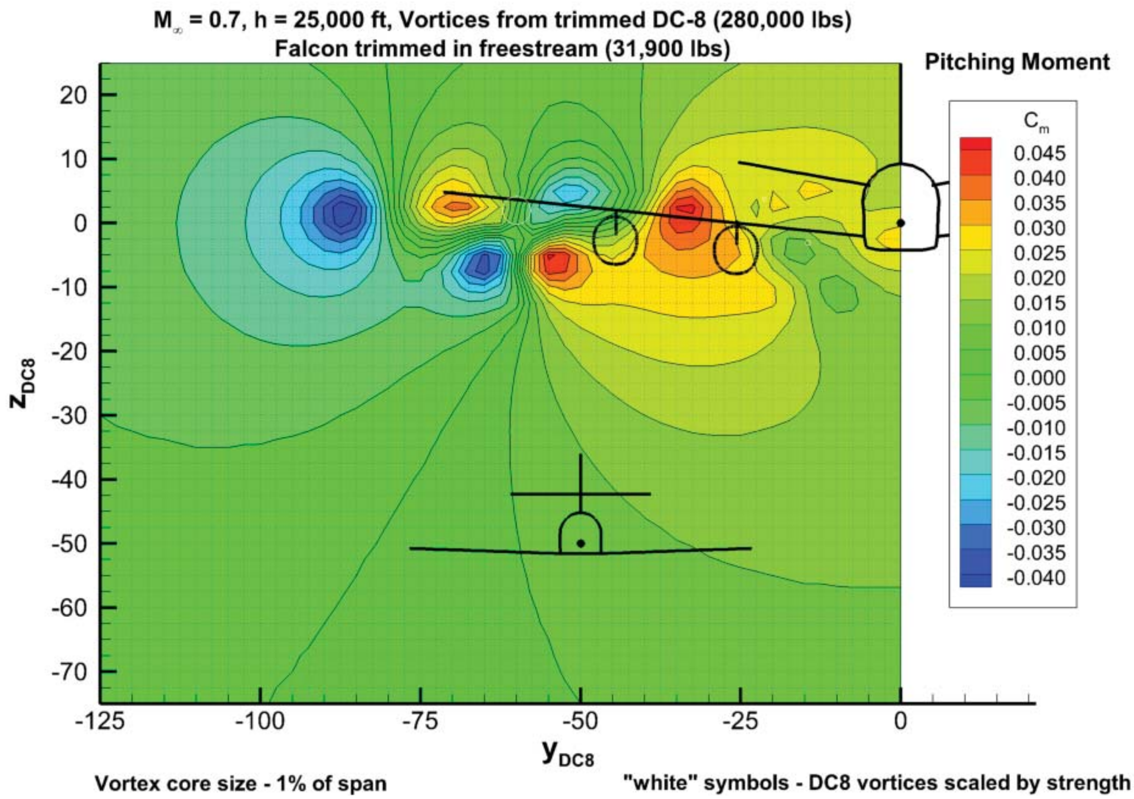
(a) Rolling Moment Coefficient

Figure E-6. DC-8 Vortex-induced Aerodynamic Characteristics on Falcon 20 in Near Field, 1% Vortex Core Radius



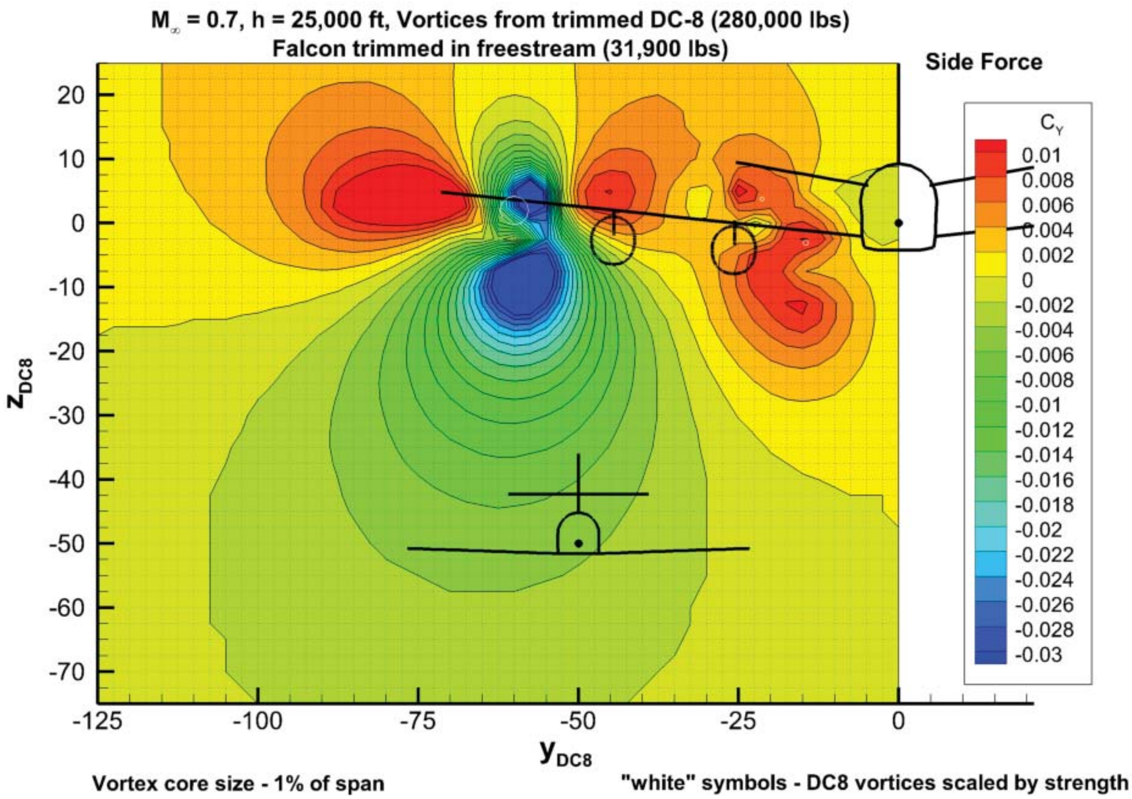
(b) Induced Normal Force Coefficient

Figure E-6. Continued



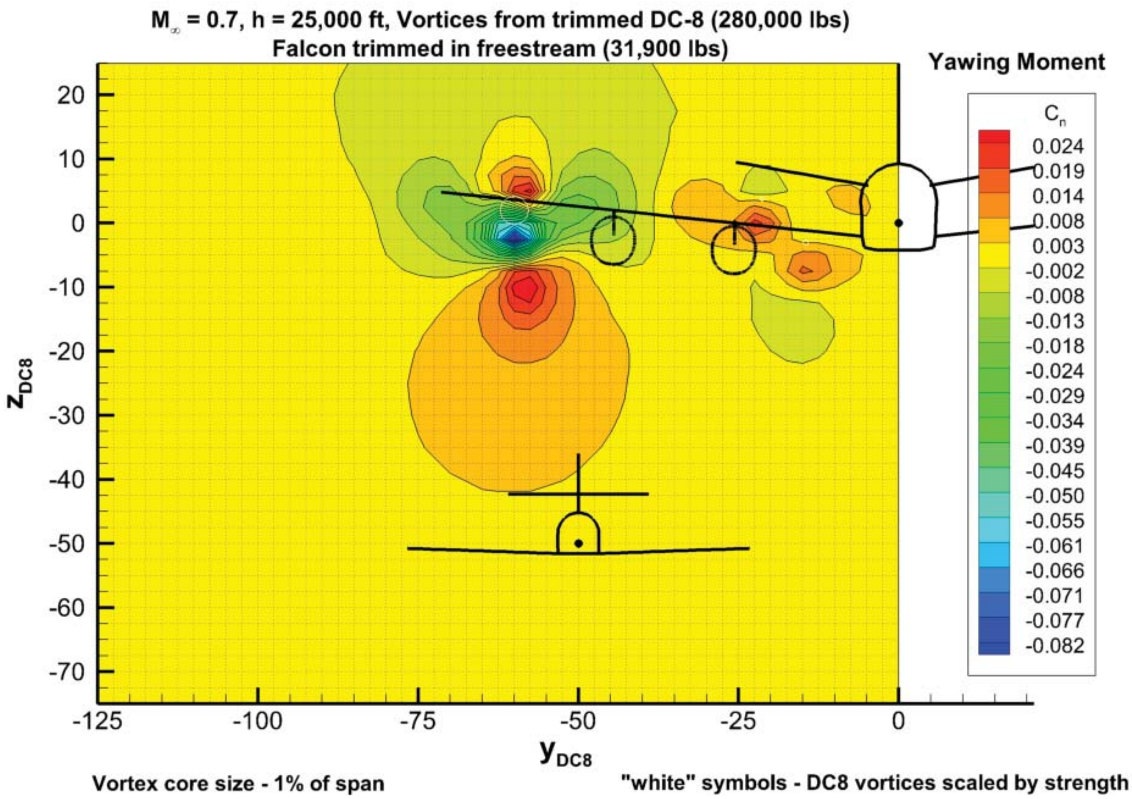
(c) Pitching Moment Coefficient

Figure E-6. Continued



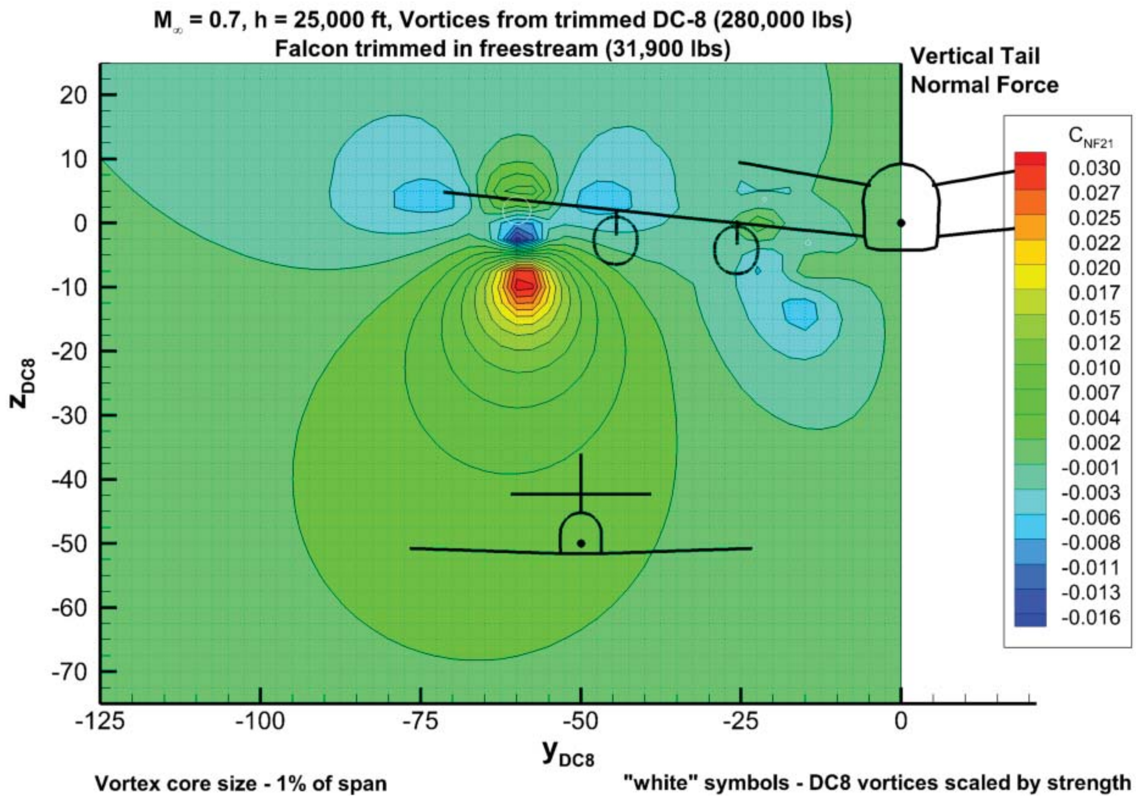
(d) Side Force Coefficient

Figure E-6. Continued



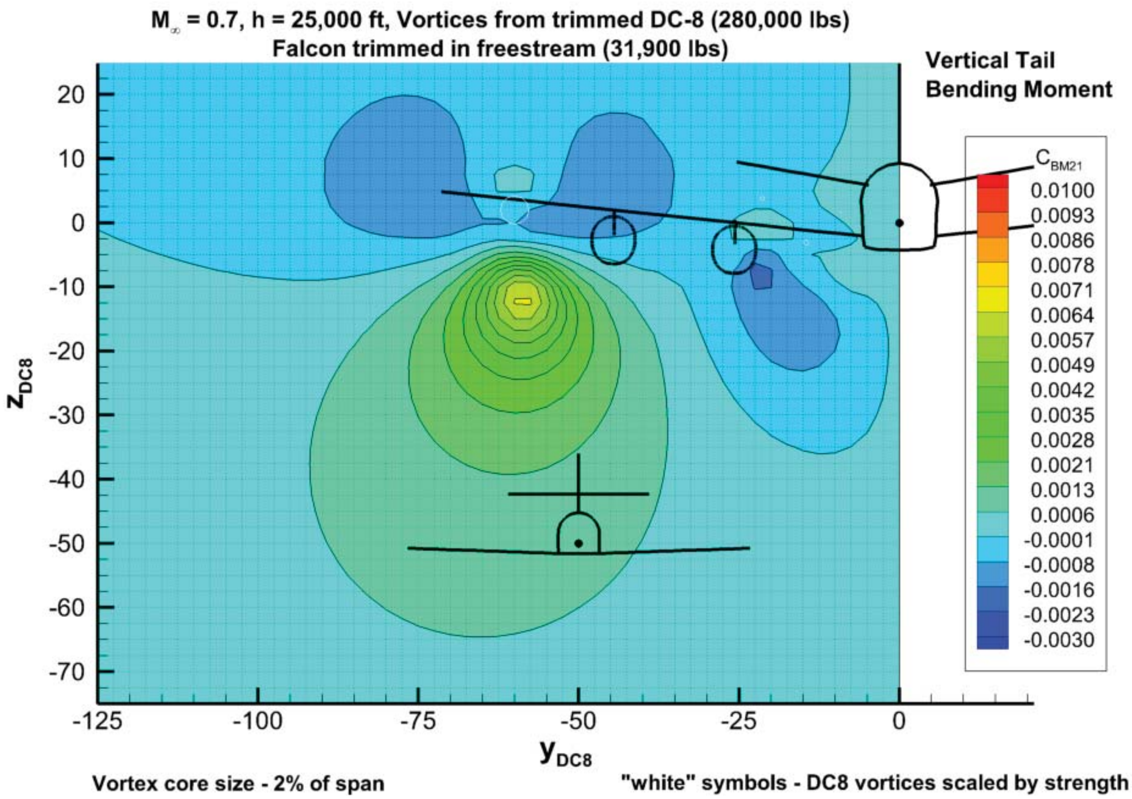
(e) Yawing Moment Coefficient

Figure E-6. Continued



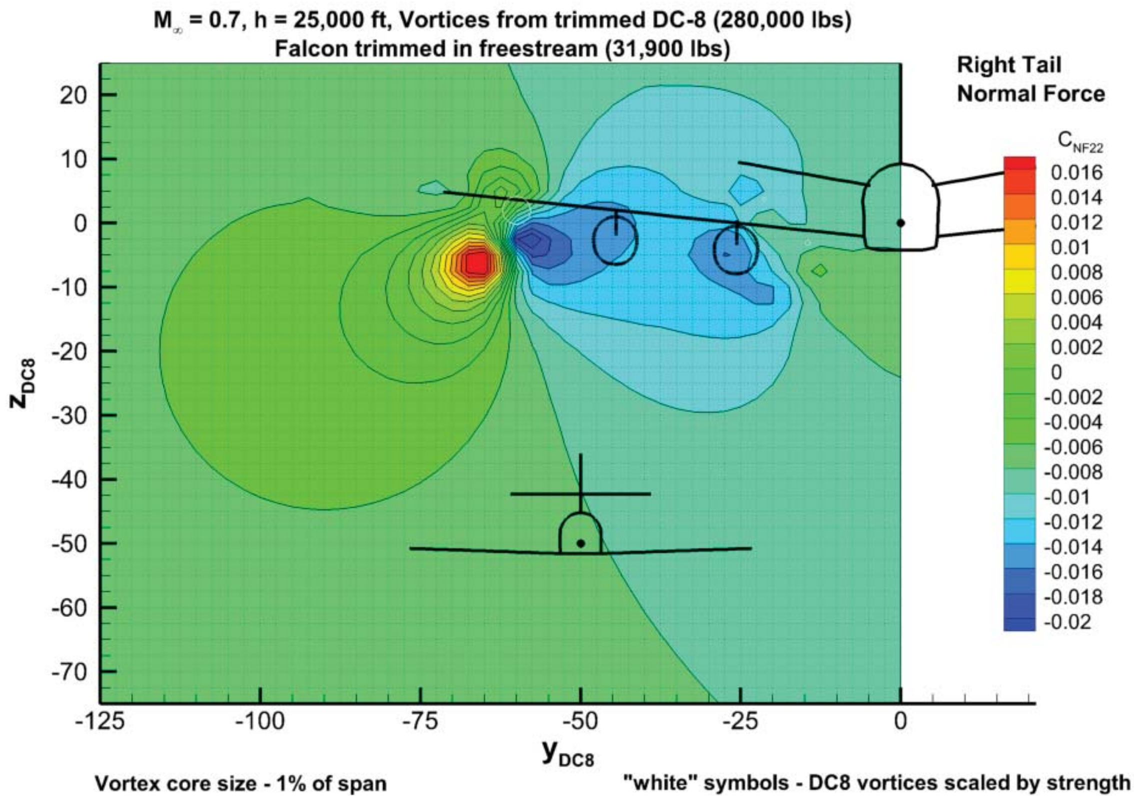
(f) Vertical Tail Normal Force Coefficient

Figure E-6. Continued



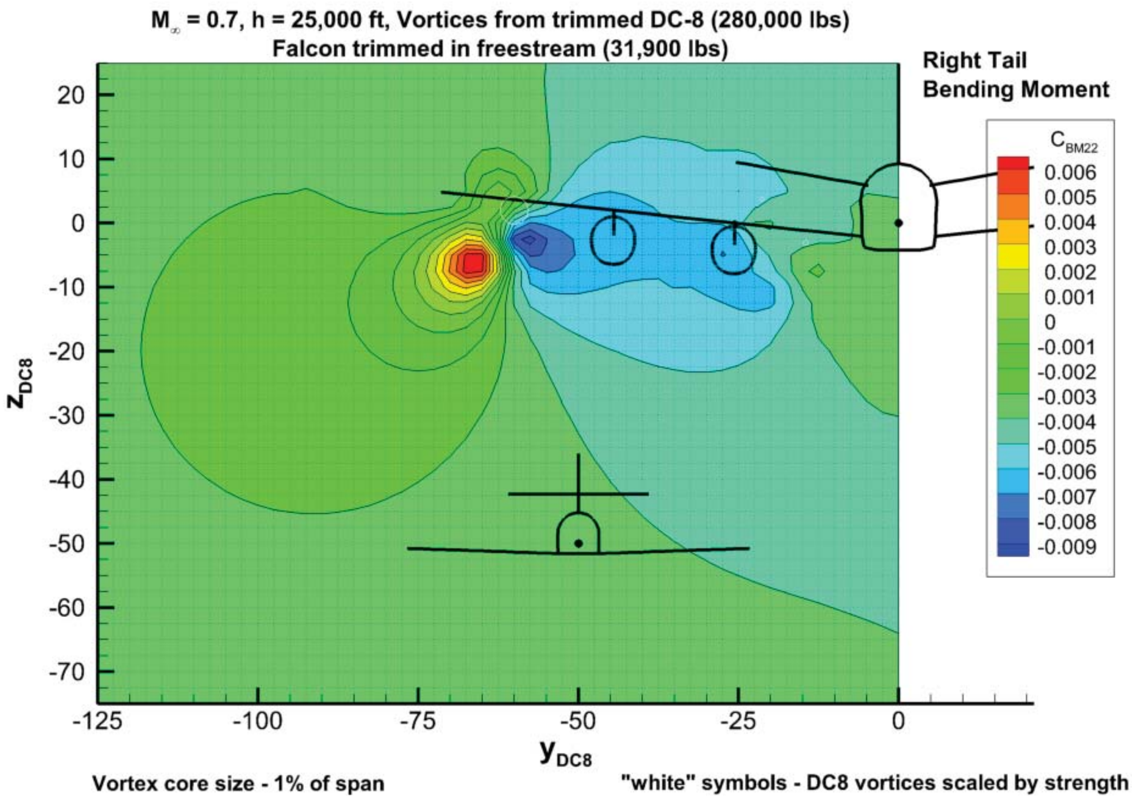
(g) Vertical Tail Root Bending Moment Coefficient

Figure E-6. Continued



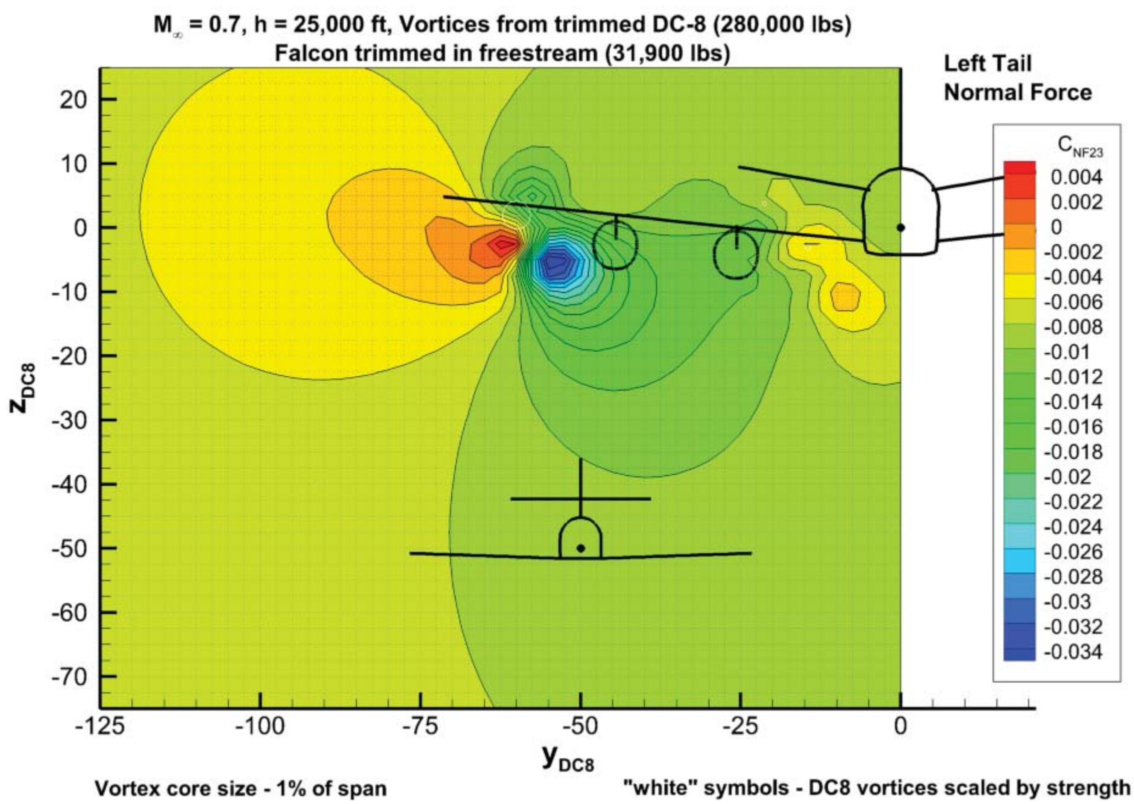
(h) Right Horizontal Tail Normal Force Coefficient

Figure E-6. Continued



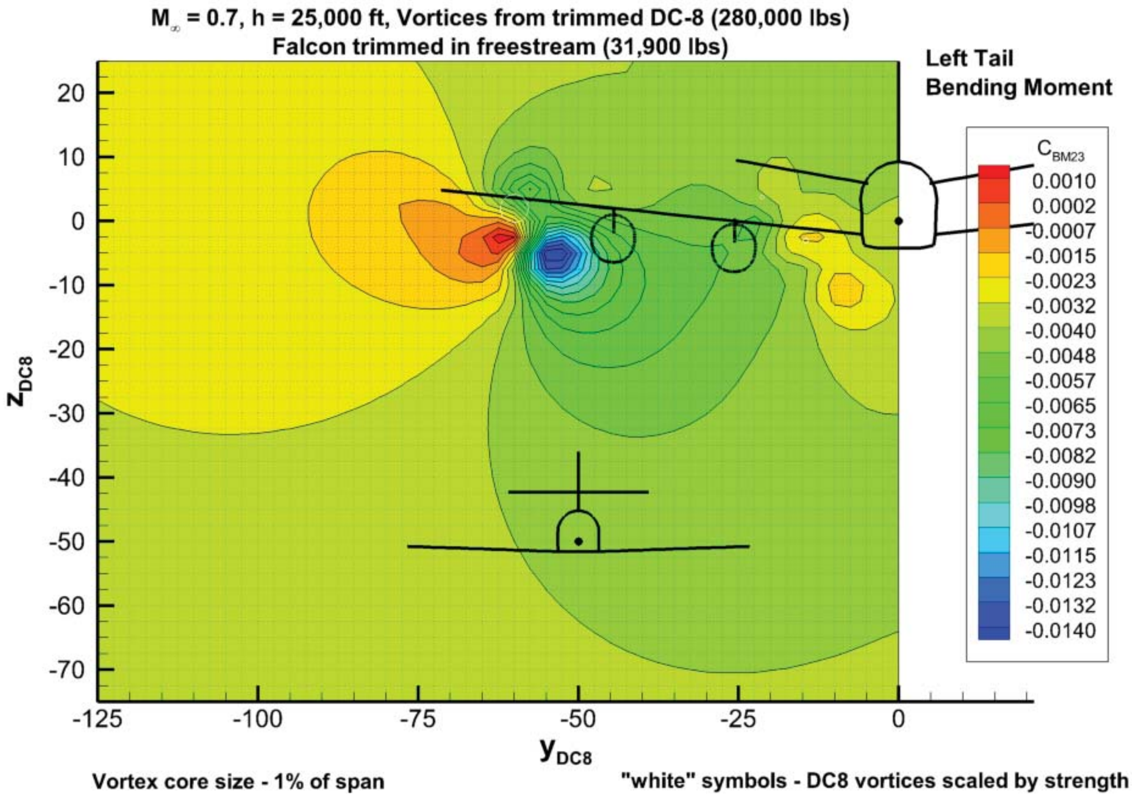
(i) Right Horizontal Tail Root Bending Moment Coefficient

Figure E-6. Continued



(j) Left Horizontal Tail Normal Force Coefficient

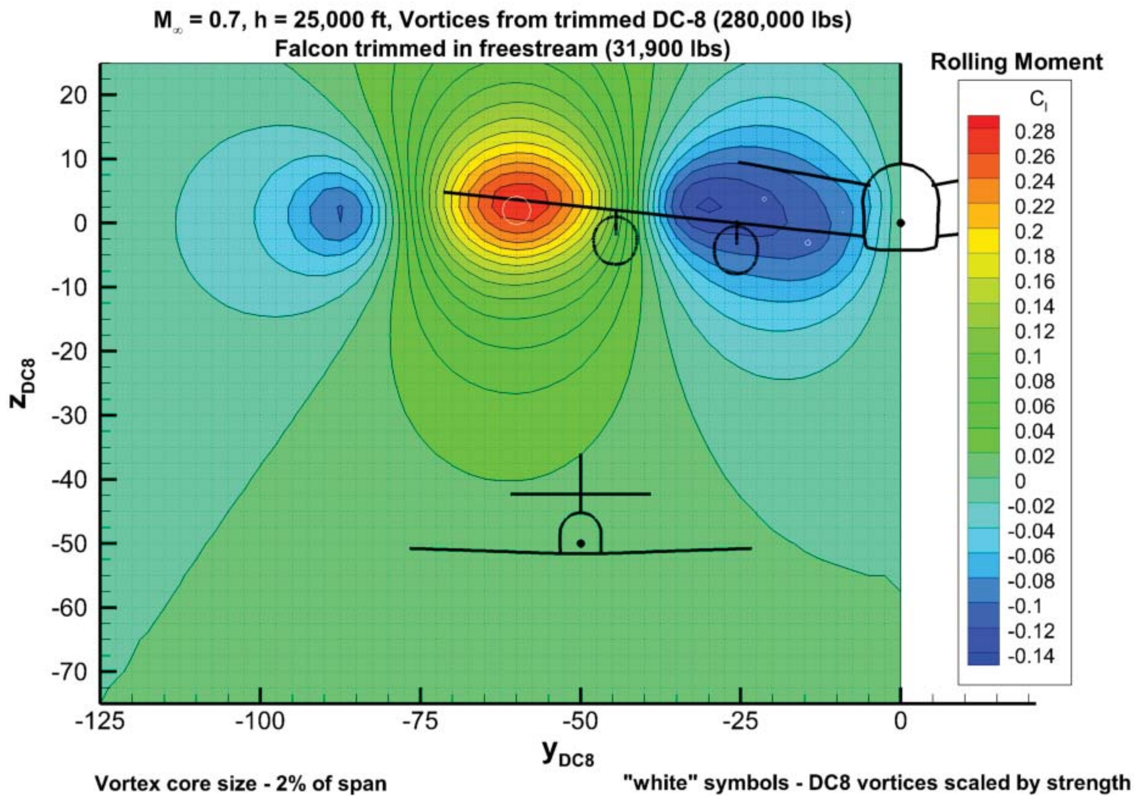
Figure E-6. Continued



(k) Left Horizontal Tail Root Bending Moment Coefficient

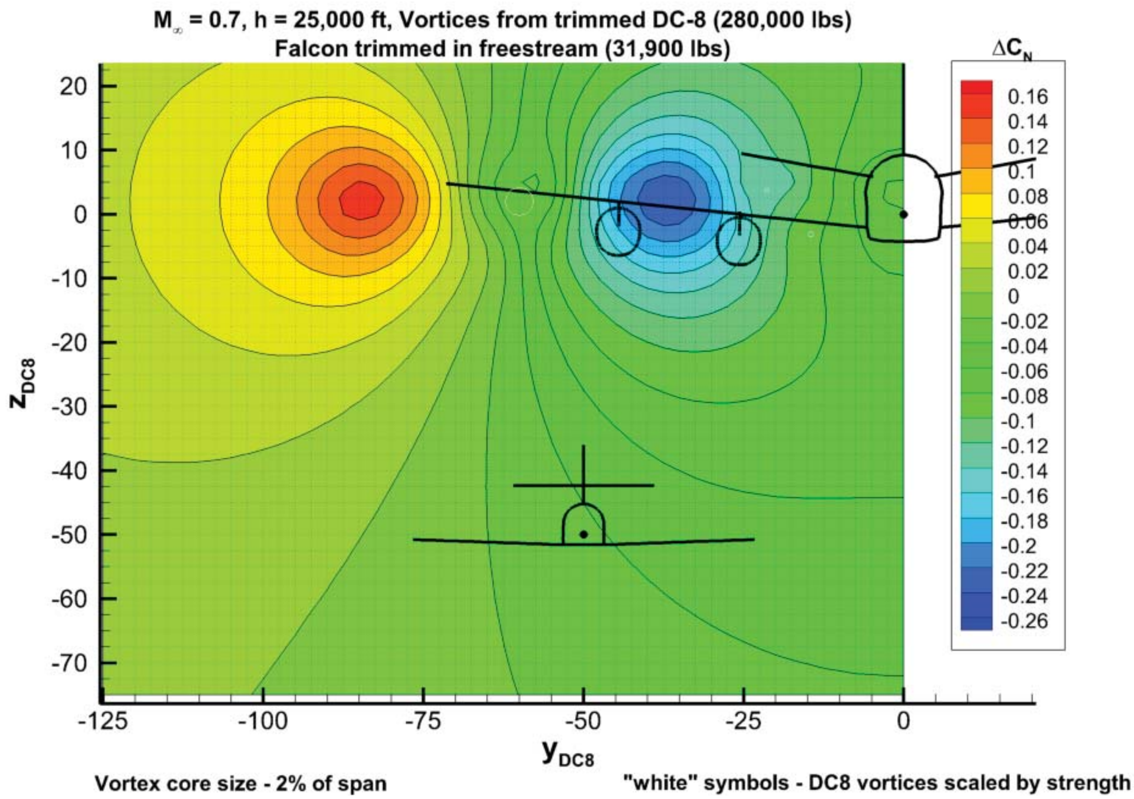
Figure E-6. Concluded

The Falcon 20 induced aerodynamic characteristics for the DC-8 vortex core radius equal to 2 percent of the DC-8 wing span are shown below (Figures E-7(a) through E-7(b)). Note that the only impact on the Falcon 20 aerodynamics is near the vortex core. When the Falcon 20 is away from the core, the vortex induced results are the same as for the smaller core radius.



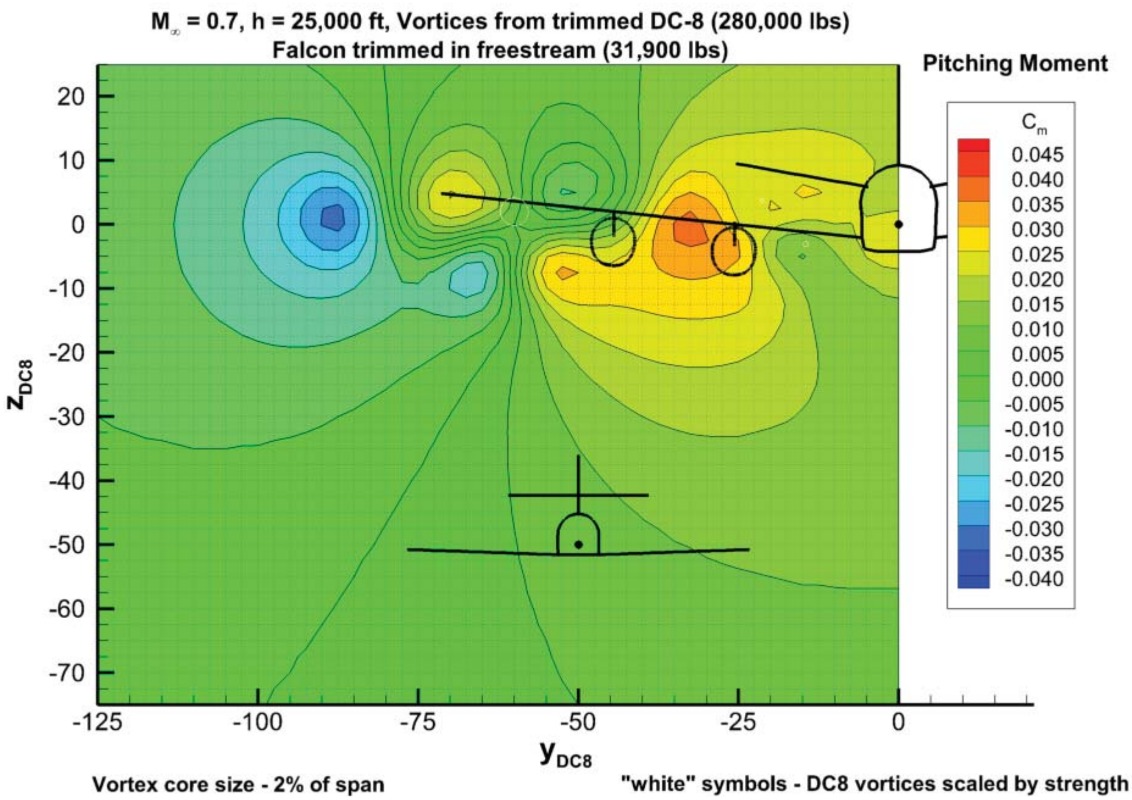
(a) Rolling Moment Coefficient

Figure E-7. DC-8 Vortex-induced Aerodynamic Characteristics on Falcon 20 in Near Field, 2% Vortex Core Radius



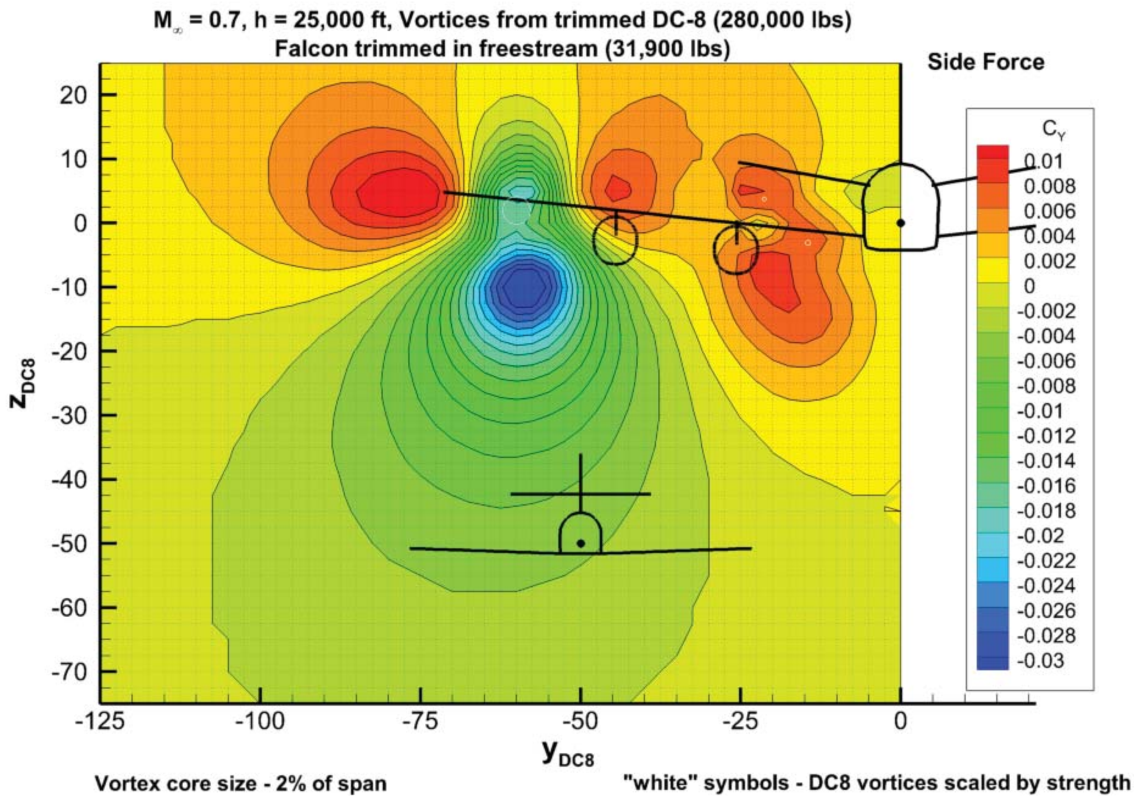
(b) Induced Normal Force Coefficient

Figure E-7. Continued



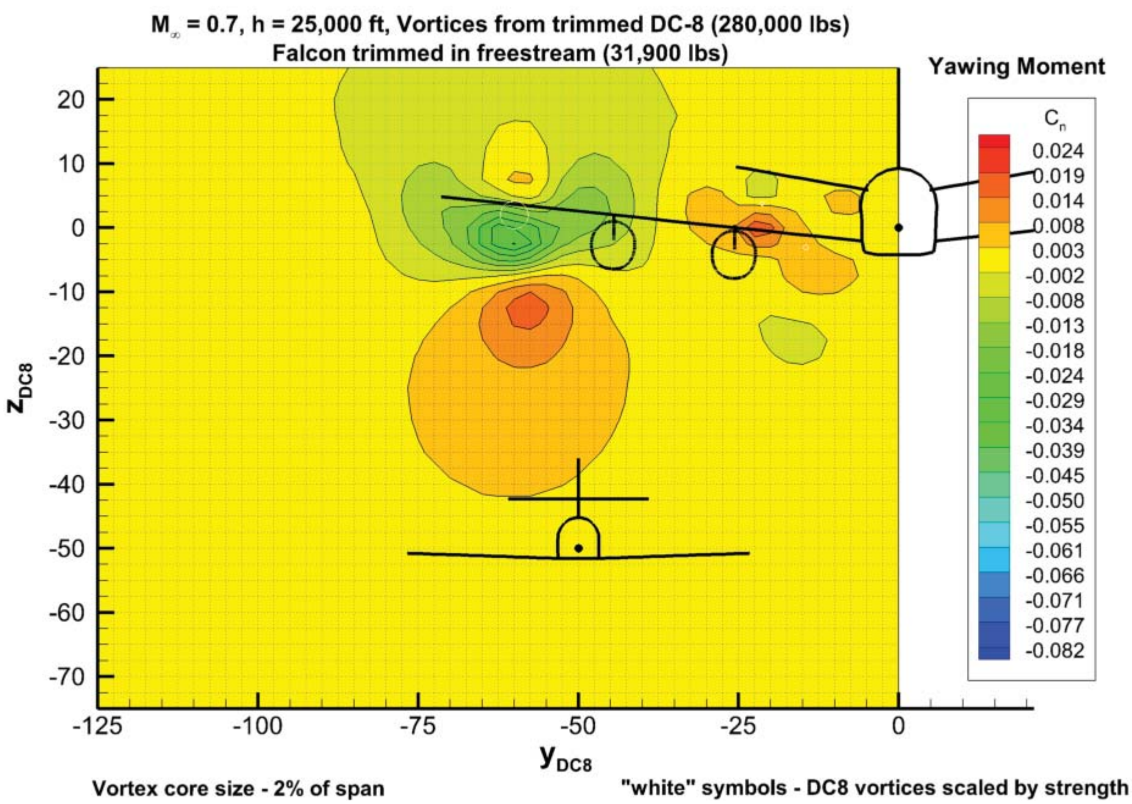
(c) Pitching Moment Coefficient

Figure E-7. Continued



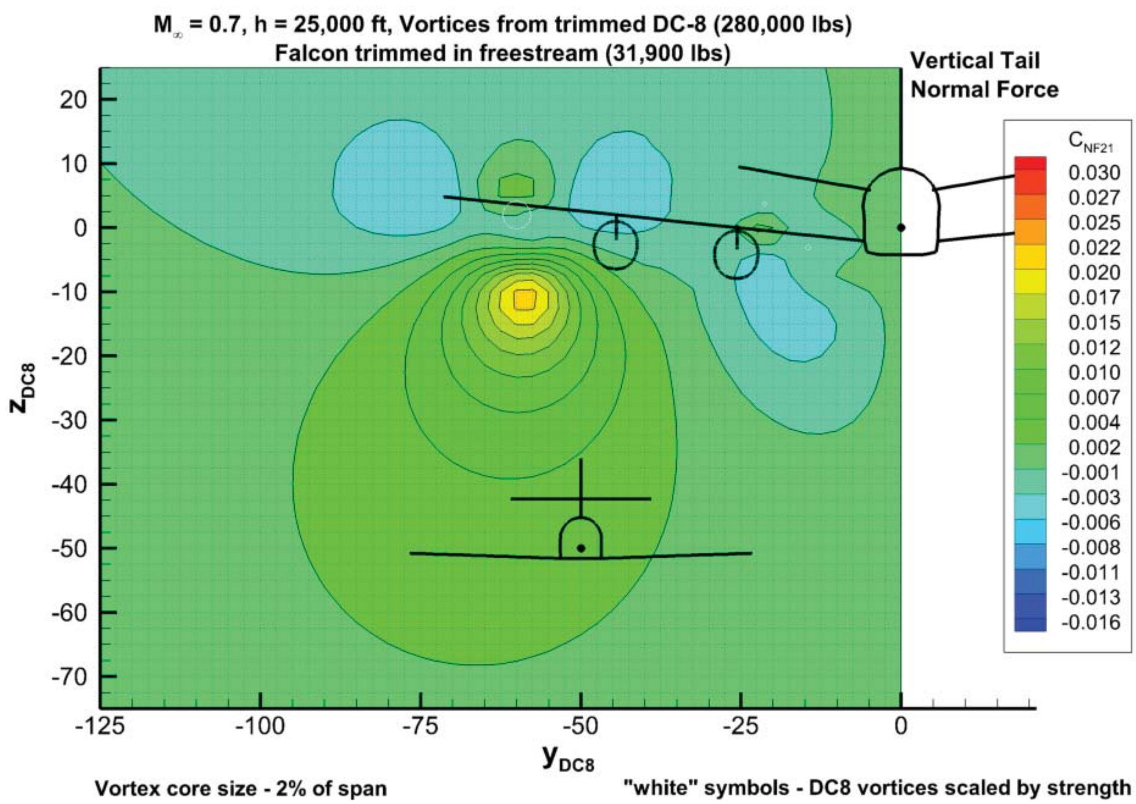
(d) Side Force Coefficient

Figure E-7. Continued



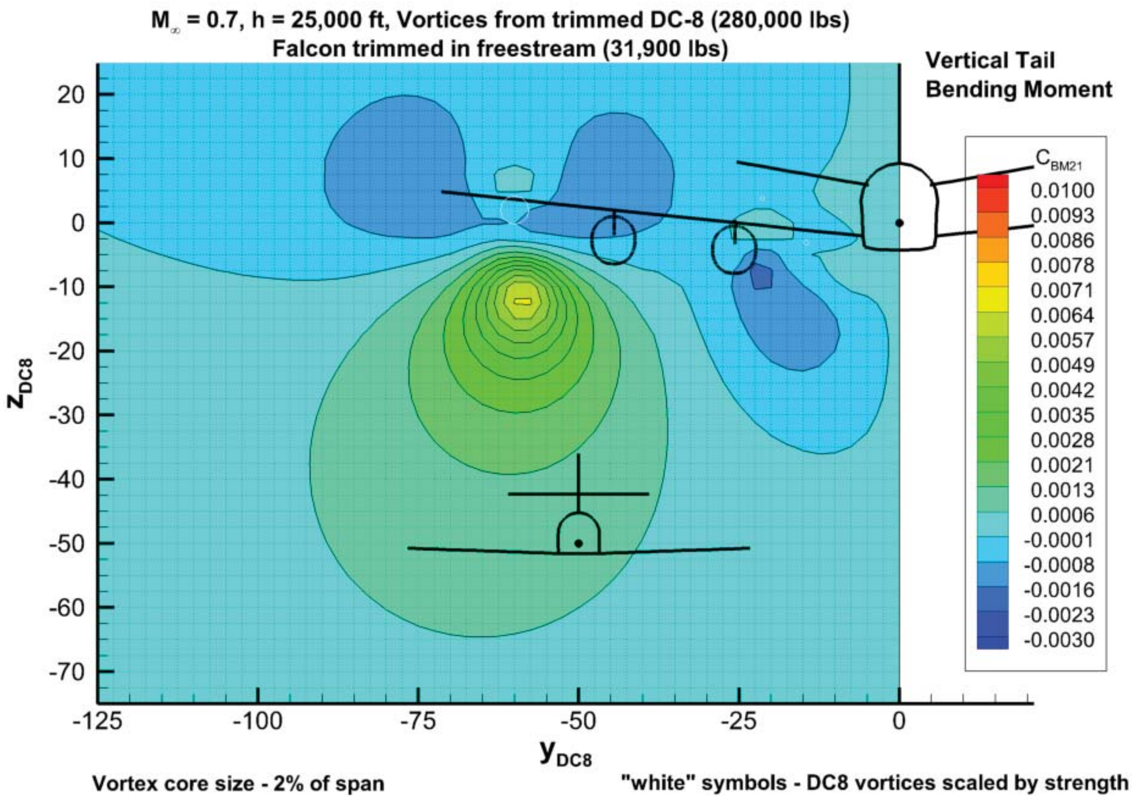
(e) Yawing Moment Coefficient

Figure E-7. Continued



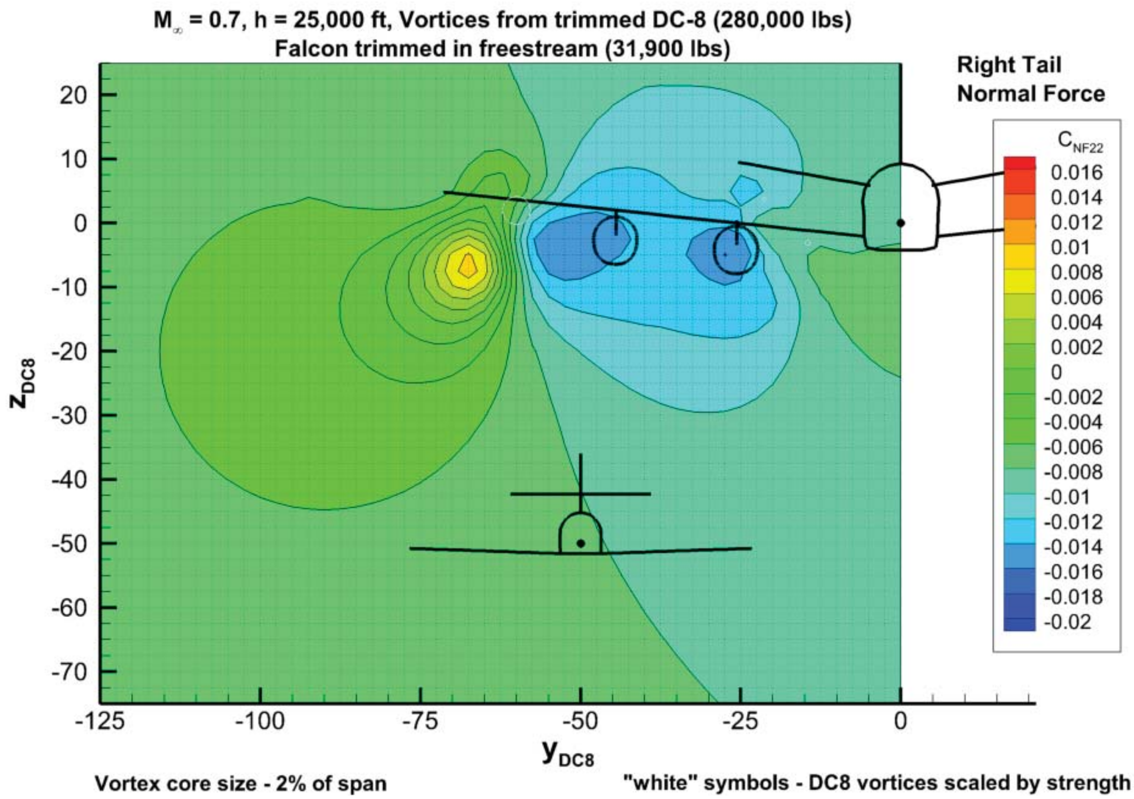
(f) Vertical Tail Normal Force Coefficient

Figure E-7. Continued



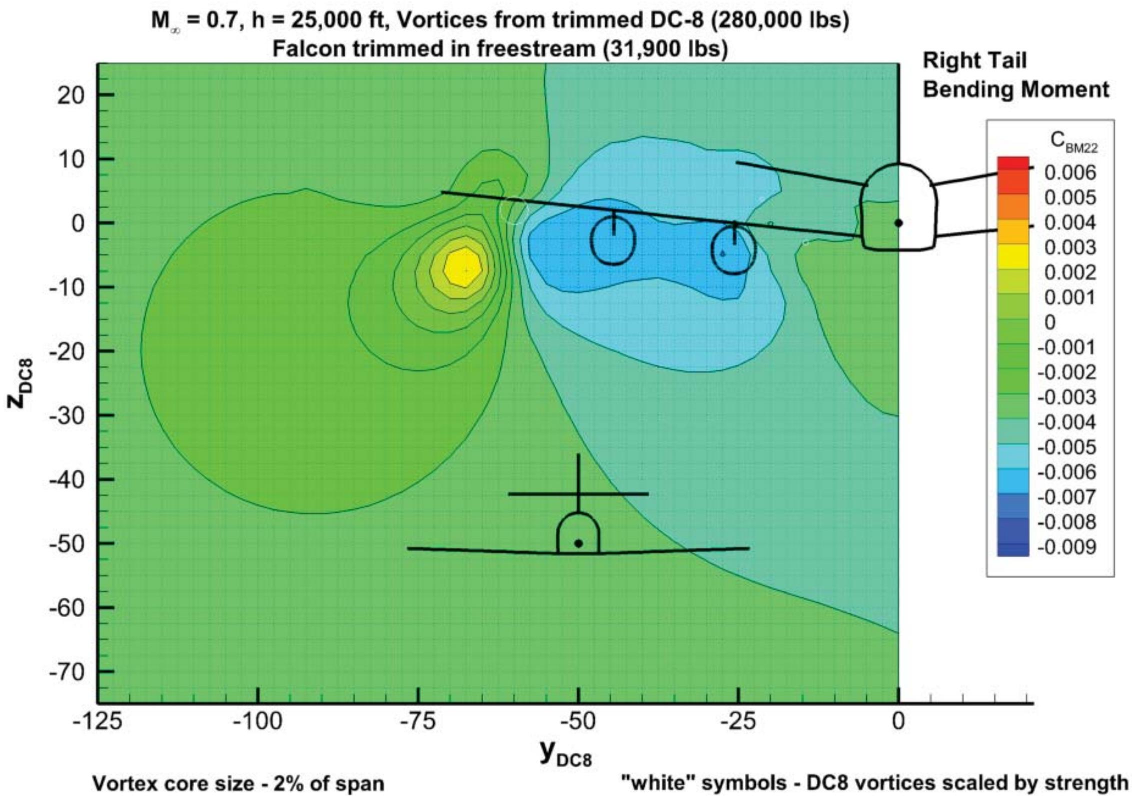
(g) Vertical Tail Root Bending Moment Coefficient

Figure E-7. Continued



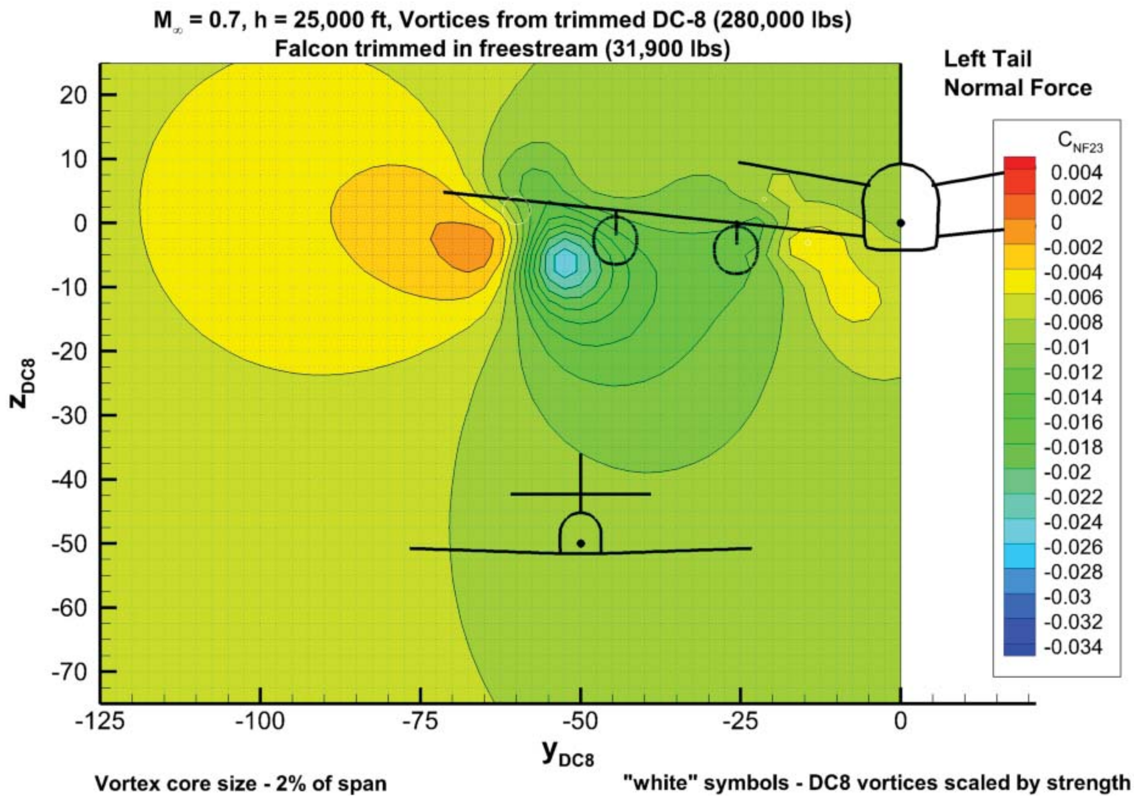
(h) Right Horizontal Tail Normal Force Coefficient

Figure E-7. Continued



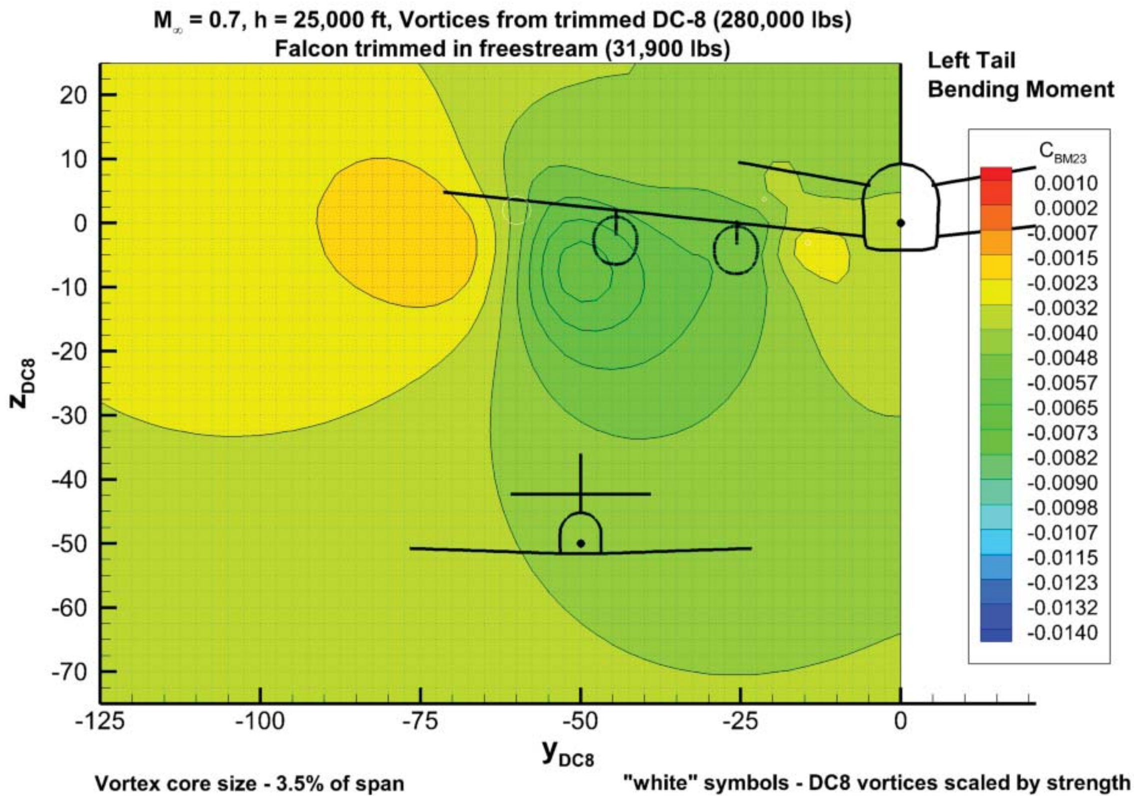
(i) Right Horizontal Tail Root Bending Moment Coefficient

Figure E-7. Continued



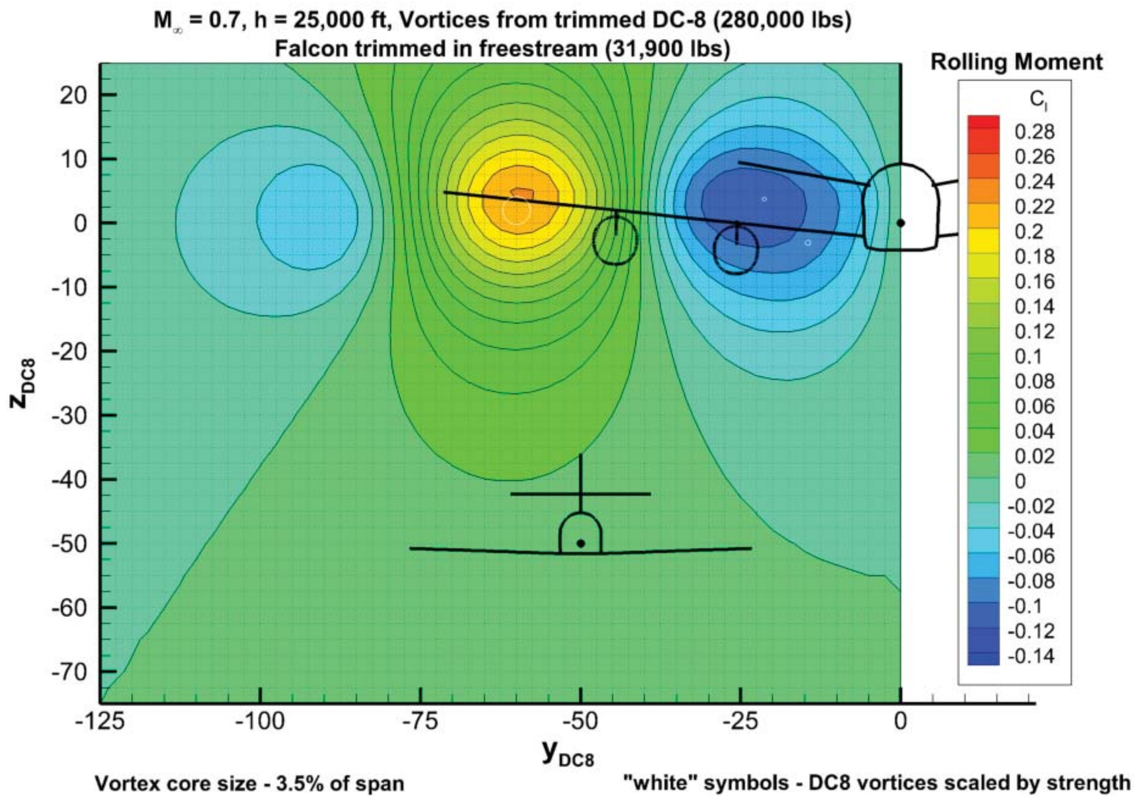
(j) Left Horizontal Tail Normal Force Coefficient

Figure E-7. Continued



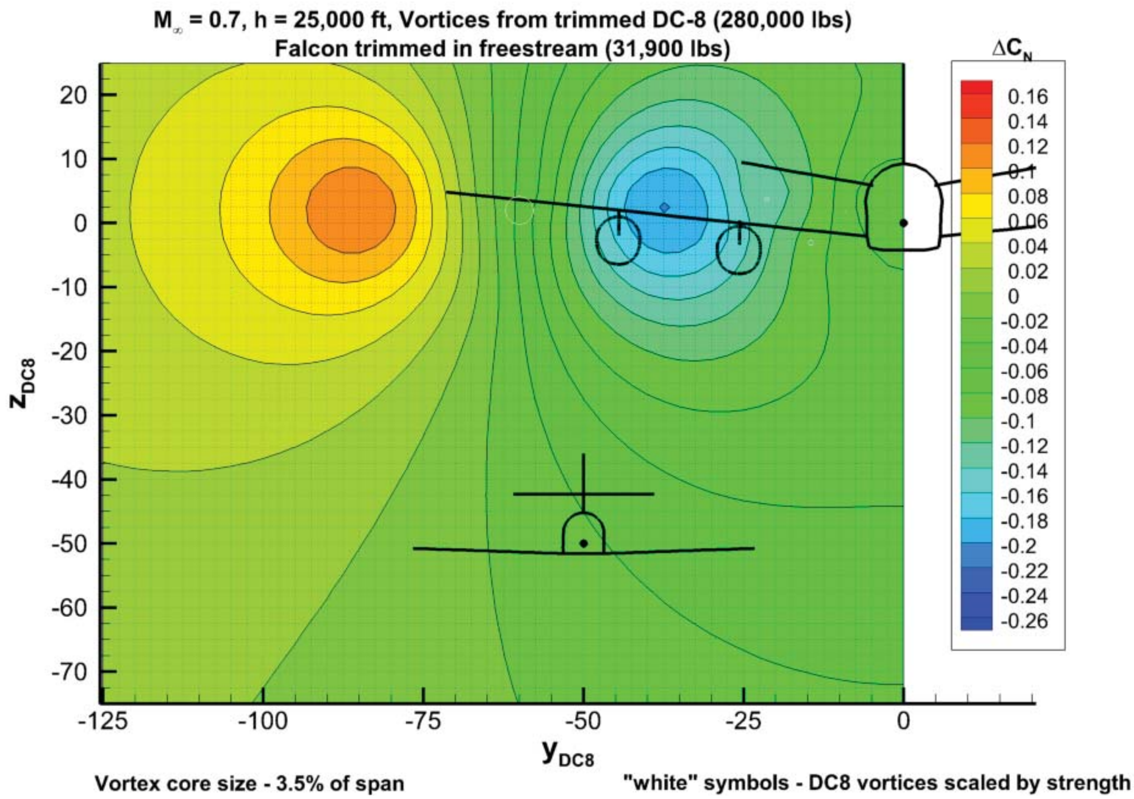
(k) Left Horizontal Tail Root Bending Moment Coefficient

Figure E-7. Concluded



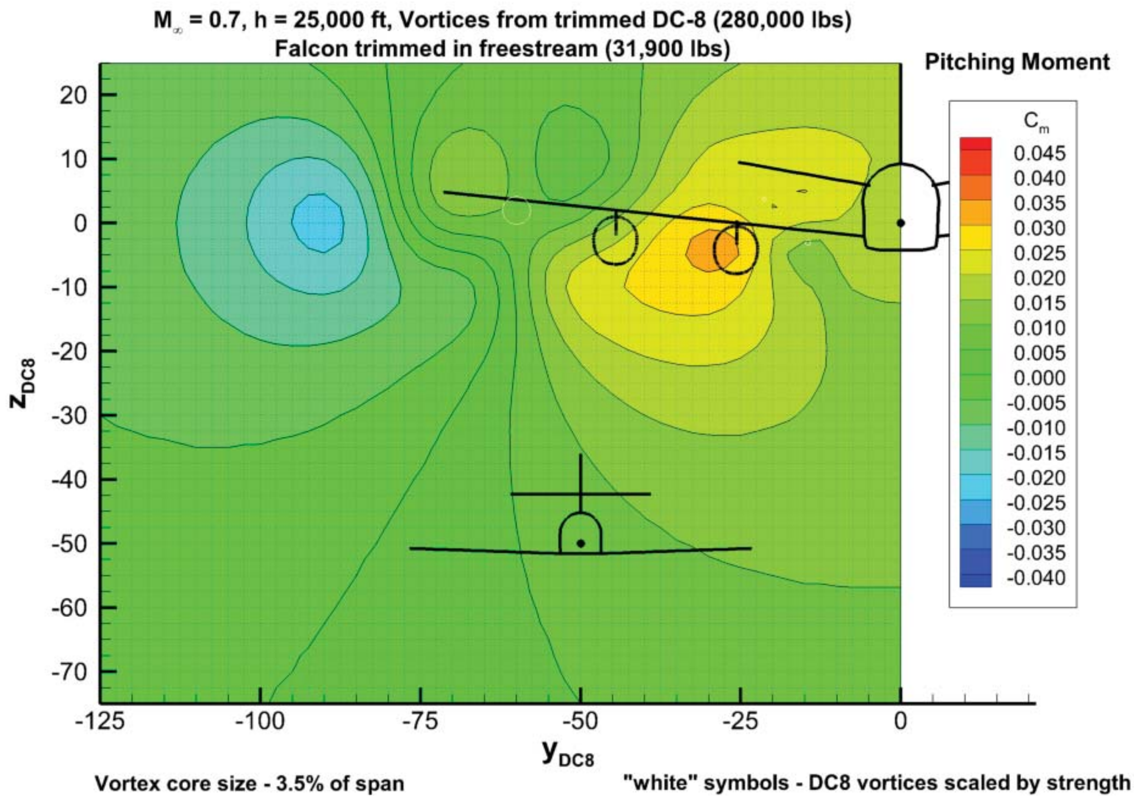
(a) Rolling Moment Coefficient

Figure E-8. DC-8 Vortex-induced Aerodynamic Characteristics on Falcon 20 in Near Field, 3.5% Vortex Core Radius



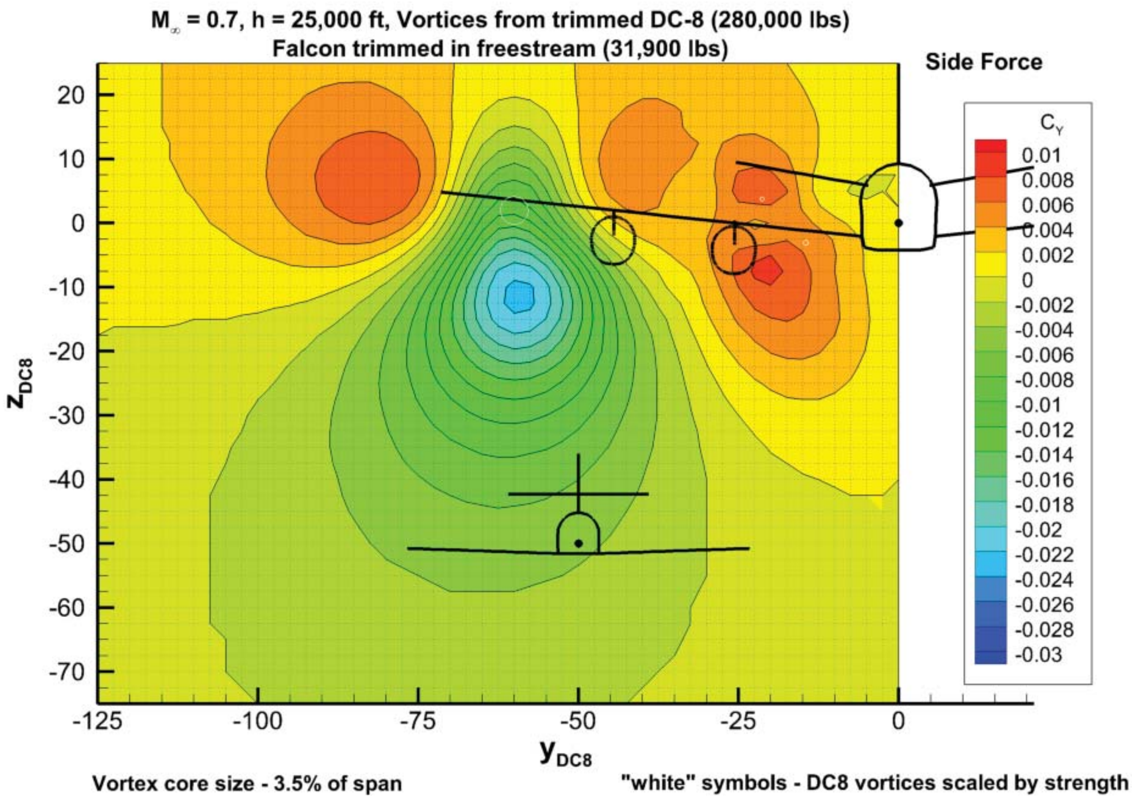
(b) Induced Normal Force Coefficient

Figure E-8. Continued



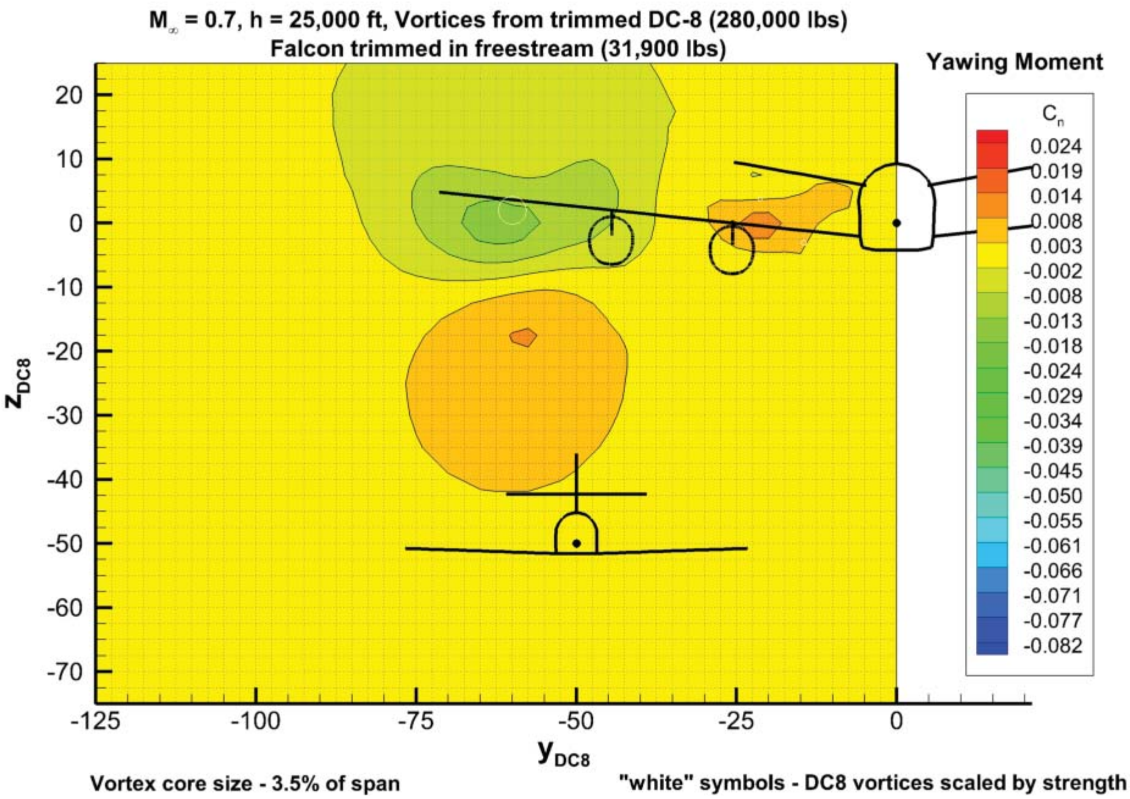
(c) Pitching Moment Coefficient

Figure E-8. Continued



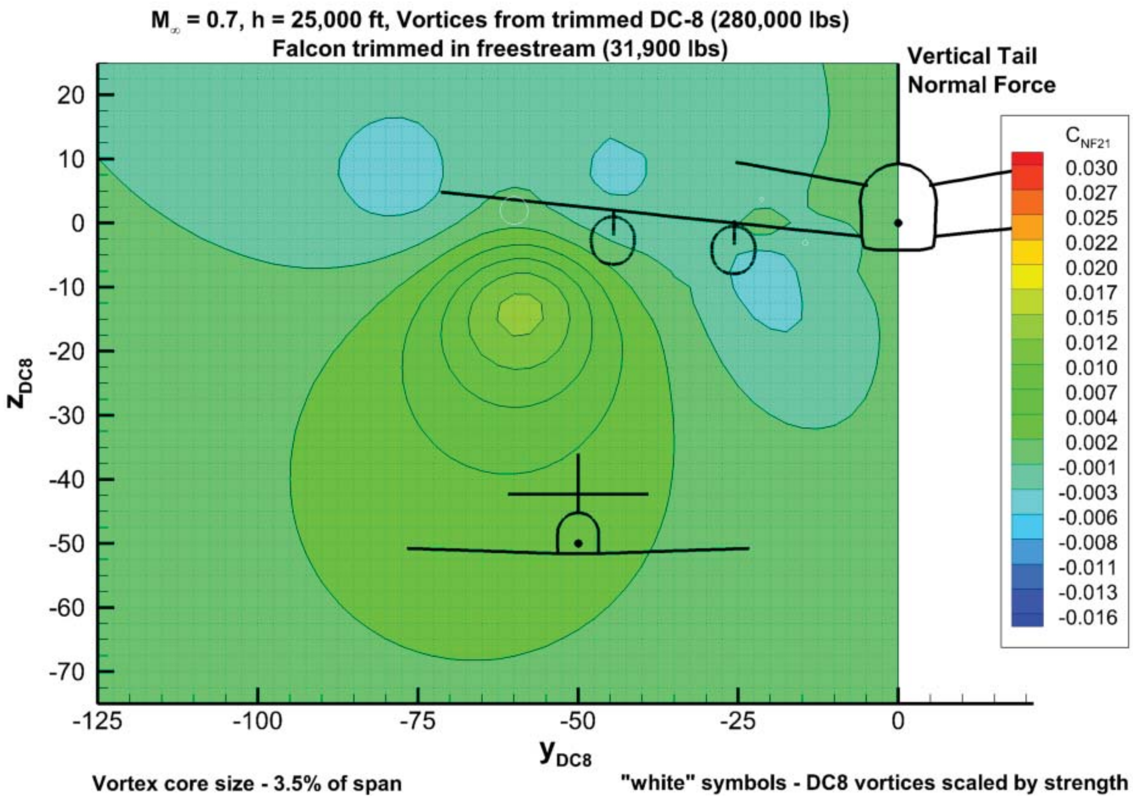
(d) Side Force Coefficient

Figure E-8. Continued



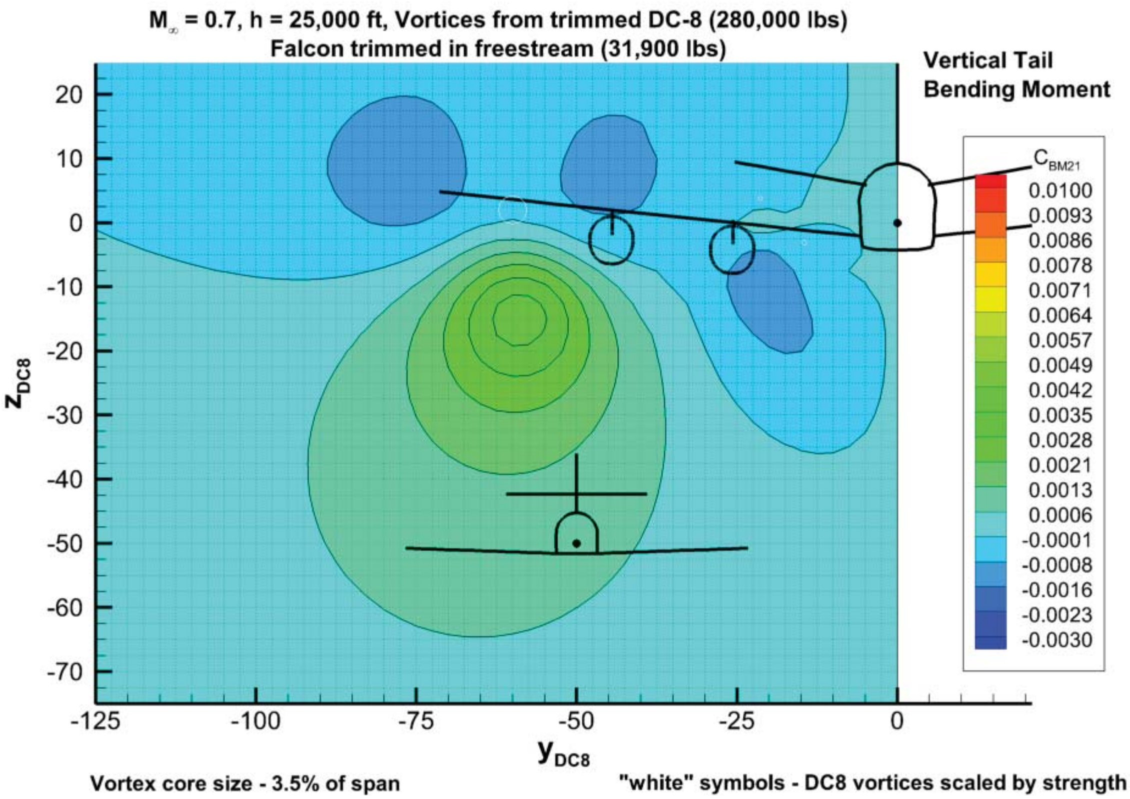
(e) Yawing Moment Coefficient

Figure E-8. Continued



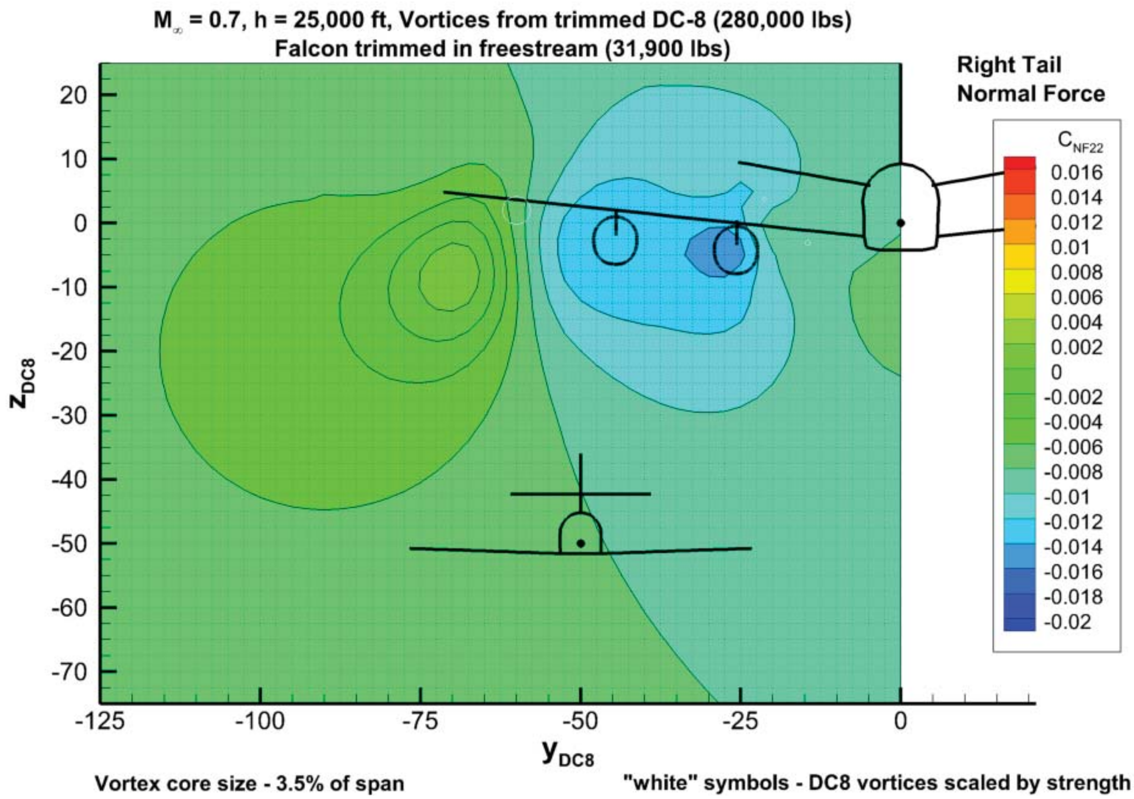
(f) Vertical Tail Normal Force Coefficient

Figure E-8. Continued



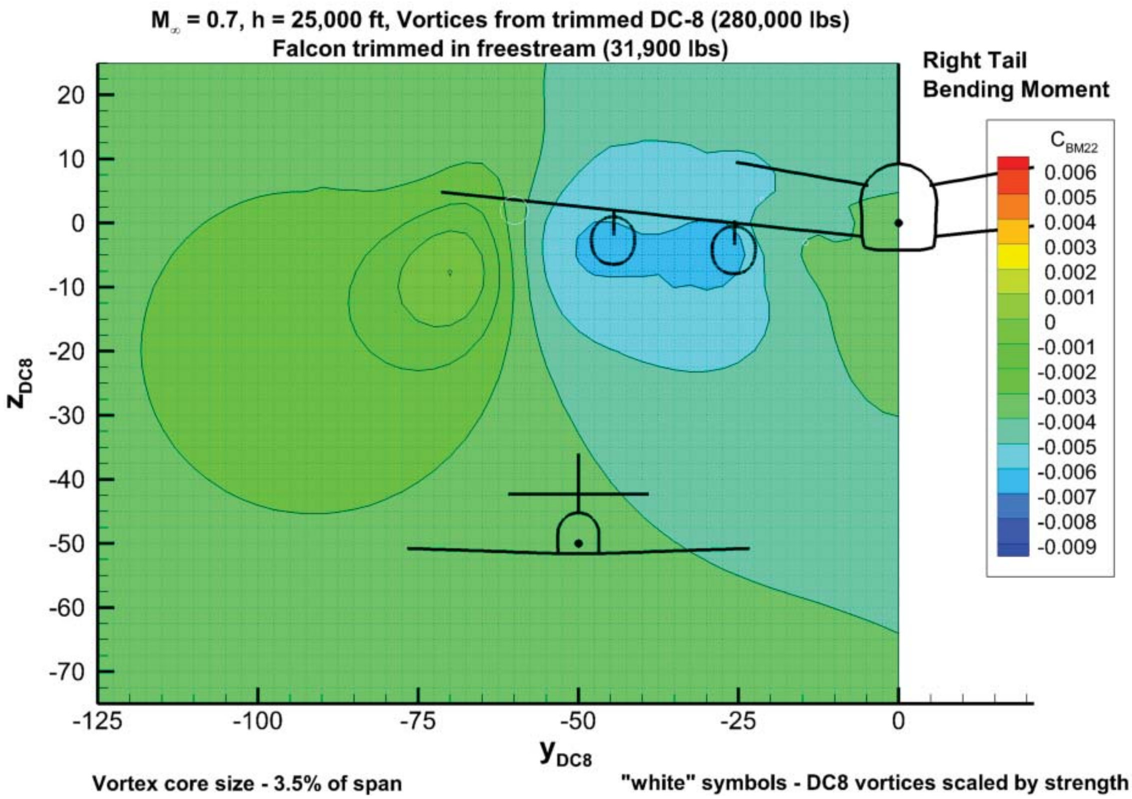
(g) Vertical Tail Root Bending Moment Coefficient

Figure E-8. Continued



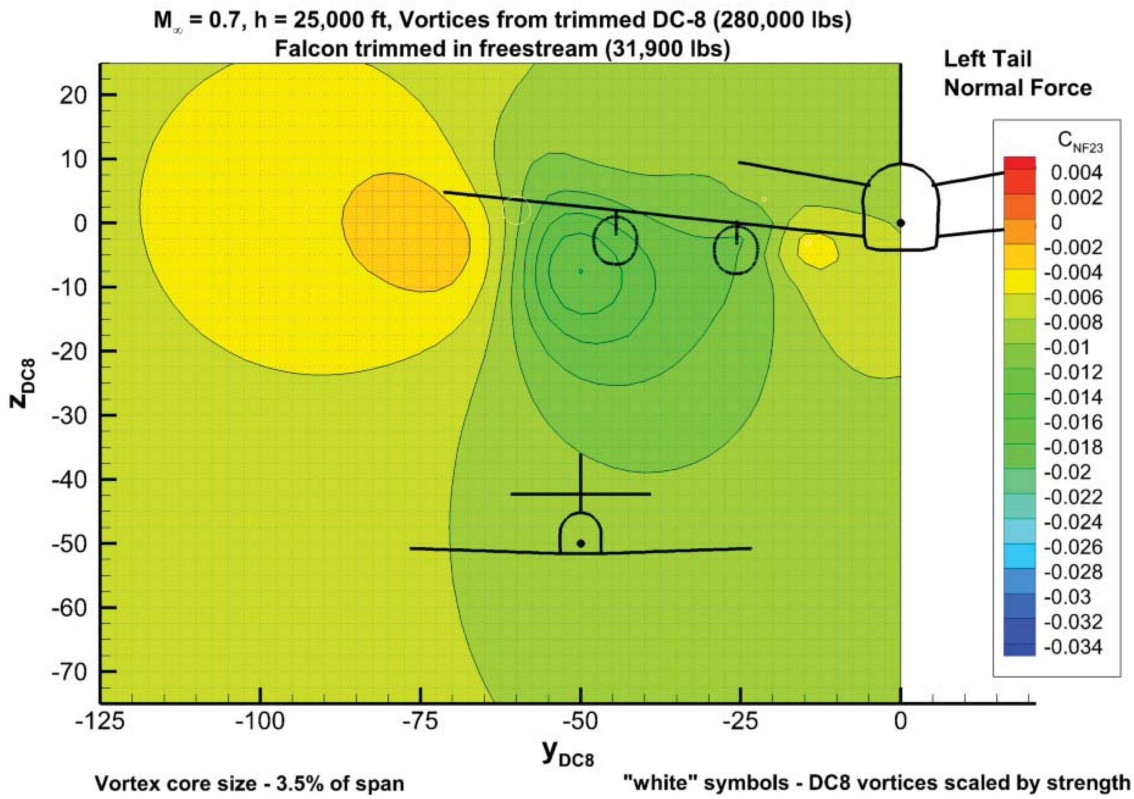
(h) Right Horizontal Tail Normal Force Coefficient

Figure E-8. Continued



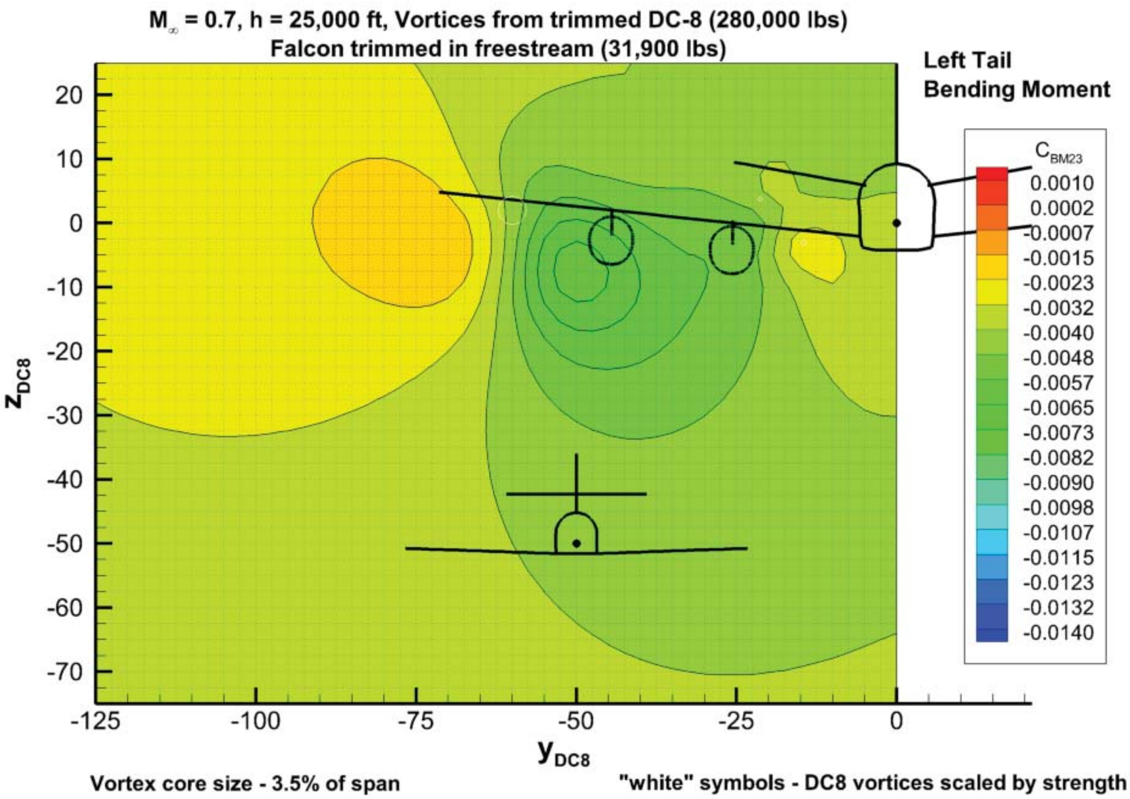
(i) Right Horizontal Tail Root Bending Moment Coefficient

Figure E-8. Continued



(j) Left Horizontal Tail Normal Force Coefficient

Figure E-8. Continued



(k) Left Horizontal Tail Root Bending Moment Coefficient

Figure E-8. Concluded

Appendix F. STRLNCH Simulations Component Loads Results

Six dynamic simulations of the Falcon 20 released at selected locations in the DC-8 wake are described in Section 7.2.4. For each simulation, the Falcon 20 in a light- or heavyweight configuration is trimmed for free-stream flight conditions and released, stick fixed, from three different locations as defined in Table 7.2-8. The details of the component loads and bending moments are available at all times throughout the simulation, and these results are presented below in graphical form. Note that the tables of values for the Falcon 20 aerodynamic characteristics in each simulation are available in digital format. The animation of each simulation is also available.

As described in Table 7.2-8, Simulation 1 is for the Falcon 20 released at the location of maximum induced rolling moment, Simulation 2 is for the Falcon 20 aligned with the centerline of the inboard DC-8 engine, and Simulation 3 is for the Falcon 20 left wing tip in the center of the primary DC-8 trailing vortex. Each simulation will be further designated as for the light- or heavyweight Falcon 20. For completeness, some of the simulation results presented in Section 7.2.4 will be repeated in this appendix to keep all results for a simulation in one place.

The lightweight Falcon 20 is released at t = 0 from the location of maximum induced rolling moment, and snapshots of the motion at 0.5-second intervals are shown in Figure F-1 for Simulation 1L.

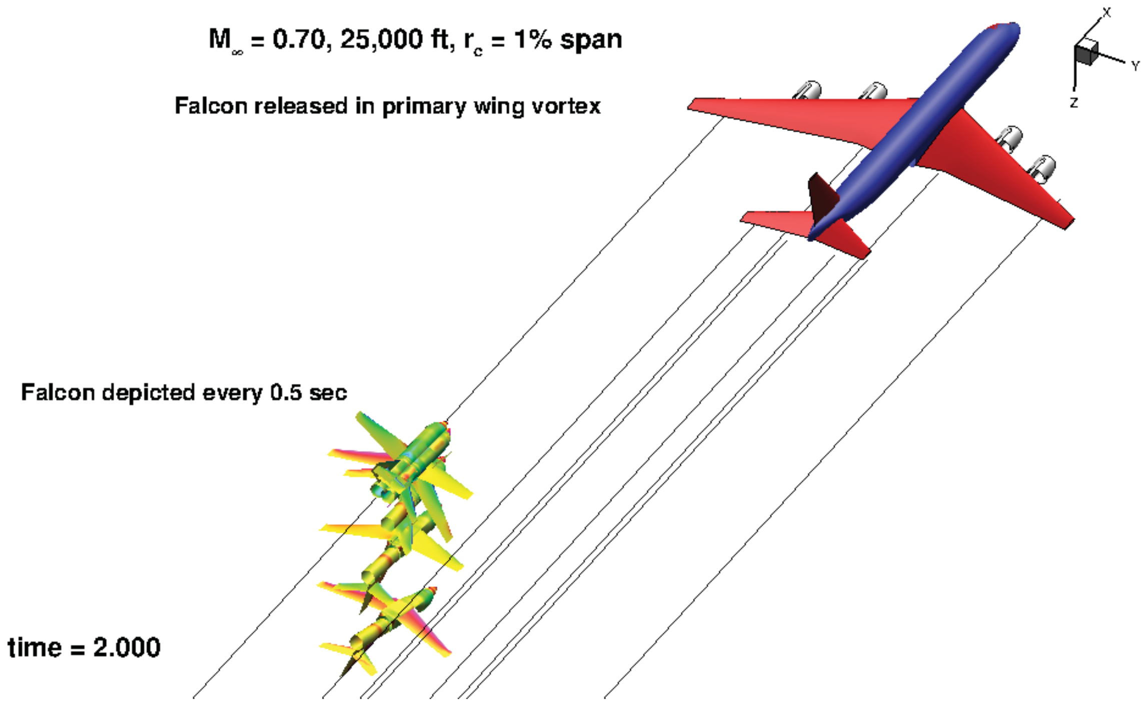


Figure F-1. Lightweight Falcon 20, Simulation 1L

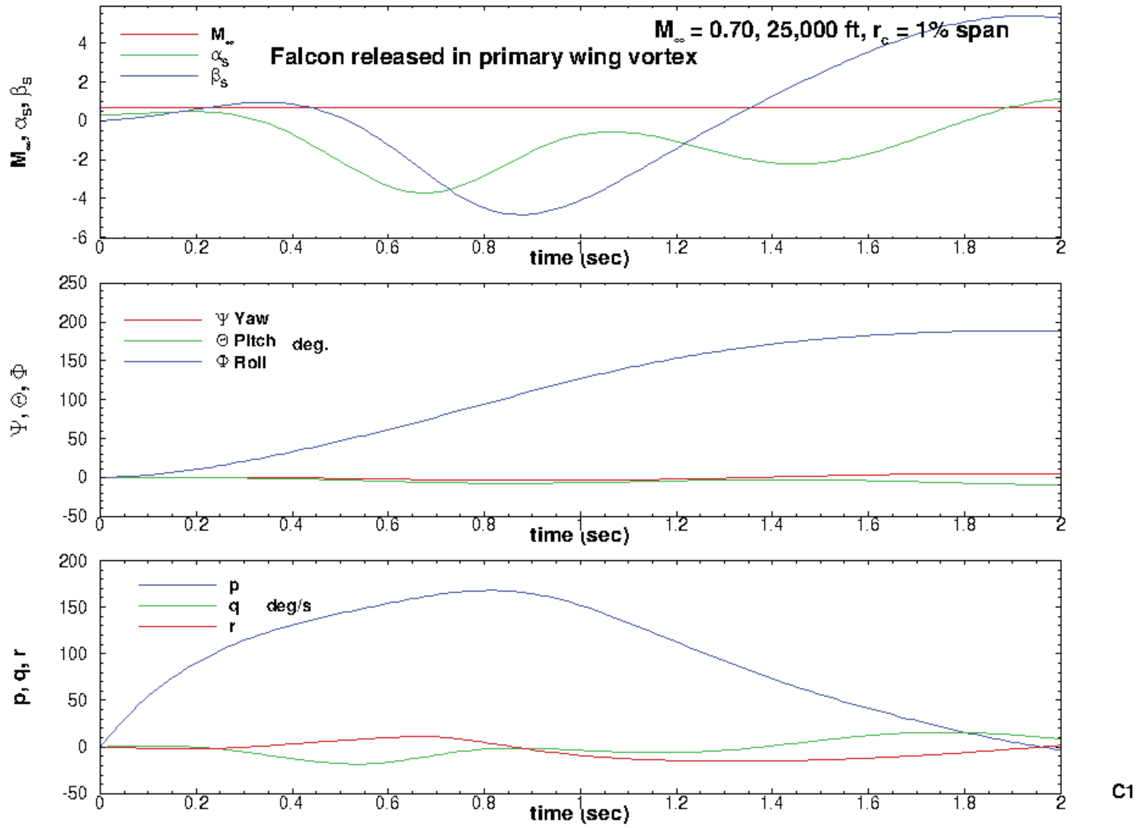


Figure F-2. Light Falcon 20 Flight Characteristics, Simulation 1L

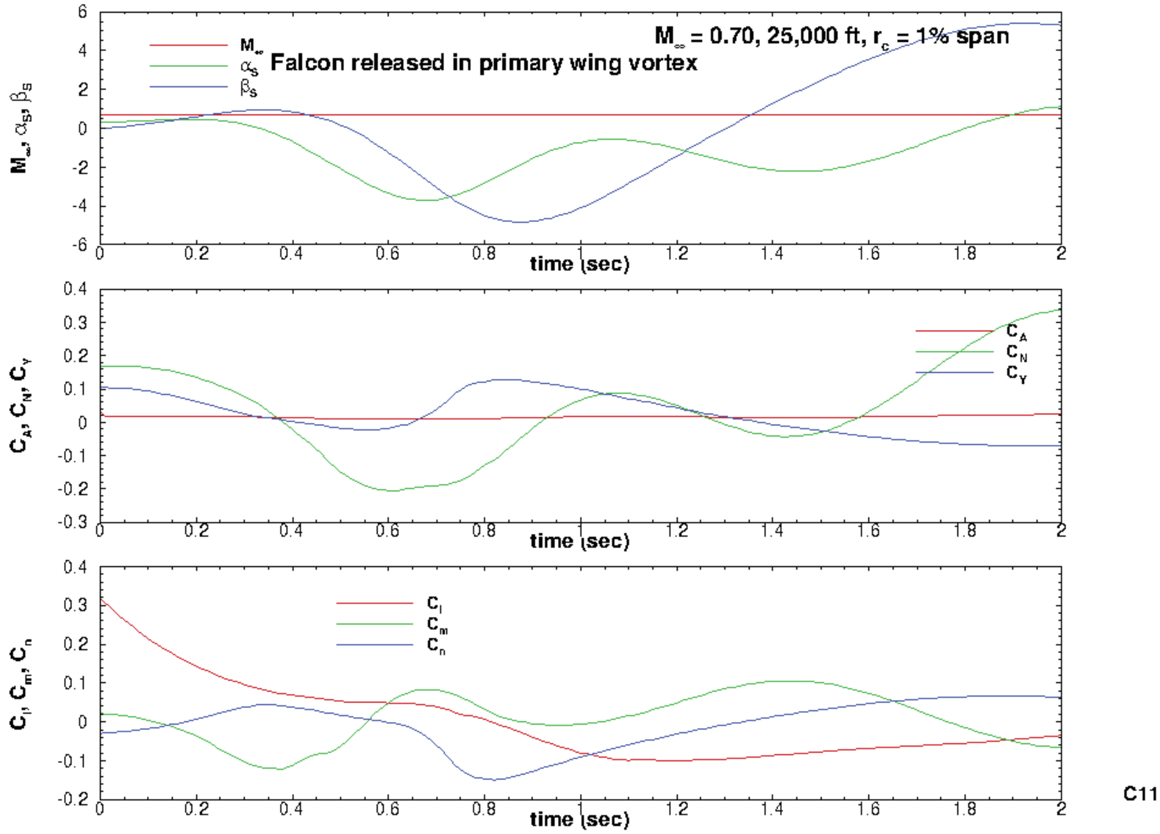


Figure F-3. Light Falcon 20 Aerodynamic Characteristics, Simulation 1L

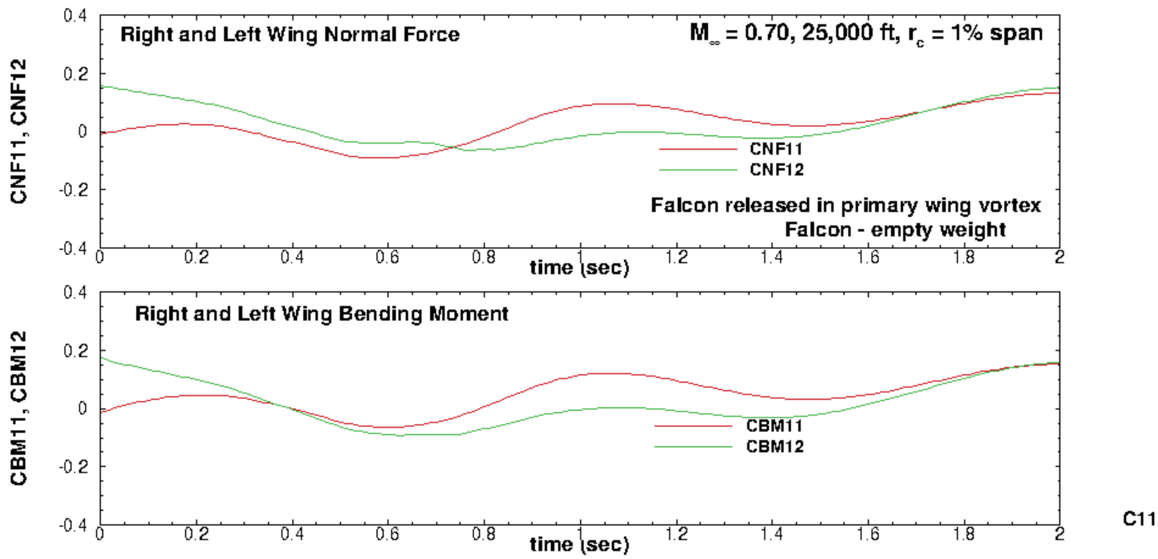


Figure F-4. Light Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 1L

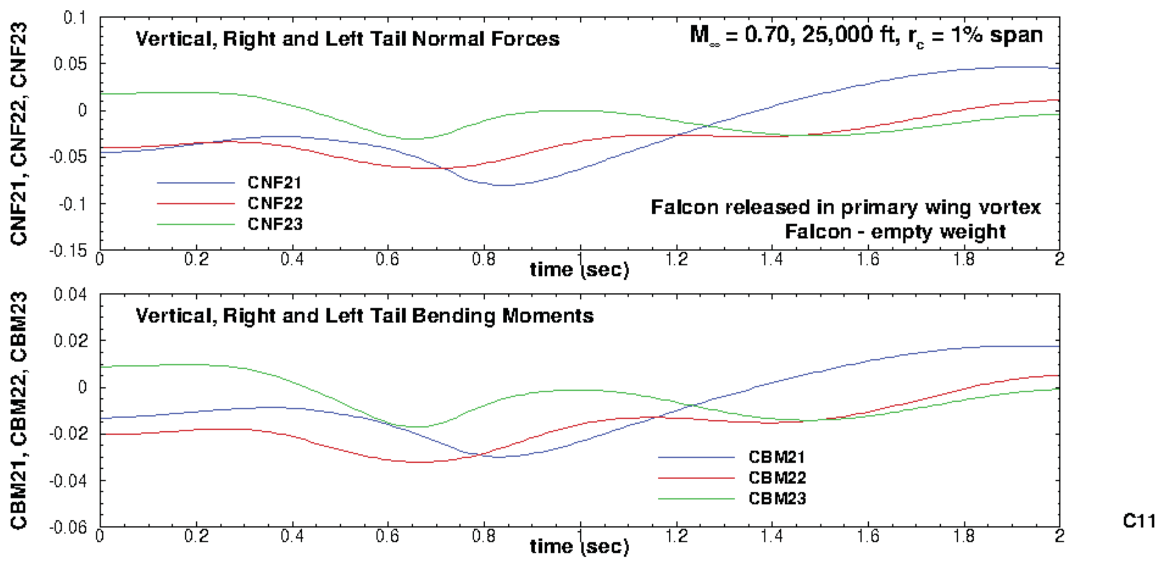


Figure F-5. Light Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 1L

The heavyweight Falcon 20 is released at t = 0 from the location of maximum induced rolling moment, and snapshots of the motion at 0.5-second intervals are shown in Figure F-6 for Simulation 1.

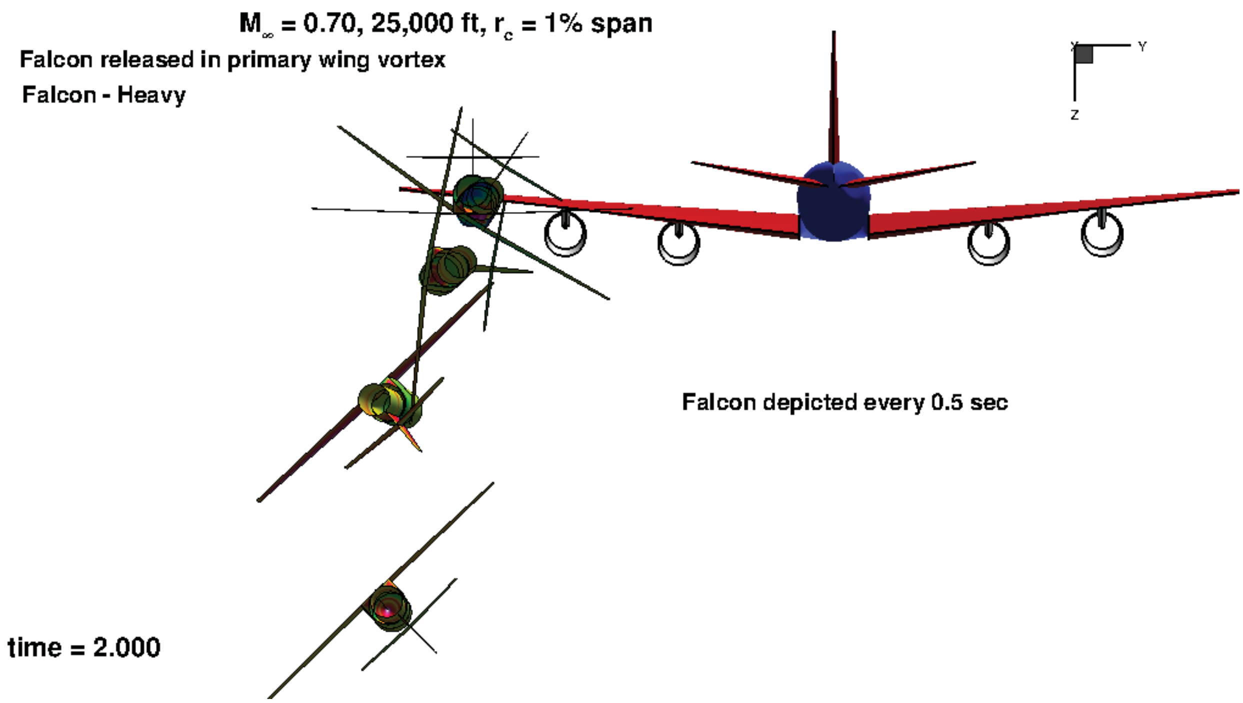


Figure F-6. Heavyweight Falcon 20, Simulation 1H

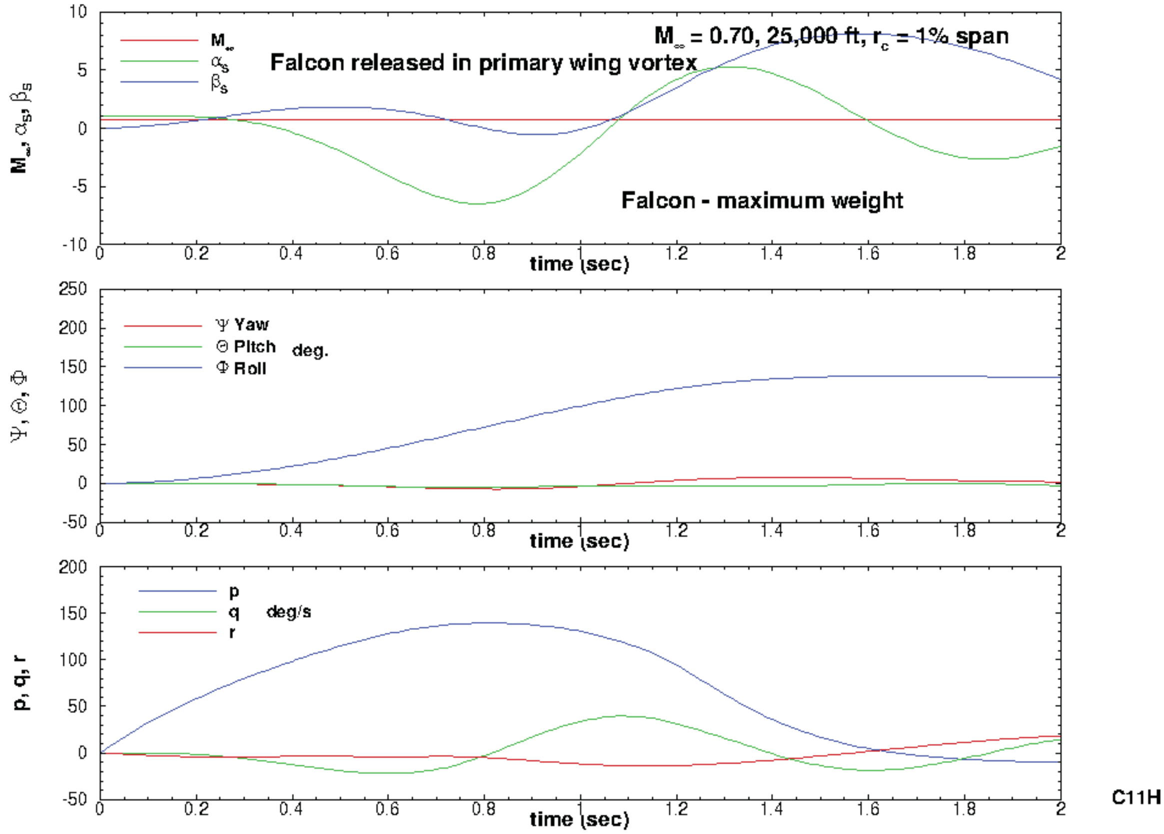


Figure F-7. Heavy Falcon 20 Flight Characteristics, Simulation 1H

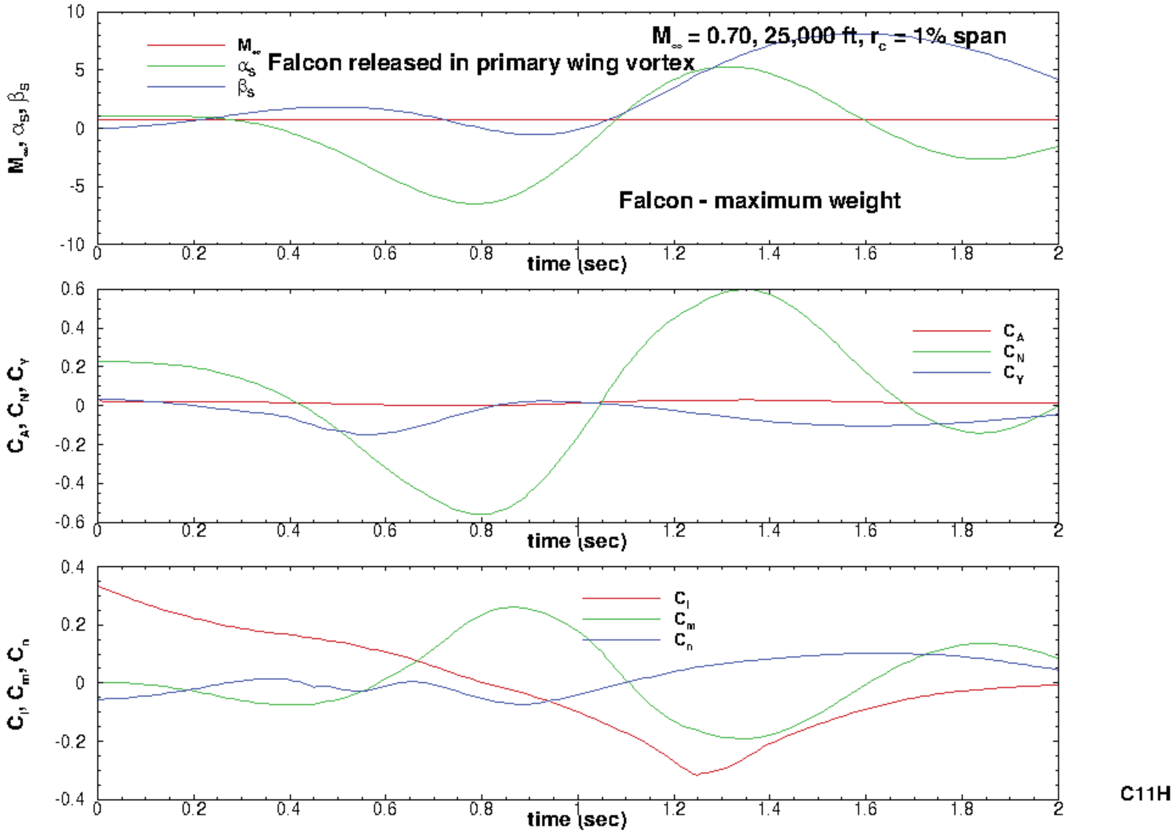


Figure F-8. Heavy Falcon 20 Aerodynamic Characteristics, Simulation 1H

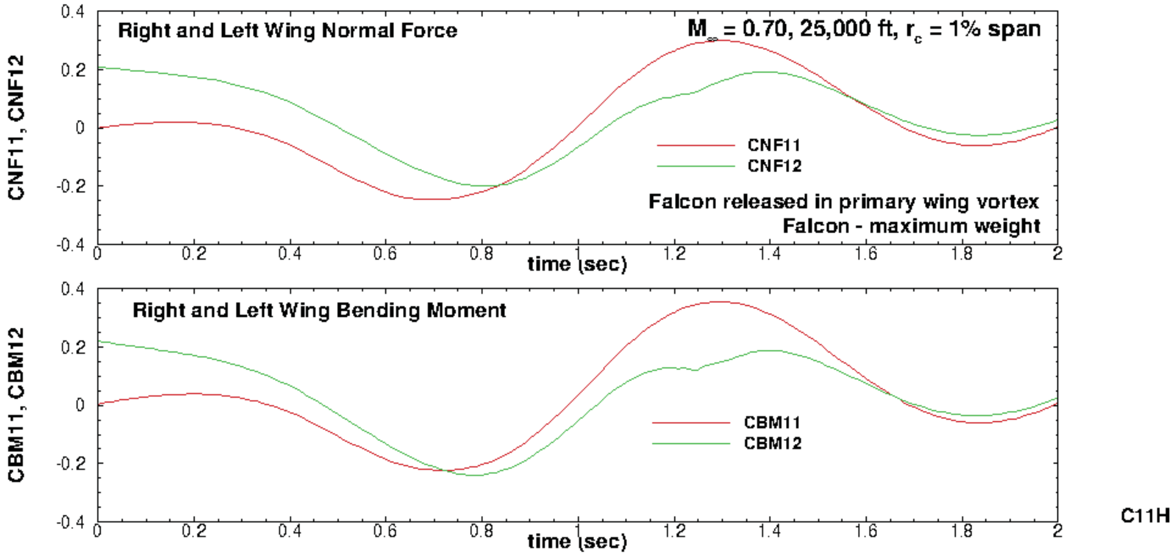


Figure F-9. Heavy Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 1H

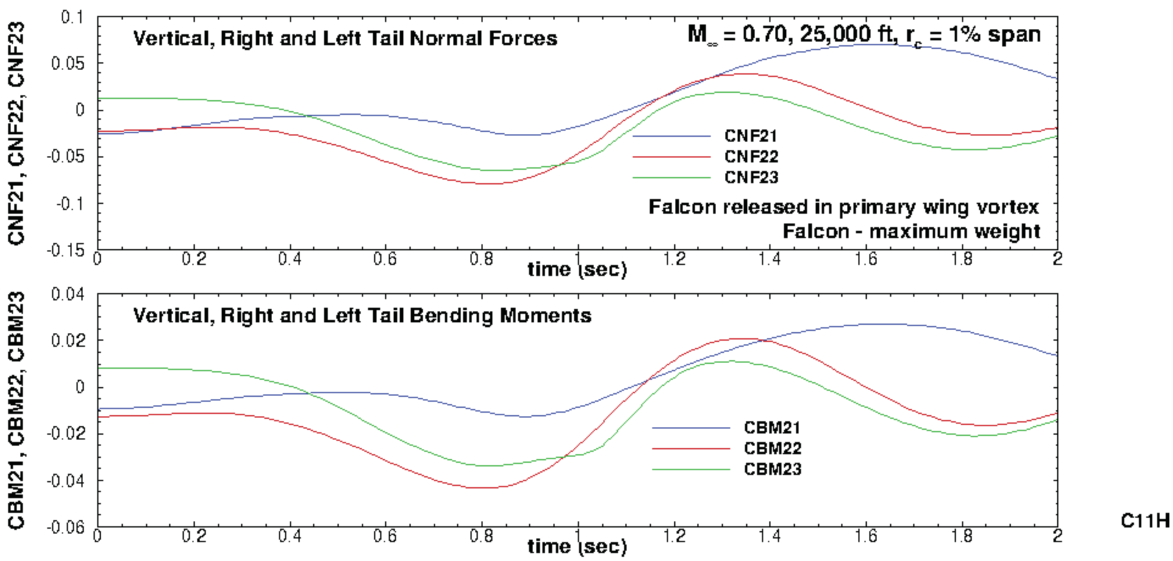


Figure F-10. Heavy Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 1H

The lightweight Falcon 20 is released at t = 0 from the location in line with the inboard engine centerline, and snapshots of the motion at 0.5-second intervals are shown in Figure F-11 for Simulation 2L.

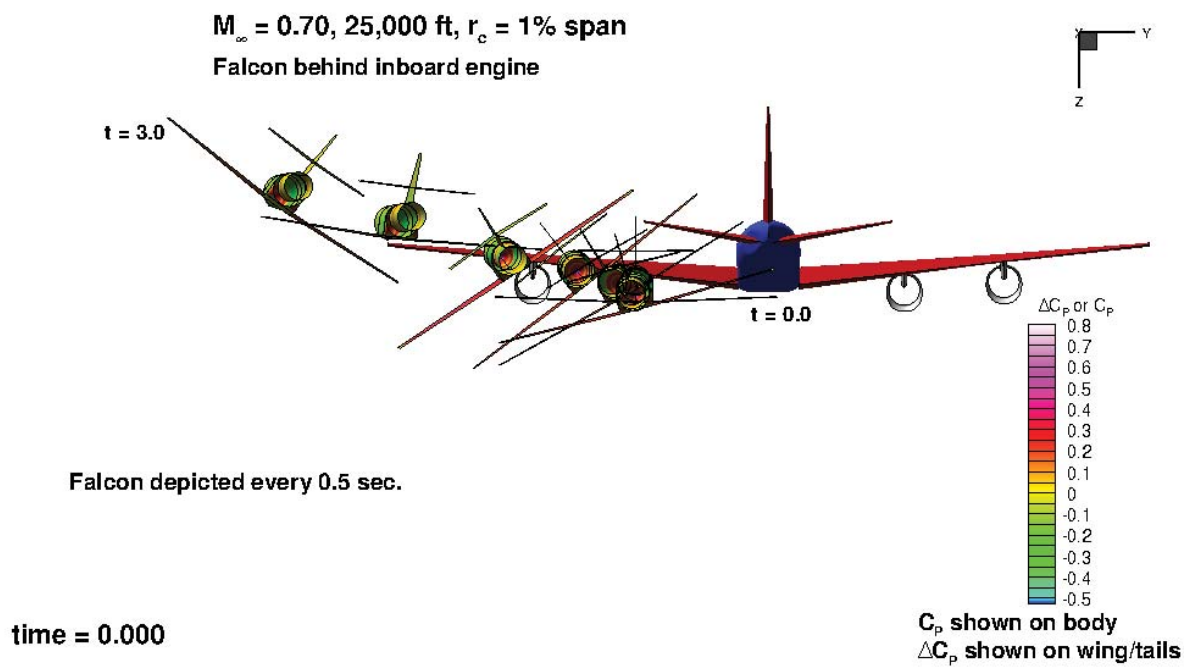


Figure F-11. Lightweight Falcon 20, Simulation 2L

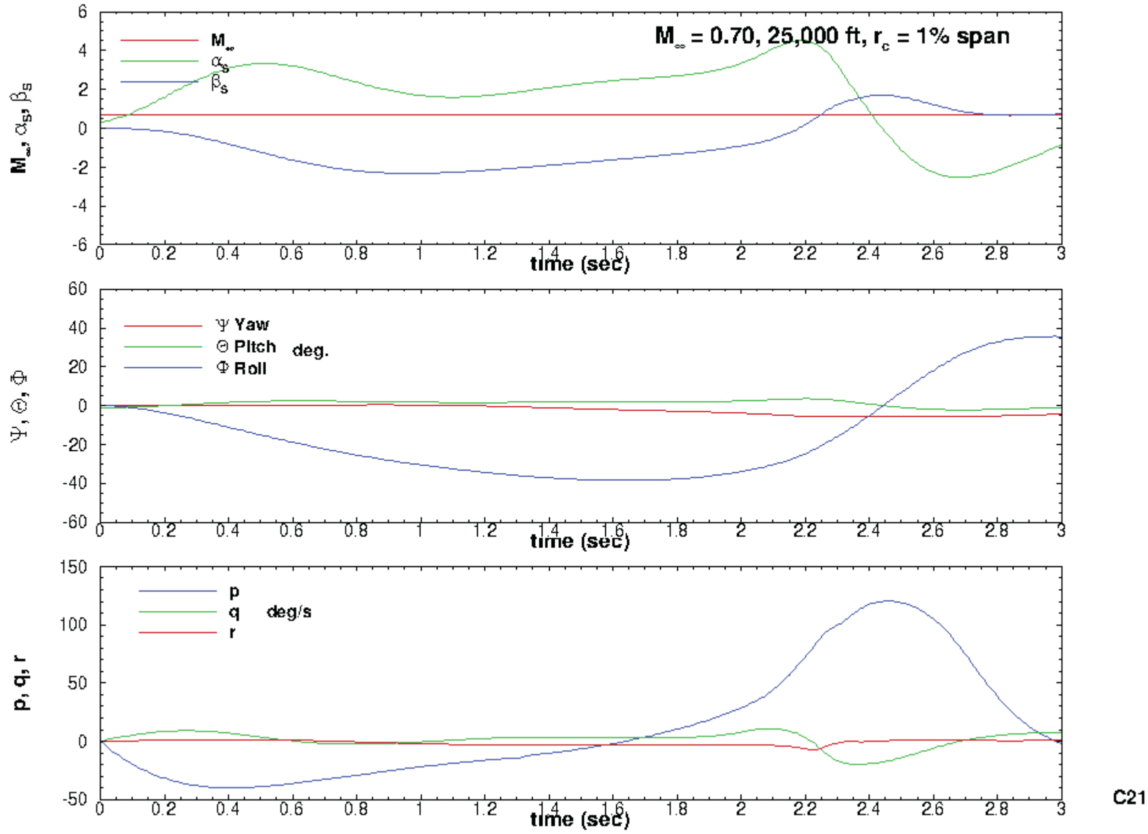


Figure F-12. Light Falcon 20 Flight Characteristics, Simulation 2L

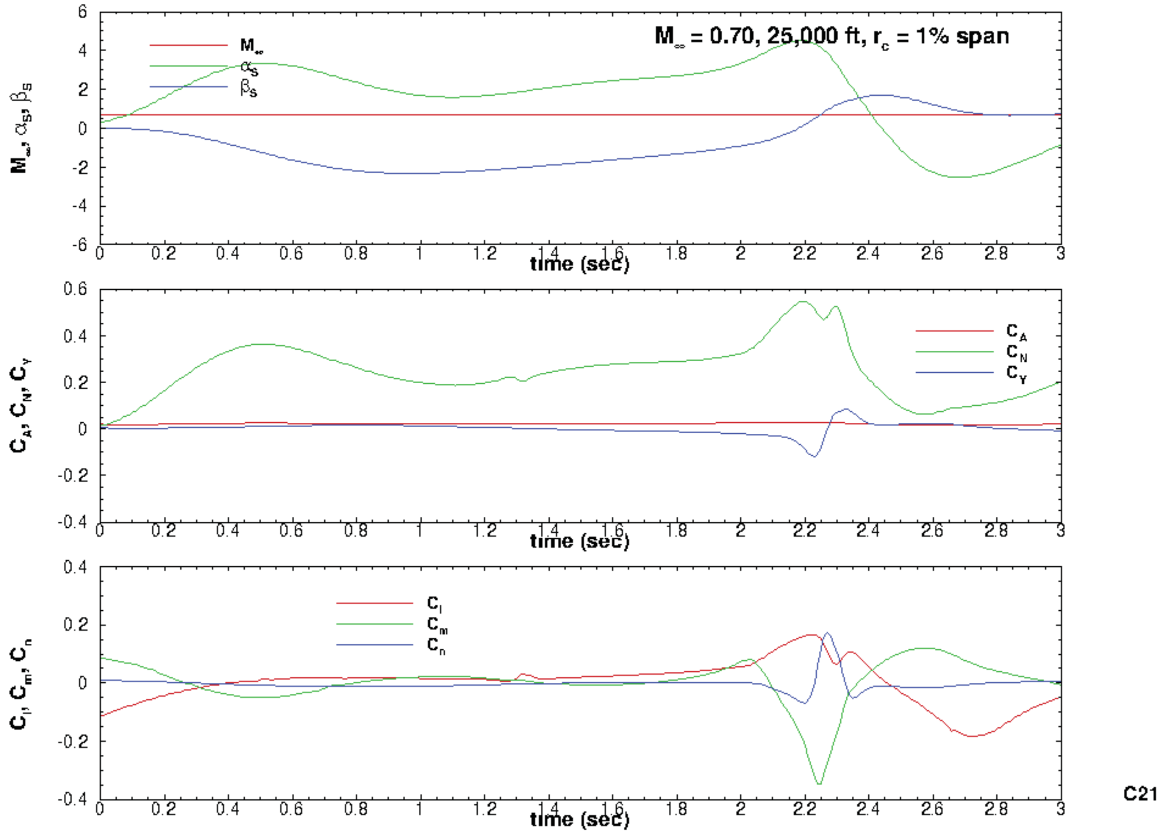


Figure F-13. Light Falcon 20 Aerodynamic Characteristics, Simulation 2L

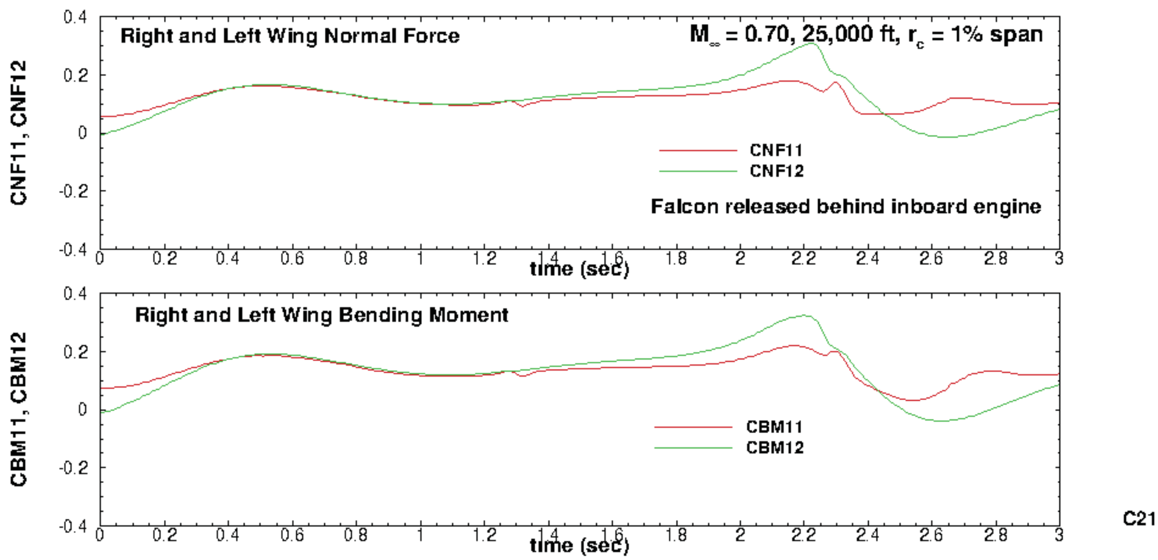


Figure F-14. Light Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 2L

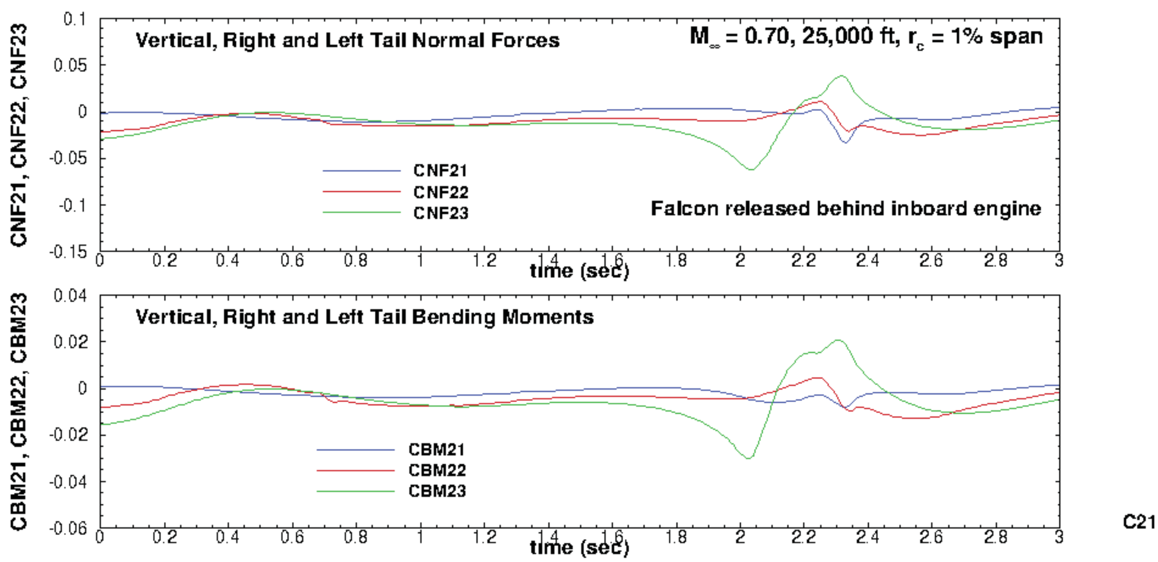


Figure F-15. Light Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 2L

The heavyweight Falcon 20 is released at t = 0 from the location in line with the inboard engine centerline, and snapshots of the motion at 0.5-second intervals are shown in Figure F-16 for Simulation 2H.

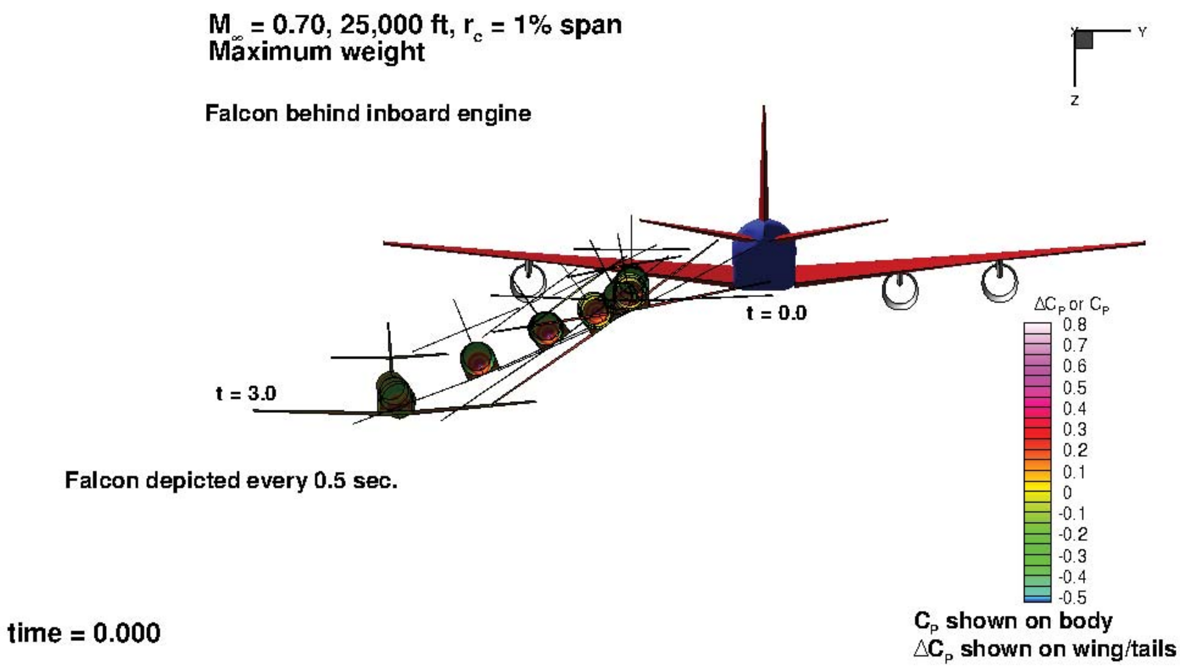


Figure F-16. Heavyweight Falcon 20, Simulation 2H

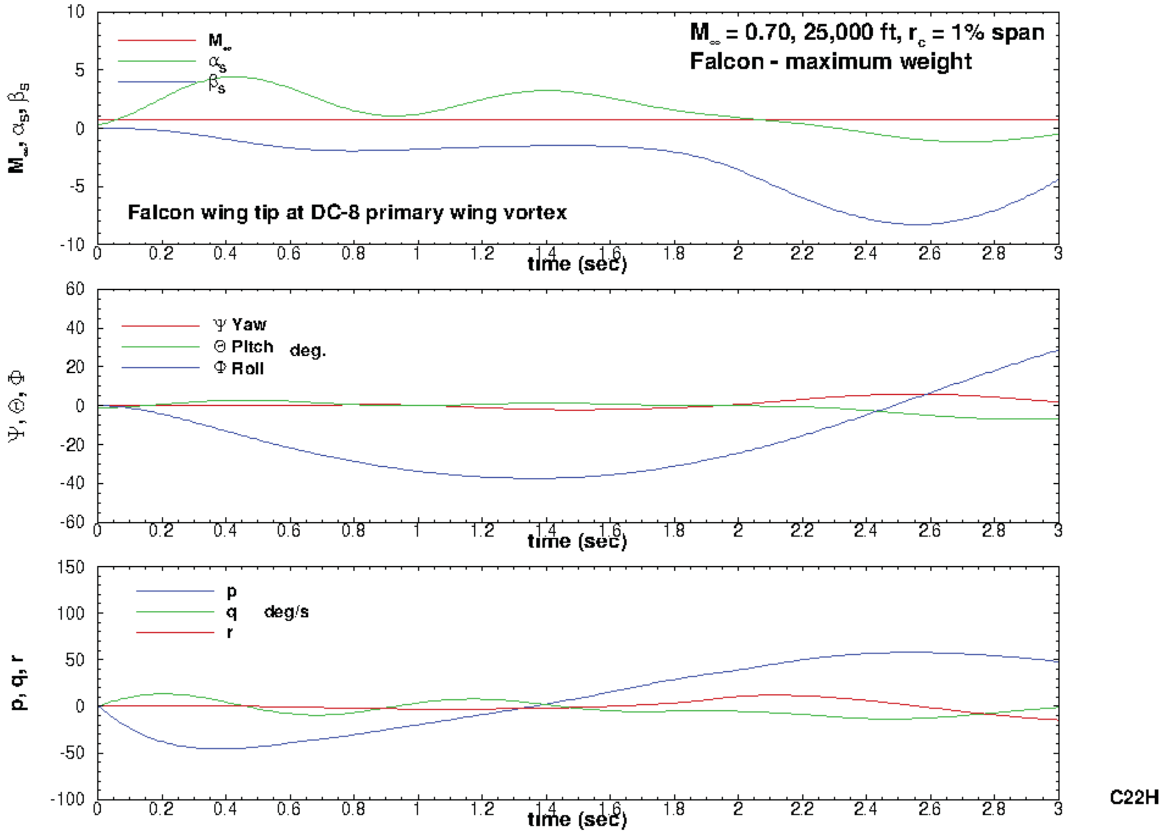


Figure F-17. Heavy Falcon 20 Flight Characteristics, Simulation 2H

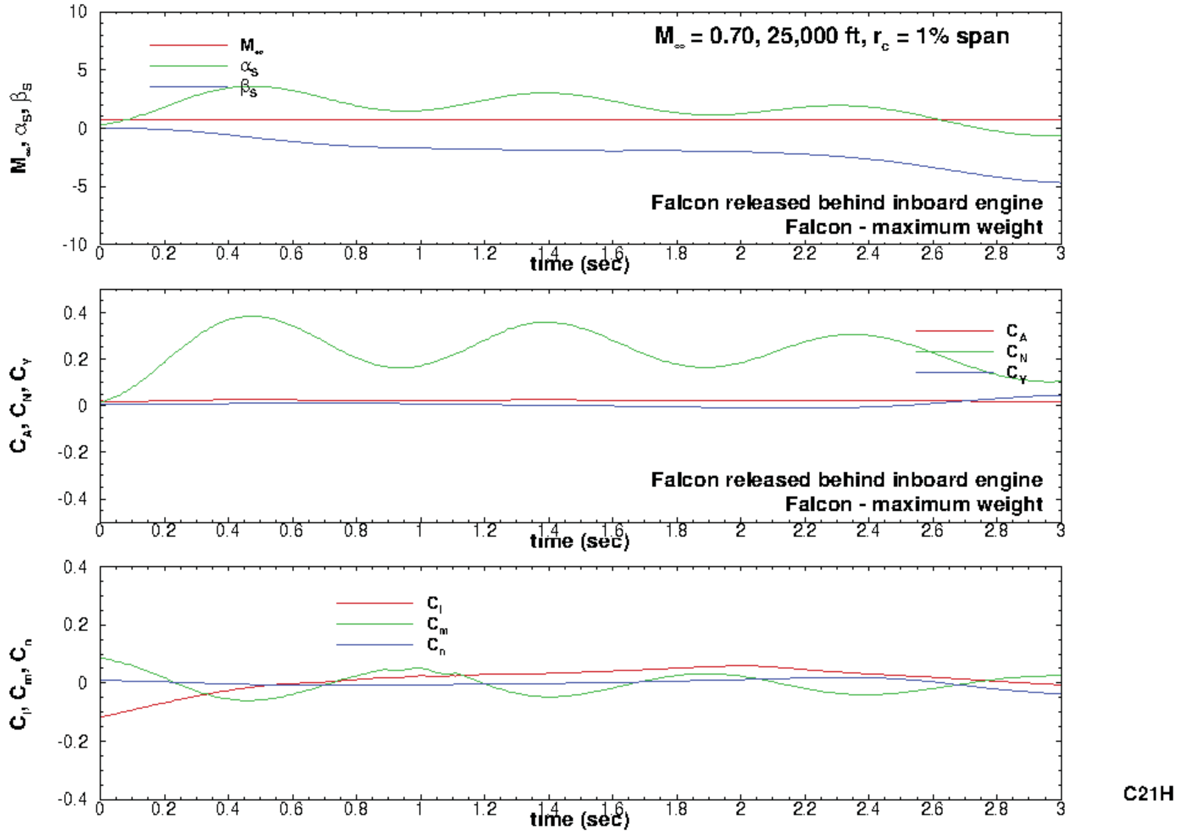


Figure F-18. Heavy Falcon 20 Aerodynamic Characteristics, Simulation 2H

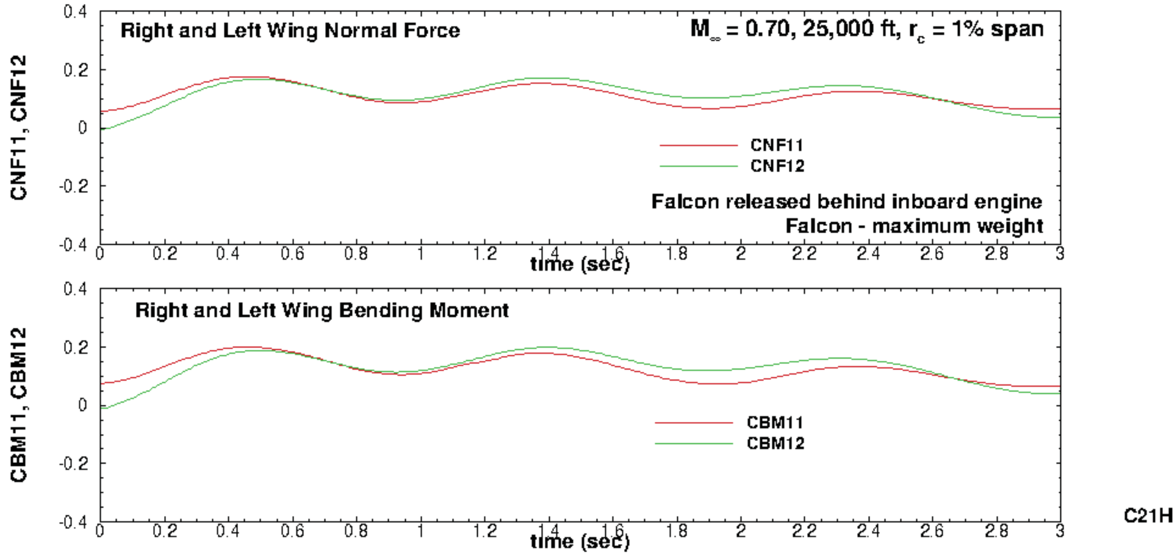


Figure F-19. Heavy Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 2H

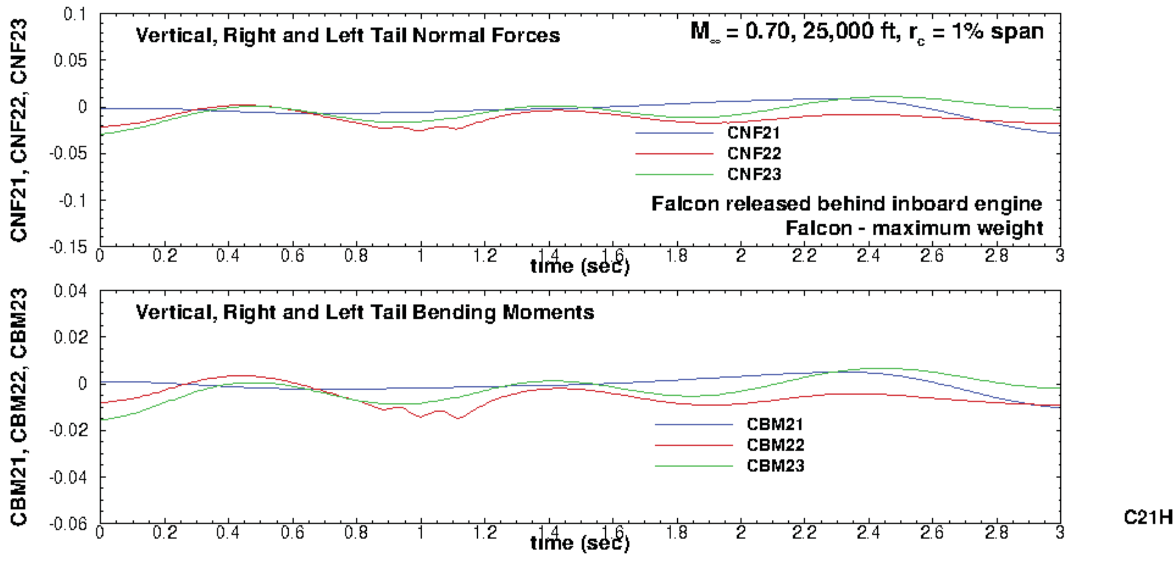


Figure F-20. Heavy Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 2H

The lightweight Falcon 20 is released at t = 0 from the location aft of the DC-8 with the left wingtip in the center of the primary trailing vortex, and snapshots of the motion at 0.5-second intervals are shown in Figure F-21 for Simulation 3L.

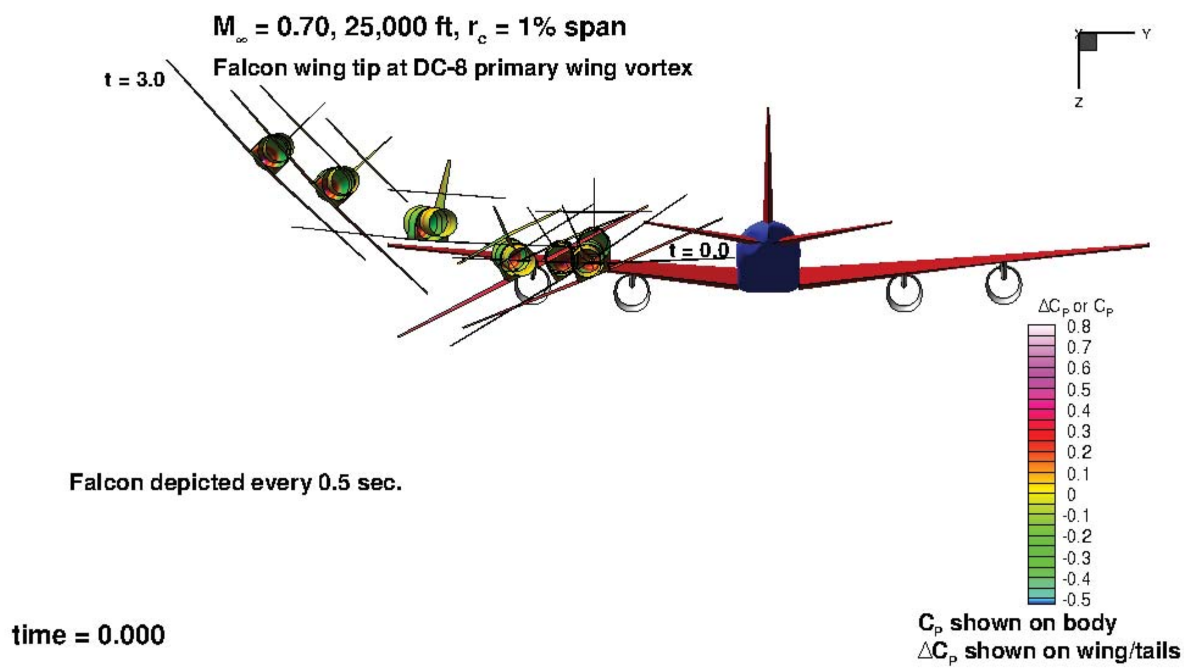


Figure F-21. Lightweight Falcon 20, Simulation 3L

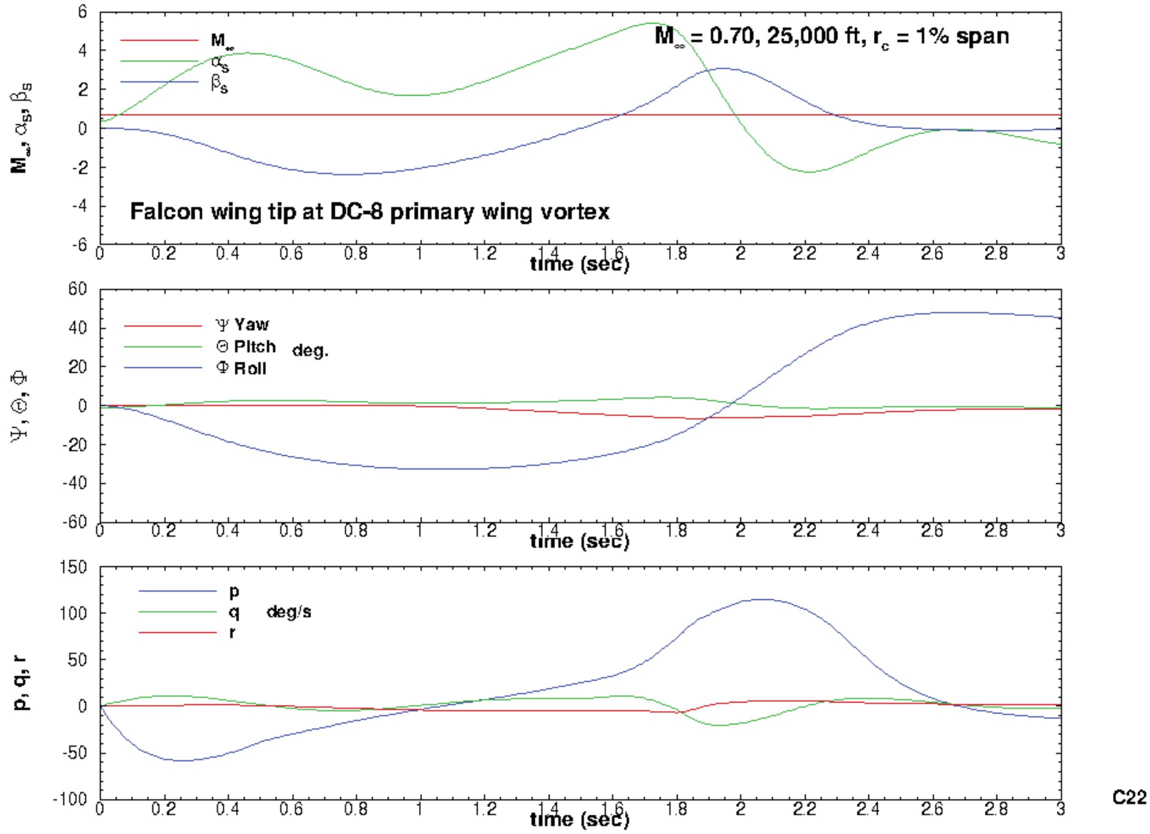


Figure F-22. Light Falcon 20 Flight Characteristics, Simulation 3L

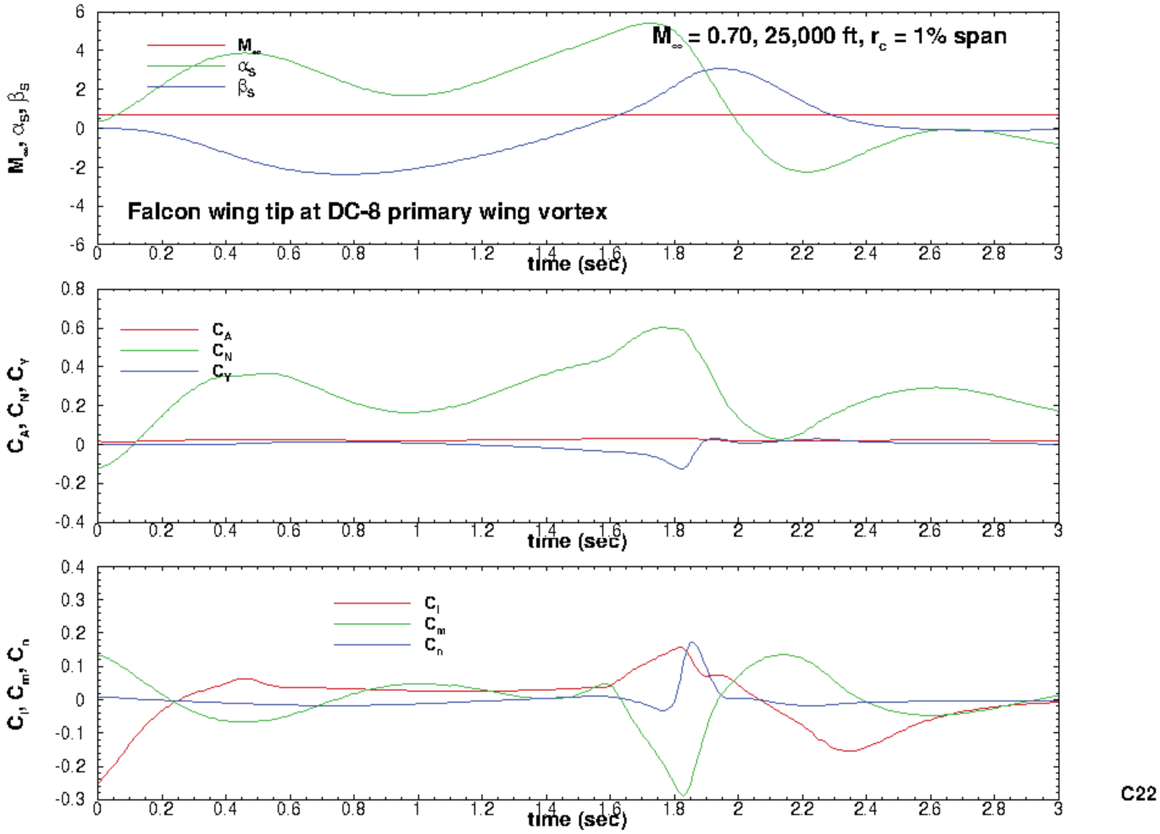


Figure F-23. Light Falcon 20 Aerodynamic Characteristics, Simulation 3L

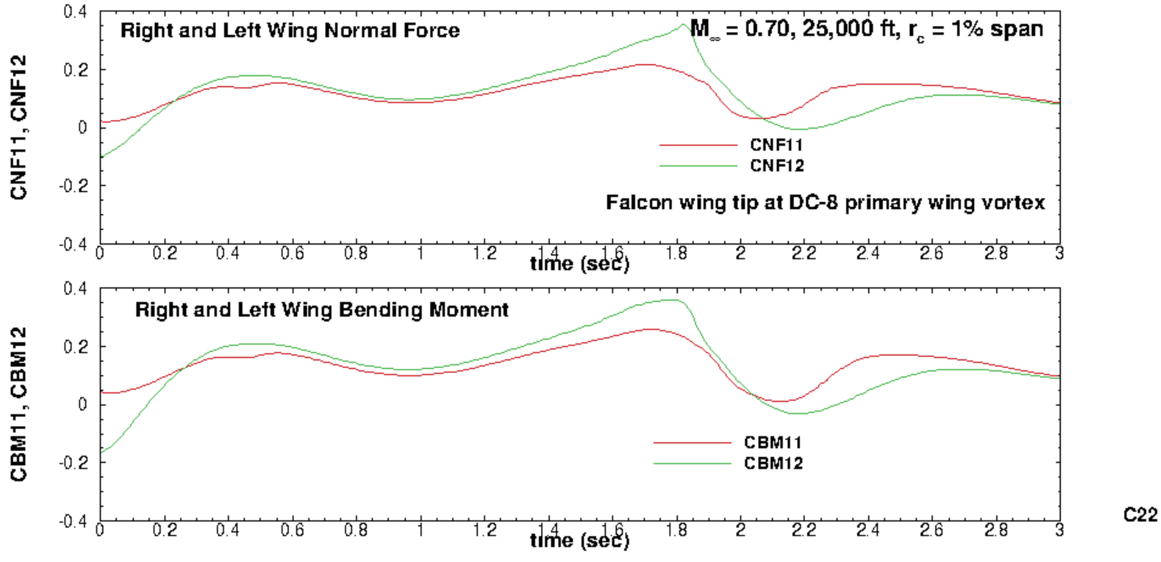


Figure F-24. Light Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 3L

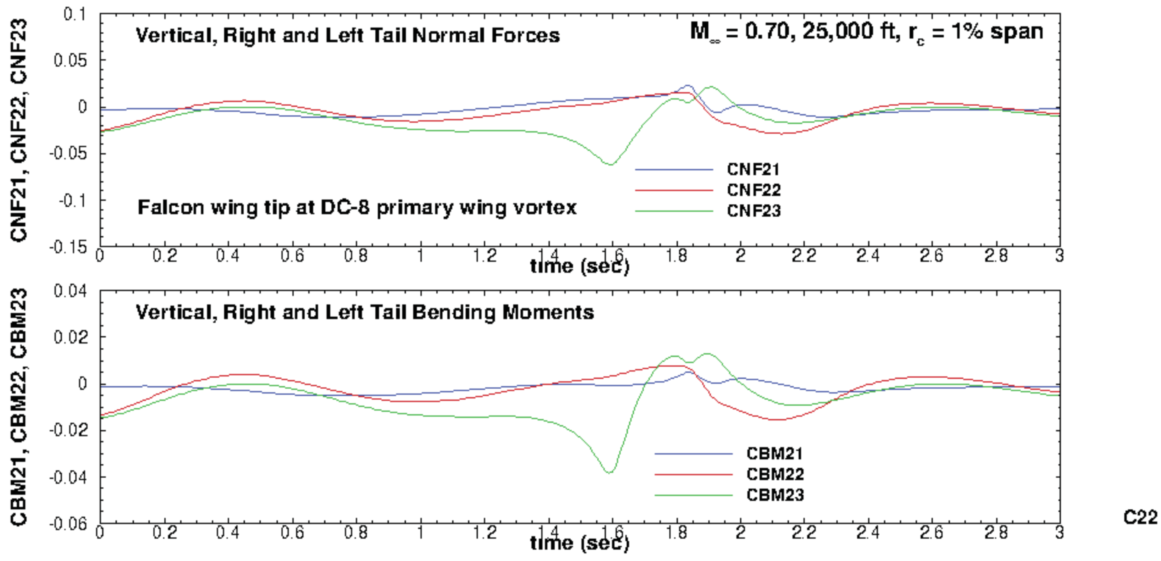


Figure F-25. Light Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 3L

The heavyweight Falcon 20 is released at t = 0 from the location aft of the DC-8 with the left wing tip in the center of the primary trailing vortex, and snapshots of the motion at 0.5-second intervals are shown in Figure F-26 for Simulation 3.

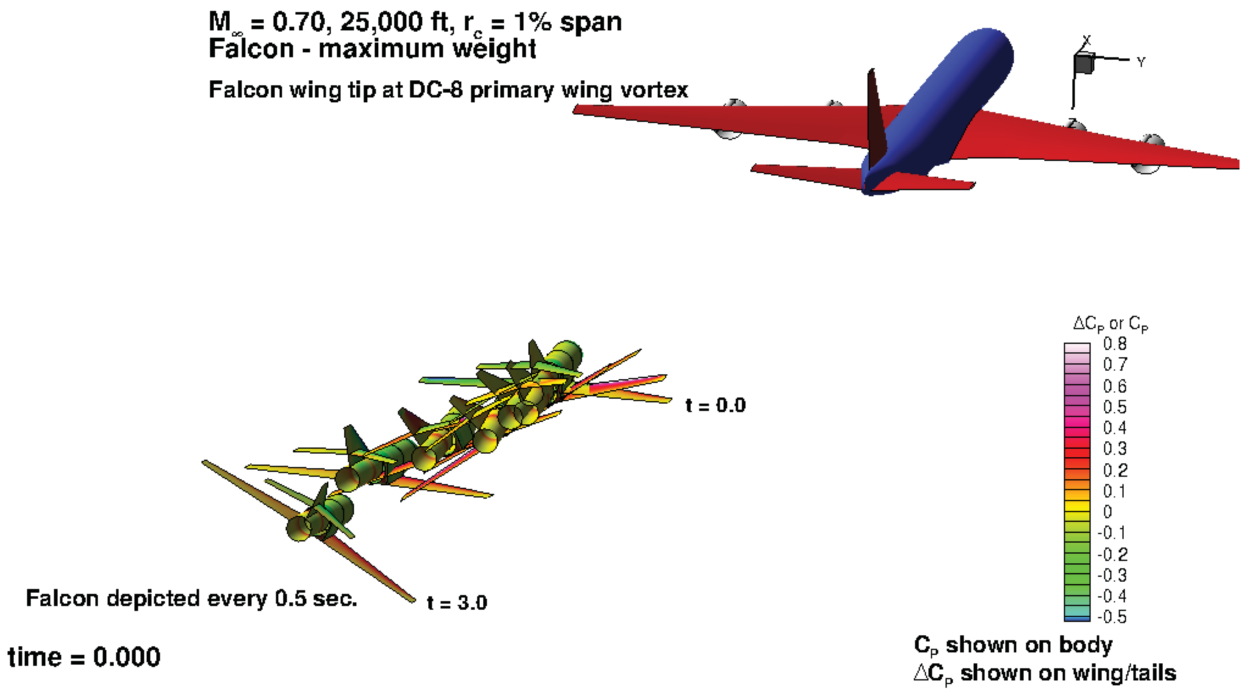


Figure F-26. Heavyweight Falcon 20, Simulation 3H

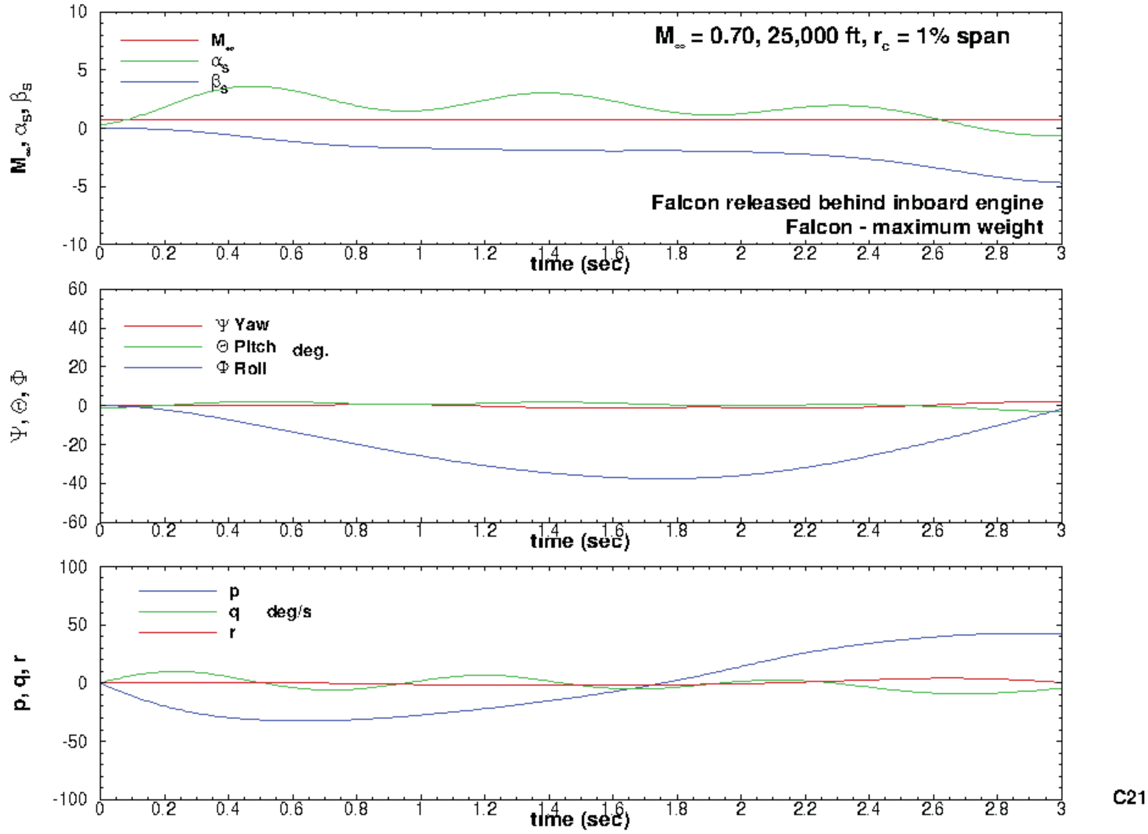


Figure F-27. Heavy Falcon 20 Flight Characteristics, Simulation 3H

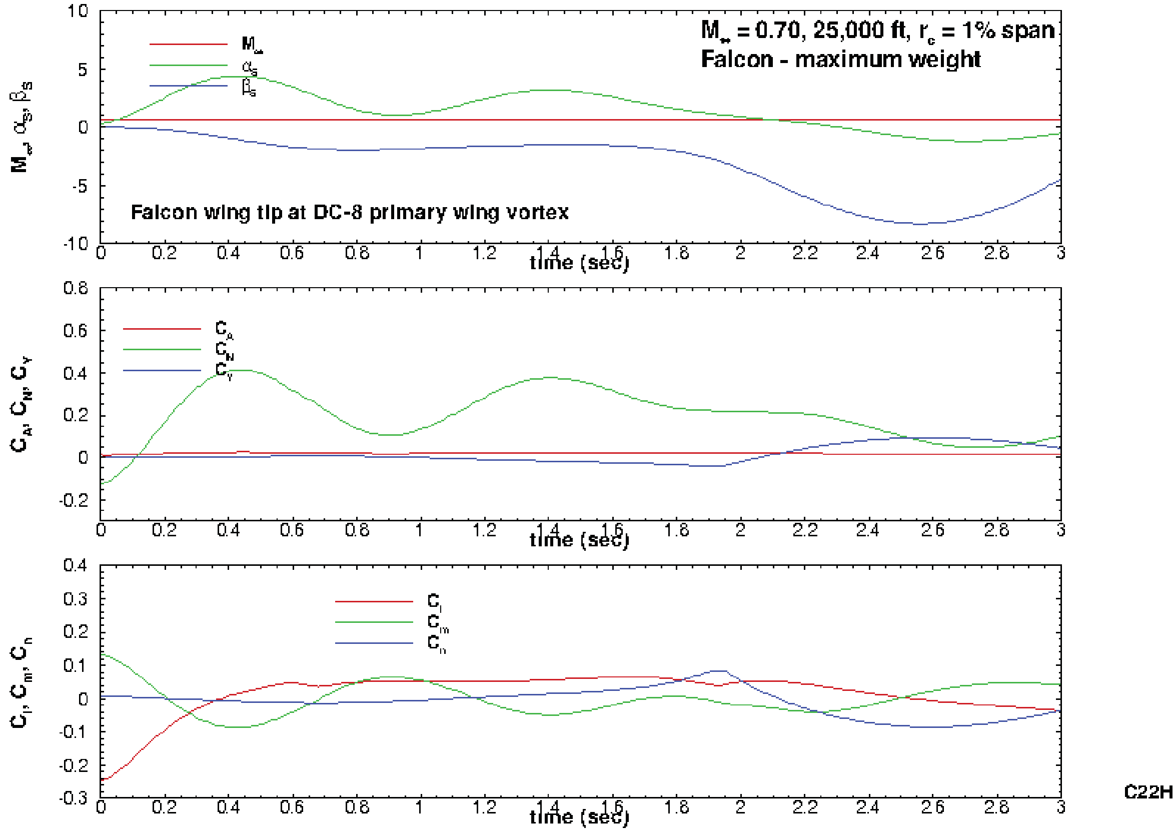


Figure F-28. Heavy Falcon 20 Aerodynamic Characteristics, Simulation 3H

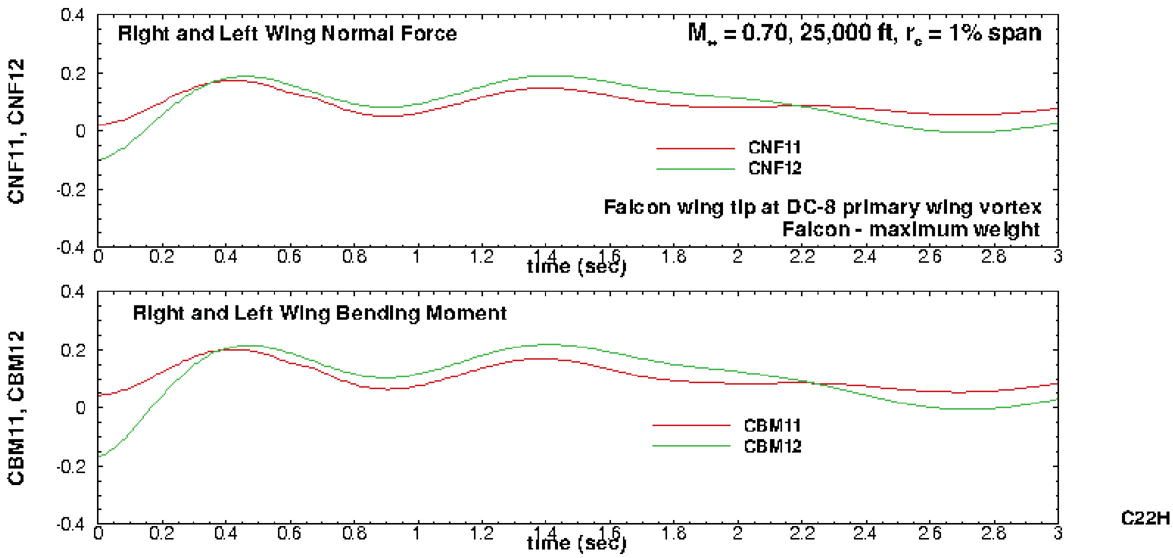


Figure F-29. Heavy Falcon 20 Wing Normal Force and Bending Moment Coefficients, Simulation 3H

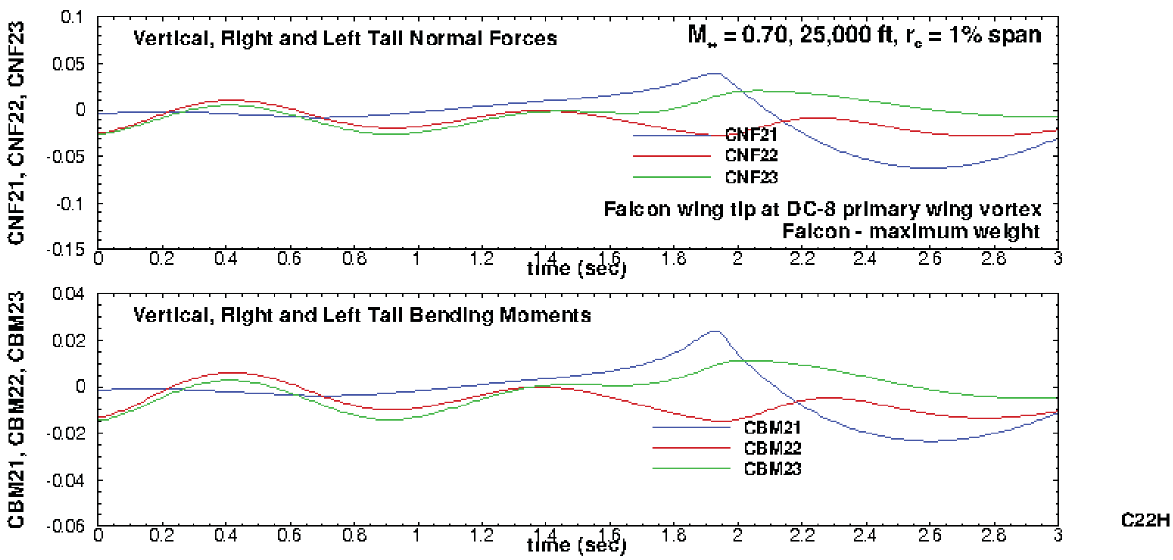


Figure F-30. Heavy Falcon 20 Tail Components Normal Force and Bending Moment Coefficients, Simulation 3H

Appendix G. DLR Teleconference Q&A

ACCESS project team questions for DLR telecom

DLR pilots Roland Welser and Stephan Grillenbeck answered questions posed by the ACCESS project team and the NESC on 18 Sep 2012 in a one hour telecom. Their answers (as transcribed by project pilot Greg Slover) are in blue lettering following the NASA questions.

1. Was the DLR FA-20 instrumented at all for monitoring structural loads anticipated from wake vortex encounters? No, the DLR FA-20 is not instrumented for structural loads.

2. What distance did you allow contrail sampling behind the leading aircraft? Sampling is broken into two separate regimes; near and far. Near is in the 1-5 wingspans aft of the lead aircraft, far is a point around 2 miles aft and further.

a. What rationale did you use for picking that distance? Near field distances avoided the lead aircraft wake vortex as the exhaust and vortex have not yet mixed. Pilots can visually identify the point where the vortex begins to mix and exit the exhaust at that point. They avoid the wake vortex visually, slide aft of the lead aircraft until the exhaust separates vertically from the wake vortex eventually having 300-400 feet vertical separation. They can then sample this separated exhaust up to 20 nm aft as long as contrails are still visible.

3. Were there any wake encounters during your sampling missions? Yes.

a. If so, what were the conditions that led up to it, how violent were they and did they exceed any monitored loads? The conditions that led up to any inadvertent vortex penetration was loss of visual contrail references at very far distances (10-20 nm).

b. What was max roll/yaw rate, G-load, bank or pitch excursion? Max roll rates estimated at 60 deg/sec, G-load was not an issue on these encounters, bank excursions were up to 90 deg and pitch excursions were +/- 5 degrees. An encounter spit the aircraft out of the wake very quickly so there was no dwell time in the vortex if inadvertently encountered.

4. What recovery procedures, if any, were developed for the risk of upsets? No special recovery procedures were developed, recovery was intuitive for the pilots.

5. Were any inspections done on the aircraft after a wake encounter? No special inspections were done as the pilots never felt any load limits were approached or exceeded. However, since DLR has been doing this for 20-30 years, the aircraft has undergone many major aircraft C and D-check inspections where any structural issues would have been found.

a. If so, did the inspections find any issues? No issues found during the normal major aircraft inspections.

6. What techniques did the pilots use to visualize where to position the aircraft for proper sampling? The contrails provided enough visual references to position the sampling aircraft.

7. What techniques did the pilots use to visualize what positions to avoid? They stopped near field sampling when vortex roll-up would become visible in the exhaust contrail. They started far field sampling when the exhaust contrail and vortex contrail began to separate again and had positive vertical safe separation.

8. Were any special cockpit displays developed to help the pilot position the aircraft correctly (or used to avoid hazardous positions). No.

9. Can NASA obtain and review DLR's safety plan and hazard analysis? DLR did not develop a safety plan or hazard analysis for these experiments. Lessons learned have been handed down from pilot to pilot over 30 years (note only a handful of pilots have participated so there has been good continuity).

10. Did DLR experience engine flameouts? Yes.

a. If so, did any fail to relight? No, it relit without problem.

b. If so, was there any damage? No.

c. How many vs. the number of sampling missions? They have only had one flameout (single) in their 20-30 years of flying these experiments.

11. Was dual engine flameout a consideration and how did DLR plan their flights to deal with this risk? Yes it is a consideration, though in Europe they have suitable airfields w/in gliding distance all over and rarely did it effect where they could conduct the experiments.

12. Was structural failure a consideration and how did DLR plan their flights to deal with this risk? Structural failure is a consideration. They plan their flights to avoid the vortex using the techniques listed in 2(a) and 7 above. They also only use their Falcon 20 for these experiments due to its reputation for robust design strength. They have a G-550 and would not do these experiments on the G-550 due to its T-tail design. They noted the FA-20 has exceeded Mach-1 in past (NASA pilots heard this anecdotally during type training at SIMCOM from a long time Falcon pilot).

13. Were any special cockpit procedures or checklists developed for these flights? No.

14. Were any aircraft systems considered go/no-go for safety of test reasons? Nothing specifically developed, though they did note that they only go into these experiments with all systems operational. They do ensure VMC is present in the sampling airspace and strive for 10,000 feet of VMC below.

NESC FTHM assessment team questions for DLR telecom

GENERAL (due to the similarity of questions between the ACCESS project team and NESC, some questions were skipped during the telecom to avoid duplication and keep the telecom to a reasonable time period, the skipped questions were at the discretion of Greg Slover who was asking the questions. NESC had difficulty dialing in to the international phone number and was only listening through a cell phone placed near the LaRC speaker phone. NESC questions may not have been fully answered since they could not directly ask them and clarify with follow-up questions.)

1. **What lead airplanes have been used in the DLR experiments? From the photos NASA received, it appears there were one or more Airbus two-engine ICAO medium class airplanes and the DLR ATTAS VFW-614 aircraft. Has there been any four-engine ICAO heavy class (>136 metric tons) aircraft used as lead aircraft? If so, what aircraft was or were used? The 4-engine heavy class aircraft DLR has sampled**

include A-340, DC-8, B-747 and B-707 aircraft. (Later e-mail confirmed an A-380 sampling mission not know to Roland at the time).

2. For each lead airplane you followed -

    - At what trail distances behind each airplane? 1-5 wingspans aft for near field and 1 or 2 miles aft to 20 miles for far field sampling.
    - Cite handling problems behind each airplane? The turbulence in the exhaust was described as a "washboard effect." Maintaining position in the washboard effect gave positive feedback they were in the right sampling position. Decreased visibility in the exhaust was a greater effect for the pilot to compensate for.
    - Cite worst involuntary upset experienced behind each airplane? Max roll rates estimated at 60 deg/sec, G-load was not an issue on these encounters, bank excursions were up to 90 deg and pitch excursions were +/- 5 degrees. An encounter spit the aircraft out of the wake very quickly so there was no dwell time in the vortex if inadvertently encountered.
    - If upset occurred, extraordinary piloting skills required to recover for any particular aircraft? No extraordinary piloting skill required.

3. What was your Falcon model number and age? FA-20E serial number 329 delivered in 1975 (compared to NASA's FA-20G serial number 447 delivered in early 80s).

4. At what altitudes were the jet exhaust samples taken for these flight tests? FL270 – FL350.

5. Please describe your weather minima for go/no go operations (visibility, cloud clearance, turbulence, icing, etc). Smooth air, VMC at sampling altitude and 10,000 feet below, discernible horizon.

6. What was the closest distance the Falcon got in trail to the lead aircraft? 100 meters. How was this distance determined? Visual references.

7. What is the greatest distance the Falcon was behind the lead aircraft to capture exhaust gases from that lead aircraft? 15-20 miles when a good contrail existed for visual reference.

APPROACH & HOLD

8. Please describe your approach to the lead aircraft in terms of

    - Lead aircraft altitude and airspeed
    - Your joining method, I.e. Rendezvous laterally from left or right or above/below center. Join with lateral separation until stable, reposition aft and high then approach contrail from above to avoid wing downwash effects.
    - Stabilized positions you held in terms of distance behind lead and offset left or right and stepdown distance.
    - Impression of wake turbulence (light or moderate per ICAO definitions) encountered in achieving your stabilized positions. Washboard effect.

- Impression of how control forces and inputs differed as dictated by jetwash, wingtip vortex, or tail surfaces.

9. (Redundant) Please describe your piloting technique to approach the lead aircraft? For example, did you approach from below the lead aircraft along its centerline? Or how was the approach made? Did the approach vary with distance from the lead aircraft? For far field sampling they would only approach the exhaust contrail from above so as to avoid the wake vortex contrail that was 300-400 feet below the exhaust contrail.

10. Please describe any communication procedures you used with the lead aircraft to coordinate maneuvers. No special communications procedures developed other than direct radio communication with lead aircraft.

11. Please describe contingency procedures you developed (lost communication, lead aircraft emergency, etc).

12. Did the Falcon have instrumentation that recorded the aircraft attitude, rates, and accelerations (to determine maximum excursions)? No.

13. Did you have any flight deck or other instrumentation to provide advice that you had been successful in acquiring the required jet exhaust samples? How were you able to determine that you were successful acquiring the exhaust samples required by the flight test? No. Although pilots noted that they can receive verbal feedback from researcher in cabin as to when they are getting the right data.

14. What was your technique to hold position once you had established the Falcon in trail of the lead aircraft?

    - If along the lead aircraft centerline, did you fly a fraction of a wing-span left and/or right?
    - At greater distance in trail of the lead aircraft, what markers did you use to determine where sampling was to occur? Visual acquisition of the exhaust contrail is mandatory to tell pilots where to position the aircraft.
    - What was your piloting technique to avoid loss of control during a possible wake encounter?
    - Were the wake turbulence effects clearly noticeable early enough during your sampling procedure so that you could decide when to abort a sampling and re-establish for another data sampling run? Yes. Washboard effect told pilots they were correctly in the exhaust contrail and an inadvertent wake vortex encounter spit them out of the wake faster than a abort decision could be made.

15. Did you experience any wake encounters during the DLR flight tests that you felt were nearing the limits of the Falcon's ability to withstand the wake vortex induced loads? Were there any wake encounters during the DLR flight test that you felt were on the safety margin? Yes there have been inadvertent wake encounters when far aft of the lead aircraft after contrail visual references began to disappear. Pilots did not feel any limits were approached. If so, what was your concern? No concerns noted.

16. Were sampling locations easier to hold near-field or far-field from the lead plane? Neither.

17. Was aero surface buffeting noticeable during sampling? Washboard effect.

18. Was aero surface buffeting noticeable during recoveries? No.

19. What is your characterization of 'maneuvering difficulty' to position the Falcon for sampling – in near field? – in far field? Nothing difficult with respect to maneuvering the Falcon. Visibility was the bigger effect but provided feedback that the aircraft was in the right spot.

20. Was active control input from the Falcon pilot required to maintain location during sampling? Yes. How much?

21. At any time on any flight, was there ever a subjective notion that the Falcon was being stressed to near any kind of structural limit? No. Was there ever a time in the sampling program when the Falcon pilot thought, "you know, maybe we shouldn't be doing this"? No. This question is the spot where Roland mentioned they would only do this with the Falcon and would avoid doing this with their G-550.

22. Based on your flight test experience does it seem practicable to plan to hold position up to 30 seconds directly *inside* a wake vortex? They avoided the wake vortex altogether, so holding position in the vortex isn't required.

UPSETS & EXIT

23. What were the maximum aircraft excursions encountered during these tests? Was the maximum in attitude (roll, pitch, yaw), in angular rates, or in accelerations? Or was it some combination? At what distance in trail of the lead were those maximums observed? See #2 above. The distances where inadvertent wake encounters occurred was stated at the 15-20 mile range when the contrail was no longer clearly visible.

24. Please describe how you departed the formation/near field flight from the lead (lateral, descent, etc).

25. (Redundant) What were the best techniques to exit the wake to minimize the load on the aircraft? Climb up then slide laterally upwind.

Appendix H. Preliminary Stakeholder Outbrief

Preliminary Stakeholder Summary	Presenter Michael Kelly
	Date October 5, 2012

Independent Assessment of
Probing Aircraft Flight Test Hazard Mitigation (FTHM)
for the
Alternative Fuel Effects on Contrails & Cruise Emissions
(ACCESS) Research Team

Assessment TI-12-00822

Mike Kelly

October 5, 2012

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 1

	NESC background & model of operation (1/3)	Presenter Michael Kelly
		Date October 5, 2012

In 2003, the Columbia Accident Investigation Board (CAIB) observed that NASA's safety organization lacked adequate technical expertise and resources for independent technical reviews of NASA's Programs and Projects.

The NASA Engineering & Safety Center (NESC) was formed as a response to this observation, with a mission to provide the Agency's Programs and Projects with rigorous independent technical perspectives on their most critical technical issues.


NESC is independent

- Centrally managed and funded through the Office of Chief Engineer.
- Unaffiliated with and unbiased by any specific NASA Program or Center.
- Unaffected and unbiased by the Programs our teams evaluate.

NESC background & model of operation (2/3)	Presenter Michael Kelly
	Date October 5, 2012

Office of the Director (7+) – Leadership team located at Langley Research Center (LaRC). Director, Deputy Director, MTSO Manager, Systems Engineering Office Manager, Deputy Director for Safety, Chief Astronaut, Chief Scientist, plus administrative.

NESC Chief Engineers (11) – Embedded executives, one at each of NASA's 10 Centers plus one at headquarters, who provide access and insight into Center-based Programs and Projects.

Principal Engineers (7) – Systems thinking project managers who lead assessment teams and advise other assessment team leaders.

Systems Engineers (~15) – Systems engineering and process specialists, who provide system engineering and integration for assessments and other NESC activities.

Management & Technical Support (~20) – Administrative management experts who provide contracting and budgeting solutions for NESC teams and the leadership team.

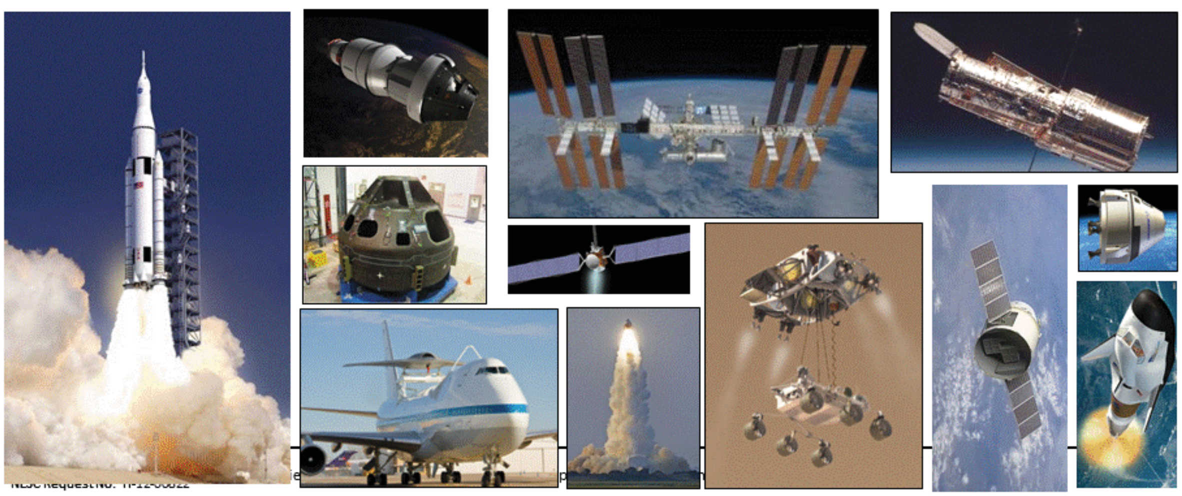
NASA Technical Fellows (15) – Agency technical discipline experts who form and lead Technical Discipline Teams (TDTs).

NESC background & model of operation (3/3)

Presenter: Michael Kelly
Date: October 5, 2012

NESC institutionalized the "Tiger Team" approach: NESC assembles diverse, expert technical teams that provide robust technical solutions to the Agency's highest-risk and most complex issues

Primary NESC assessment team deliverables are technical findings and recommendations rigorously traceable to those findings - documented in engineering reports.



NESC FTHM Team List

Presenter
Michael Kelly
Date
October 5, 2012

Last	First	Team Contributions	Center/Contractor
Core Team			
Kelly	Michael	NESC Lead	LaRC
Roche	Joe	NESC Deputy Lead	GRC
Pahlavani	Patricia	MTSO Program Analyst	LaRC
Mendenhall	Mike	Aero Lead	Nielsen Engineering and Research, Inc.
Lesieutre	Dan	Aerodynamic Analyst	Nielsen Engineering and Research, Inc.
Pandya	Shishir	Aerodynamicist	ARC
Pototzky	Tony	Loads & Dynamics	LaRC
Modlin	Tom	Loads & Dynamics	Retired JSC
Cruz	Josue	Loads & Dynamics	DFRC
Hartshorn	Fletcher	Loads & Dynamics	Tybrin Corporation
Clarke	Bob	Test Hazard Mitigation	DFRC
Rose	William	Test Hazard Mitigation & Aero Analysis	Rose Engineering and Research (REAR)
Yechout	Tom	Test Hazard Mitigation	U.S. Air Force Academy
Lilley	Steve	NSC S&MA	GRC
Consultants			
Bryant	Wayne	Wake Turbulence Expert	Retired FAA Chief Science & Technical Advisor
Stewart	Jim	NESC Chief Engineer	DFRC
Administrative Support			
Burgess	Linda	Planning and Control Analyst	LaRC/AMA
Campbell	Jonay	Technical Writer	LaRC/NG
Derby	Terri	Project Coordinator	LaRC/AMA

NESC Request No: TI-12-00822

This briefing is for status only and does not represent complete engineering data analysis

5

Schedule

Presenter
Michael Kelly
Date
October 5, 2012

Assessment Plan was approved August 2, 2012.

8/10 Assessment Kickoff

9/26 Assessment 'Completed'

10/5 Stakeholder Need Date

AUGUST						
S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

SEPTEMBER						
S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

OCTOBER						
S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 6

Recommendations

Presenter
Michael Kelly
Date
October 5, 2012

The following preliminary NESC recommendations to mitigate structural hazard are directed to the ACCESS Integration Manager, unless otherwise noted.

Backup charts contain supportive material briefed to the NESC Review Board October 4, 2012.

Recommendation R-1

Presenter
Michael Kelly
Date
October 5, 2012

R-1: Enforce as a *mission rule* that WVC be made visible by rolled up exhaust contrail for all NF and FF experiments. (O-1, F-1, F-2, O-2, F-3)

- **If conditions are unfavorable for contrail formation, transit to a more favorable location or use alternate means to make contrails visible.**

O-1: Visible contrails provided unambiguous cues to avoid WVC encounter and confirm entry into sampling area.

F-1: DLR Falcon 20 pilots conducting similar experiments for approximately 30 years have always adhered to a flight rule to only conduct NF and FF experiments when atmospheric conditions make the engine exhaust contrails rolled up around the WVC visible.

F-2: During the period of review, ACCESS team members discussed the possibility of beginning flight tests only when atmospheric conditions make the engine exhaust contrails rolled up around the WVC visible, but relaxing the requirement once experience was gained.

O-2: FF visibility of contrails provides value not only for safety but also for mission success.

F-3: The margin of safety of the vertical tail cannot be determined without strength capability information from the manufacturer.

- Design envelopes are not for sale.
- Load conditions can be submitted to the manufacturer for assessment against design envelopes for a fee.

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 8

Recommendation R-2 (1 of 6)

Presenter
Michael Kelly
Date
October 5, 2012

R-2. Conduct pre-experiment flight tests in NF and FF zones, dedicated to developing pilot proficiency in avoiding WVCs. (F-4, F-5, F-6)

- Do not collect research data during these flight tests
- Consider the included candidate methods, procedures, and activities for pre-experiment flight tests

F-4: DLR Falcon 20 pilot reports from similar flight tests are applicable to the ACCESS experiment but carry limitations that necessitate NASA Falcon 20 pilot training experience avoiding WVC encounters (details listed in Backup).

F-5: The NF WVC and exhaust rollup behavior behind the DC-8 is poorly understood, and the NF zone will be dependent on aircraft weight, altitude, geometry, and atmospheric conditions (details listed in Backup).

F-6: The FF contrail/core separation phenomenon described by DLR Falcon 20 pilots is poorly understood (details listed in Backup).

Recommendation R-2 (2 of 6) Finding F-4 Details

Presenter
Michael Kelly
Date
October 5, 2012

F-4: DLR Falcon 20 pilot reports from similar flight tests are applicable to the ACCESS experiment but carry limitations that necessitate NASA Falcon 20 pilot training experience avoiding WVC encounters.

- Emulating the DLR Falcon 20 pilots NF and FF WVC avoidance techniques, practices, and procedures is not equivalent to first-hand experience and is insufficient by itself to mitigate or reduce the risk of WVC encounter.
- NASA Falcon 20 pilots' direct experience flying the NASA Falcon 20 is limited to the time since its acquisition in November 2011.
- Atmospheric conditions and other factors may yield results different than those reported by DLR pilots, who reported an NF zone of 1 to 5 wingspan lengths and an FF zone of 2 to 20 miles behind four-engine aircraft between 27,000 and 35,000 ft in altitude.
- DLR Falcon 20 pilots reported they could "feel" when approaching WVC in NF but were not specific as to which lead aircraft this subjective experience applied.
- DLR Falcon 20 pilots transferred tribal knowledge about FF WVC avoidance with each other with no formal documentation.
- DLR Falcon 20 pilots experienced an unspecified number of inadvertent FF WVC encounters in the 10- to 20-mile range that were all recovered with no apparent structural damage noted during subsequent regularly scheduled detailed aircraft maintenance inspections. DLR reported:
  - Roll excursions never exceeded 90-degree attitude, 60-degrees-per-second rate.
  - Pitch excursions never exceeded +/–5 degree attitude.
  - Horizon recovery was reported to be 'natural' in the Falcon 20.
  - If deviate, it "spits you out" quickly.
  - On occasions when encountered the WVC, found it difficult to stay inside it.
- They had no special systems on the Falcon for go/no-go or safety of flight..

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 10

Recommendation R-2 (3 of 6) Findings F-5, F-6 Details

Presenter: Michael Kelly

Date: October 5, 2012

F-5: The NF WVC and exhaust rollup behavior behind the DC-8 is poorly understood, and the NF zone will be dependent on aircraft weight, altitude, geometry, and atmospheric conditions.

- WVC location will depend on numerous factors that will make their position difficult to predict based on previous experience first hand or by others.
- DLR Falcon 20 pilots reported an NF zone between 1 and 5 wingspan lengths behind four-engine aircraft between 27,000 and 35,000 ft in altitude but were unspecific about type.
- Consideration of DLR descriptions of NF geometry and the risk of WVC encounter must consider the geometric differences between types. The clearance between Falcon 20 wingtip when on station behind a lead aircraft inboard engine and the lead aircraft's 78-percent wing half-span location, for the four aircraft reported to have been followed by DLR Falcon 20 pilots—DC-8-72, B-707-320, A-340-500 and A-380-800—is +5.4, –2.4, +23.7, and +33.3 feet, respectively.
- Photometric analysis of an unscientific sampling of 12 images of four-engine aircraft contrails archived on public aviation photo Web sites revealed consistent downward motion of inboard engine exhaust plumes relative to outboard plumes throughout a region no less than 4 to 5 wingspan lengths behind the aircraft.
- Photometric analysis of an unscientific sampling of 12 images of four-engine aircraft contrails archived on public aviation photo Web sites revealed inboard engine exhaust plumes diffusing, rising, and rolling up with wake vortices consistently beyond 9 wingspan lengths behind the aircraft.

F-6: The FF contrail/core separation phenomenon described by DLR Falcon 20 pilots is poorly understood.

- DLR Falcon 20 pilots described the vertical distance between the clearly separated visible (upper) exhaust contrail and the (lower) WVC to be at least 300 feet.
- DLR Falcon 20 pilots reported FF sampling in the exhaust plume contrail as a buffeting "washboard" effect that stopped when they exited the contrail.
- DLR Falcon 20 pilots experienced partial-to-complete loss of visibility due to immersion in the exhaust contrail during FF operations.

NESC Request No: TI-12-00822

This briefing is for status only and does not represent complete engineering data analysis

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Recommendation R-2 (4 of 6)

Candidate methods, procedures, and activities – near field

Presenter: Michael Kelly
Date: October 5, 2012

Pre-experiment flight tests in the NF:

- Observe visible engine contrail (inboard) and visible WVC (outboard) behavior from multiple angles before attempting entry.
- Turn auto pilot and auto throttle OFF prior to initial entry.
- Do not use rudder pedal during approach, entry, while inside the NF zone, or during nominal or unexpected exit from the NF zone.
- Initially limit airspeed to at or below maneuvering speed (V_a) to allow for full aileron deflection at all credible conditions that the aircraft could experience during flight; once experience is gained, consider increasing airspeed to be consistent with mission objectives.
- Initially observe the precautions as listed in Section 7 of the flight manual for entering severe turbulence/thunderstorm (except autopilot/autothrottle use); continue this practice unless it poses a greater hazard .
- Develop knock-it-off disengagement criteria based on crew observations (pilot subjectivity) and instrument indications.
- Develop knock-it-off disengagement criteria (red lines) for monitored WVC proximity warning instrumentation (if any).

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 12

Recommendation R-2 (5 of 6)

Candidate methods, procedures, and activities – far field

Presenter: Michael Kelly
Date: October 5, 2012

Pre-experiment flight tests in the FF:

- Observe visible engine contrail (separated upper) and visible WVC (separated lower) behavior from multiple angles before attempting entry.
- Turn auto pilot and auto throttle OFF prior to entry; once established in position, evaluate use of autopilot in attitude hold, altitude hold, and turbulence settings to determine the optimal method of stabilization and sampling .
- Do not use rudder pedal during approach, entry, while inside the FF zone, or during nominal or unexpected exit from the FF zone.
- Initially limit velocity to at or below maneuvering speed to allow for full aileron deflection at all credible conditions that the aircraft could experience during flight; once experience is gained, consider increasing airspeed.
- Initially observe the precautions as listed in Section 7 of the flight manual for entering severe turbulence/thunderstorm; once experience is gained, can enter using precautions as listed in Section 7 of the flight manual for entering moderate turbulence.
- Develop knock-it-off disengagement criteria based on crew observations (pilot subjectivity) and instrument indications.
- Develop knock-it-off disengagement criteria (red lines) for monitored WVC proximity warning instrumentation (if any).
- Consider descending into the better visibility region just beneath the separated exhaust contrail and above the wake vortex; deliberately assume this risk posture to gain experience and feel for the aircraft response when approaching the wake vortex from above.

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Recommendation R-2 (6 of 6)

Candidate methods, procedures, and activities – pre research

Presenter
Michael Kelly
Date
October 5, 2012

Before research experiment flight tests:

- Develop overhead view and rear view maps of the NF and FF zones with identified WVC and engine plume zones, based on pilot experiences and on collected data (if any) to facilitate crew briefing, crew cross-training, in-flight marking of discovered conditions, and mission debriefing, and to improve crew situational awareness of DC-8 WVC and engine exhaust behavior and Falcon WVC encounter as they will vary with density altitude and moisture content.

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 14

Recommendation R-3 (1 of 2)

Presenter
Michael Kelly
Date
October 5, 2012

R-3. Consider adding instrumentation (as listed) to the Falcon 20 or the DC-8 (F-7, O-3)

- to provide an alternative to detecting WVC proximity when atmospheric conditions disfavor contrail formation, or
- to mitigate the risk or detect the effects of structural damage following WVC encounter.

F-7. The following instrumentation, listed in order of assessed priority, may supplant pilot visual observance of contrails to avoid WVC proximity or to mitigate the risk of structural damage (as indicated). Real-time monitoring by the flight crew and/or postflight analysis by the supporting data team are identified (details listed in Backup).

O-3. The short scheduled time between instrumentation installation, which begins in November 2012, and the beginning of experimental flight tests in February 2013 may impact programmatic risk assessment decisions involving adding safety-of-flight instrumentation.

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 15

Recommendation R-3 (2 of 2) Finding F-7 Details

Presenter Michael Kelly

Date October 5, 2012

F-7. The following instrumentation, listed in order of assessed priority, may supplant pilot visual observance of contrails to avoid WVC proximity or to mitigate the risk of structural damage (as indicated). Real-time monitoring by the flight crew and/or postflight analysis by the supporting data team are identified:

- Smoke generators weighing less than 100 lbs on the DC-8 outboard wing pylons, or install an oil injection system behind both outboard DC-8 engines. Real-time mitigation.
- An alpha and a beta vane on the Falcon 20 left wingtip, and a data acquisition system and recorder, monitored during pre-experiment flight tests to identify if useful as a WVC proximity knock-it-off disengagement parameter. Post flight analysis would be needed to develop in-flight knock-it-off criteria.
- Accelerometers on the Falcon 20 left wingtip, vertical tail tip, and horizontal tail tip, oriented normal to each surface, and a data acquisition system and recorder, monitored during pre-experiment flight tests to identify if useful as a WVC proximity knock-it-off disengagement parameter; if large response at dominant frequencies is observed, could be deductively associated with the first few modes of vibration and may require follow up conversations with the aircraft manufacturer; conduct a pre-flight impulse (hammer) response test to identify simple modes and their natural frequencies. Post flight analysis would be needed to develop in-flight knock-it-off criteria.
- Uncalibrated strain gages at locations near the root attachment of the vertical tail judged by project engineers (if not identified by the aircraft manufacturer) to be in primary load path and to have potential for high strain; to be interrogated between flights in an unloaded condition and assessed for strain shifts that might be indicative of yielded structure. Lack of strain shift would not conclusively mean no yield has occured, but a strain shift would compel structural inspections. Post flight mitigation.
- Strain gages at locations near the root attachment of the vertical tail judged by project engineers (if not identified by the aircraft manufacturer) to be in primary load path, and install a data acquisition system and recorder, monitored during pre-experiment flight tests to identify if useful as a WVC proximity knock-it-off disengagement parameter; recorded for post flight analysis; conduct a pre-flight calibration exercise that applies a known load to the vertical tail (need not be elaborate). Post flight analysis would be needed to develop in-flight knock-it-off criteria.
- An INU/GPS and a data acquisition system and recorder to allow recording of Falcon 20 Euler angles, angular rates, positions, linear velocities, and accelerations to facilitate postflight reconstructions and loads computations in the event of inadvertent WVC encounter. Post flight mitigation.
- Pressure transducer on the Falcon 20 left wingtip, and a data acquisition system and recorder, monitored during pre-experiment flight tests to identify if useful as a WVC proximity knock-it-off disengagement parameter; recorded for post flight analysis. Postflight analysis would be needed to develop in-flight knock-it-off criteria.

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Recommendation R-4 (1 of 5)

Presenter
Michael Kelly
Date
October 5, 2012

R-4: Consider the provided independent static loads calculated for 1%, 2% and 3.5% core sizes. (F-3, F-8, F-9, F-10, F-11, F-12, F-13, F-14, F-15, F-16)

- **Results for 1% core size are compared with manufacturer design conditions**
- **Results from the core size parametric study can be applied with project assumptions about decay models to assess structural risk**
- **Make note of the assumptions and limitations of the provided results.**

Recommendation R-4 (2 of 5)
Findings F-8, F-9, F-10 Details

Presenter
Michael Kelly
Date
October 5, 2012

F-3: Margins of safety cannot be determined without strength capability information from the manufacturer.

- **Design envelopes are not for sale**
- **Load conditions can be submitted to the manufacturer for assessment against design envelopes for a fee.**

F-8: Inadvertent Falcon 20 lateral motion in the NF zone until its left wingtip encounters a DC-8 aircraft WVC is assessed to be a *credible* scenario based on consideration of Falcon 20 and DC-8 dimensions.

- **Crew experience reduces but does not eliminate the risk.**

F-9: Inadvertent Falcon 20 lateral motion in the NF zone until its empennage fully encounters the DC-8 WVC is assessed to be a *noncredible* scenario.

- **Research data suggest slow penetration of a rolled up WVC is resisted at small encounter angles (reference Hohne et al.); Full penetration of a rolled up WVC at higher relative angles (10–15 degrees) is likely only if attempted deliberately.**
- **Independent simulation showed the downwash flow field inboard of the WVC will roll the aircraft away as its wingtip enters the WVC.**

F-10: Inadvertent Falcon 20 rolling exit following left wingtip NF encounter with a DC-8 WVC until the Falcon 20 empennage encounters the DC-8 WVC is assessed to be a *less credible but possible scenario* based on consideration of Falcon 20 and DC-8 dimensions and on dynamic simulation results.

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 18

Recommendation R-4 (3 of 5) Findings F-11, F-12, F-13 Details

Presenter
Michael Kelly
Date
October 5, 2012

F-11: Falcon 20 vertical tail normal force and root bending moment from WVC encounter with no inertial relief was computed by independent analysis to remain below 100% design limit load. Make note of the assumptions and limitations of the provided results.

F-12: Falcon 20 horizontal tail differential load from WVC encounter with no inertial relief was computed by independent analysis to exceed 100% design limit load. Make note of the assumptions and limitations of the provided results.

	Documented Maximum Design Condition	NESC TEAM Computed Vortex Induced Shear (1% Core Radius)		ACCESS TEAM Computed Shear	NESC TEAM Computed Vortex Induced Bending Moment (1% Core Radius)		ACCESS TEAM Computed Bending Moment
		lbs	Percent DLL	Percent DLL	ft-lbs	Percent DLL	Percent DLL
Right Wing	Vertical Gust	30,321	65.6	N/A	335,771	69.2	N/A
Left Wing	Vertical Gust	29,943	64.7	N/A	286,988	59.1	N/A
Vertical Tail	Lateral Gust	3,769**	79.6	18	13,278**	92.7	327***
Right Horizontal	Vertical Gust	–2,678	26.7	184	–10,702	21.3	180
Left Horizontal	Vertical Gust	–4,413	43.9	184	16,817	33.5	180
Differential Horizontal Load	Unsymmetric Vertical Gust	–2,887	144.	N/A	–10,969	109.	N/A

** Vertical bending moment includes differential horizontal tail loads.
***Location used to take the moment about at the root is not known. Could potentially differ from point used by NESC team.

Recommendation R-4 (3 of 5) Findings F-11, F-12, F-13 Details

Presenter
Michael Kelly
Date
October 5, 2012

F-13: Computed results from a parametric study of loads versus core size using an independent analysis tool can be applied with project assumptions about decay models to assess structural risk. Make note of the assumptions and limitations of the provided results.

Falcon Component	Maximum	Falcon Baseline*	DC-8 Vortex Core Radius (% span)** 1%	2%	3.5%
Right Wing	Normal Force, lbs	14,999	30,321	26,762	23,425
	Bending Moment, ft-lbs	151,921	335,771	287,860	243,776
Left Wing	Normal Force, lbs	14,999	29,943	25,145	21,914
	Bending Moment, ft-lbs	151,921	286,988	253,704	223,424
Vertical Tail	Normal Force, lbs	0	3,769	2,486	1,559
	Bending Moment, ft-lbs	0	12,005	7,332	4,379
	Total* Bending Moment, ft-lbs	0	13,278	9,120	6,180
Right Horizontal Tail	Normal Force, lbs	–864	–2,678	–1,948	–1,862
	Bending Moment, ft-lbs	–3,891	–10,702	–7,970	–7,641
Left Horizontal Tail	Normal Force, lbs	–864	–4,413	–3,067	–2,191
	Bending Moment, ft-lbs	–3,891	–16,817	–12,153	–8,876

Recommendation R-4 (4 of 5)
Findings F-14, F-15, F-16 & F-3

Presenter
Michael Kelly
Date
October 5, 2012

F-14: (intentionally blank)

F-15: (intentionally blank)

F-16: (intentionally blank)

Recommendation R-4 (5 of 5) Model comparison

Presenter Michael Kelly
Date October 5, 2012

NESC Model	ACCESS Team's Model
DC-8 weight = 280,000 lbs	DC-8 weight = 280,000 lbs
Falcon weight = 31,900 lbs	Falcon weight = N/A (not specified because no inertial loading was calculated)
Altitude = 25,000 ft	Altitude = 27,000 ft
1- to 3.5-percent core radii models	1-percent core radius model
No vortex decay	Linear rate of decay model
Wake modeled by multiple vortices from wing and tail	Wake represented by vortex pair from wing
Panel Method	Aerodynamic Strip Theory
Calculated wing distribution	Assumed elliptically loaded wing
Some computations with estimated aircraft inertia	All computations without inertial loads
Digitized Falcon geometry	Digitized Falcon geometry
Vortex loads in combination with level flight loads	Vortex loads in combination with level flight loads and possibly gust loads
Calculated tail load with the nose of the Falcon anywhere in the wake of the DC-8	Assumed worst case tail load was with vortex centered at the cruciform of the vertical and horizontal tails
Compared vortex loads to fin gust load and rudder load, but not in combination	Compared vortex loads to fin gust load and fin gust + rudder load

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 22

Recommendation R-5 (1 of 2)

Presenter
Michael Kelly
Date
October 5, 2012

R-5: Consider the independent dynamic simulation results of the Falcon 20 response to a WVC encounter when assessing the Falcon 20 NF and FF structural risks from an inadvertent WVC encounter. Make note of the assumptions and limitations of the provided results. (F-17, F-18, F-19, F-20, F-21, F-22)

- **FF simulation (assuming no core decay) simulation beginning with Falcon 20 nose in a 1-percent WVC.**

Recommendation R-5 (2 of 2) Findings F-17, 18, 19, 20, 21, 22

Presenter
Michael Kelly
Date
October 5, 2012

F-17: For the NF dynamic simulation of inadvertent lateral motion until the *wingtip* encounters the flow around a 1-percent WVC, with no control surface inputs, the Falcon 20 rolled away naturally. Further analysis is pending.

F-18: For the FF dynamic simulation of inadvertent descent into a 1-percent WVC (beginning the simulation with the Falcon *nose* inside the core), with no control surface inputs, the Falcon 20 rolled away naturally, with maximum roll rate and angle consistent with DLR experience: 90-degree maximum roll, 60-degree-per-second maximum rate.

F-19: For the NF dynamic simulation of the nominal condition of sampling behind the inboard engine, with no control surface inputs, the Falcon 20 …(analysis is pending)

F-20: Results showing load inertial relief from dynamic simulation with estimated aircraft moments of inertia are pending.

F-21: (intentionally blank)

F-22: (intentionally blank)

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Recommendation R-6

Presenter
Michael Kelly
Date
October 5, 2012

R-6. Do not conduct FF sampling behind "target of opportunity" commercial transport aircraft in controlled airspace prior to conduct of pre-experiment flight tests due to uncharacterized risk of inadvertent WVC encounter. (F-23)

- **The principal unaddressed risk, even at FAA-approved FF distances beyond 5 miles, is engine(s) flameout while enroute cross-country over a region that may lack a suitable reachable airfield; DLR experience shows Falcon 20 flameout risk from WVC ingestion is nonzero.**

F-23: DLR Falcon 20 pilots experienced a single-engine flameout caused by WVC ingestion into an engine, unspecified if NF or FF.

- Engine was relit in flight and the aircraft landed safely.
- No damage was noted during postflight inspection.
- ACCESS flight test rules during NF and FF experiments are expected to require staying at all times within gliding distance (conservatively calculated) to mitigate the hazard resulting from a dual engine flameout.

Recommendation R-7

Presenter
Michael Kelly
Date
October 5, 2012

R-7: Enforce as a *mission rule*, Falcon 20 pilots to minimize control inputs if an inadvertent WVC encounter appears imminent or is indicated to be imminent by instrumentation (if any); allow the vortex wake to move the Falcon naturally out of the vortex flow and then stabilize the aircraft. (F-24, F-25, O-4, O-5, O-6)

F-24: DLR experience and numerical simulations indicate that upsets are self-limited and "self-recovery" is likely.

O-4: In the case of large beta buildup following an upset, rudder reversals can result in vertical tail loads in excess of design capability.

O-5: It was not clear whether HU-25 artificial feel units in combination with variable length bell cranks ("Arthur Q units") are adequate to prevent wing overload from pilot control inputs countering a WVC entry.

O-6: DLR required all aircraft systems to be operable for the mission so any indication of Arthur Q or artificial feel unit failure for them would have been an abort criterion.

Recommendation R-8

Presenter
Michael Kelly
Date
October 5, 2012

R-8: ACCESS Falcon 20 pilots, after an inadvertent WVC encounter, once clear of the vortex perform a rapid and positive centering of the flight controls to minimize excursions in sideslip and angle of attack and to reduce the likelihood of spin entry through inertial coupling. (F-25)

F-25: Flight test report *AFFTC-TR-84-1, HU-25A AIREYE SAFETY OF FLIGHT TEST PROGRAM PERFORMANCE AND FLYING DUALITIES EVALUATION (restricted by the U.S. Export Control Act),* described a Falcon 20 upset and recovery that occurred in 1983 wherein within 10 seconds of the upset the aircraft "rolled to the right, through inverted flight, continuing for approximately one and one-half full rolls (520 degrees of attitude change), with several intermediate roll rate reversals. When control was regained, the aircraft was in a 100- to 110-degree right bank with the nose well below the horizon." The report concluded that "The characteristics of this departure were not unlike those found in some current United States Air Force fighter aircraft which exhibit rolling departures. The pilot can expect to see high roll rates and roll accelerations with several roll reversals occurring as the sideslip angle changes sides, and the aircraft will tend to pitch up to a higher than l-g load factor. In all cases of rolling departures, past experience has indicated that the best recovery technique is a rapid and positive centering of the flight controls. This helps to minimize excursions in sideslip and angle of attack, and the aircraft is less likely to transition to a spin through inertial coupling. The aircraft will generally recover itself or transition to a recognizable out of control mode at which time the appropriate recovery controls should be applied."

Recommendation R-9

Presenter: Michael Kelly
Date: October 5, 2012

R-9: Pursue the request for quote from the Falcon 20 manufacturer to assess aero loads conditions results against aircraft design load limits. (F-3, F-26, O-7)

F-26: Although objective evidence suggests the risk of Falcon 20 structural overload and failure is acceptable, this risk cannot be quantified without knowledge of aircraft limit load capability.

O-7: Load conditions can be submitted to the manufacturer for assessment against design envelopes for a fee.

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	Backup	Presenter Michael Kelly
		Date October 5, 2012

REFERENCE CHARTS

Material presented to the NESC Review Board (NRB) 10/4/12.
This material is for reference only; not approved by the NRB

- Background
- Problem Statement
- Executive Summary
- Project In-Briefing
- Previous Flight tests with leader/follower aircraft
- Mitigation through avoidance
- Wake vortices 101
- Near field ACCESS experiment
- Between near field and far field
- Far field ACCESS experiment
- Aero loads – model, results
- Aero loads comparison
- Core size parametric study
- Dynamic simulations

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Background

Presenter Michael Kelly
Date October 5, 2012

The Aeronautics Research Mission Directorate (ARMD) chartered the Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) research team to conduct experimental flight tests to investigate the potential for alternative fuels to reduce the impact of aviation on air quality and climate.

The use of alternative fuels may yield benefits including reduced particulate and gaseous emissions, reduced or eliminated contrails, and reductions in carbon dioxide.

The ACCESS team plans to fly a series of flights between February 18 and March 31, 2013, using NASA's DC-8-72 commercial transport jet aircraft and a specially instrumented NASA HU-25C "Falcon 20" business transport jet aircraft to obtain *in situ* airborne emission measurements of alternative fuels engine exhaust.

The flight test experiments will originate and terminate at the NASA Dryden Flight Research Center in Edwards, California, and will be conducted in airspace "well away from flight corridors," between altitudes of 27,000 and 39,000 ft and along 10- to 20-mile tracks aligned with the wind direction.

Background

Presenter: Michael Kelly
Date: October 5, 2012

<u>Douglas DC-8-72, T/N N817NA</u>
- Based at NASA DFRC
- Four-engine
- 41,000-ft ceiling
- 157 ft long, 148-ft wingspan
- Special viewports
- Wingtip pylons that can accommodate 100 lbs, with power and signal cables

<u>Dassault Falcon 20G, T/N N525NA (Coast Guard HU-25C Guardian)</u>
- Based at NASA LaRC
- Twin-engine
- 42,000-ft ceiling
- 55 ft long, 54-ft wingspan
- Aerosol/gas inlet probe on top
- Cloud droplet probe on top
- Diode laser hygrometer in window
- Cloud droplet probe under left wing

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Problem Statement

Presenter Michael Kelly
Date October 5, 2012

The Falcon 20 will collect data behind the DC-8 within two experimental zones referred to as the "near field" (NF) and the "far field" (FF).

A safety hazard review resulted in three identified hazards that have potential consequences, including loss of mission success, damage to asset, loss of asset, or loss of personnel, associated with flying the Falcon 20 in the wake of the DC-8:

- Aircraft structural failure.
- Engine out due to ingestion of distorted flow.
- Aircraft controllability/operability at unusual attitudes.

ACCESS Project Integration Manager, Mr. Brian F. Beaton, of the NASA Langley Flight Research Services Directorate (RSD), requested that the NESC form a team to independently assess the Falcon 20 structural failure risk associated with flying in the wake of the DC-8, in particular the risk from encountering a wake vortex, and to identify potential flight test hazard mitigation actions to ensure flight safety.

- Specific focus was requested for the Falcon 20 vertical tail.
- Results were requested prior to a review scheduled for early October 2012.

Executive Summary

Presenter: Michael Kelly

Date: October 5, 2012

Asking today for approval of *preliminary* "top" NESC recommendations and their associated findings and observations (beginning on chart 51).

- Stakeholder need date is October 5, 2012.
- Secondary findings, observations, and NESC recommendations will be included in the final report.
- Preliminary findings, observations, and NESC recommendations may be revised in the final report.

Not requesting approval of the explanatory material included for the benefit of NESC Review Board.

- Will become narrative material in the final report.

Executive Summary

Presenter
Michael Kelly
Date
October 5, 2012

NESC Team Activities Summary

- Researched and discussed the state of knowledge regarding the evolution of exhaust and wake vortices from the NF to the FF.
- Considered and discussed pilots' lessons learned from previous similar experiments.
- Considered and discussed the ACCESS Project's loads assessment.
- Conducted independent loads assessment.
- Conducted independent trajectory simulations.
- Developed flight test hazard mitigations and formulated recommendations.

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Project In-briefing	Presenter Michael Kelly Date October 5, 2012

The ACCESS project team provided a briefing on August 14, 2012, to familiarize the NESC team with their concept of operations and to provide the results of the structural assessment they had conducted.

Margins of safety could not be determined for the project's computed loads without strength capability information from the manufacturer.

- Design envelopes are not for sale.
- Load conditions can be submitted to the manufacturer for assessment against design envelopes for a fee.

Loads were compared with the design load conditions documented in Dassault report number DTX-37713 (parts 1 and 2), entitled "Mystère (Falcon) 20 Series With Fairings, Calculation of Loads," dated April 1966.

The NESC team assessed the ACCESS team results, methods, and assumptions.

- A conservative 1-percent vortex core model was used.
- The strip theory used is a valid conservative approach, with the assumption of linear aerodynamics and no inertial relief.
- The loads results were well in excess of the Falcon design loads.

Previous Flight Tests with Leader/Follower Aircraft

Presenter: Michael Kelly
Date: October 5, 2012

Through mid-September, the ACCESS team had been unsuccessful in recovering information about other flight research experiments with leader/follower aircraft.

NASA Wallops Flight Facility (WFF)
- **Subsonic Assessment Near-Field Interactions (SNIF-1), Summer 1995—Sabreliner chased NASA B737, P-3B, and C-130 over east coast.**
- **Subsonic Assessment Near-Field Interactions (SNIF-2), Winter 1996—Sabreliner sampled MD80, B757, and B747 in east-coast flight corridors.**
- **Subsonic Assessment Cloud and Contrail Effects Special Study (SUCCESS), Spring 1996—Sabreliner chased NASA DC-8 and B757.**
- **Subsonic Assessment Near-Field Interactions (SNIF-3), Summer 1997—Sabreliner sampled ANG F-16s over Vermont and New Jersey.**

German Aerospace Agency (DLR)
- **SULFUR flight series, mid 1990s—Falcon 20 chasing ATTAS, A310, A340, B707, B747, B737, DC8, and DC10.**
- **Pollution from aircraft emissions in the North Atlantic (Polinat), late 1990s—Falcon 20.**
- **CONCERT, 2009–2011—Falcon 20, various aircraft.**
- **Lufthansa flight experiment, Spring 2012—Falcon 20 chasing A380 with bio fuel.**

National Research Council (NRC) Canada
- **Wake/Vortex Dynamics Measurements—T33 chasing commercial and military aircraft.**
- **Alt Fuel effects—T33 chasing military aircraft burning biofuel.**

The DLR campaign was of particular interest because it involved a Falcon 20 aircraft following various commercial transport aircraft.

Mitigation Through Avoidance

Presenter
Michael Kelly
Date
October 5, 2012

Toward the end of the period of assessment on September 18, 2012, two DLR Falcon 20 pilots made themselves available to answer questions from the ACCESS team and the NESC team and to share their lessons learned.

The DLR research team had conducted flight tests over a period of approximately 30 years flying a Falcon 20E (more than 5 years older than the NASA Falcon 20G) behind two-engine aircraft and behind DC-8, B-707, A-340, and A-380 four-engine aircraft.

DLR's principal safety mitigation for 30 years has been to avoid encounters with wake vortices by only flying when conditions make them visible.

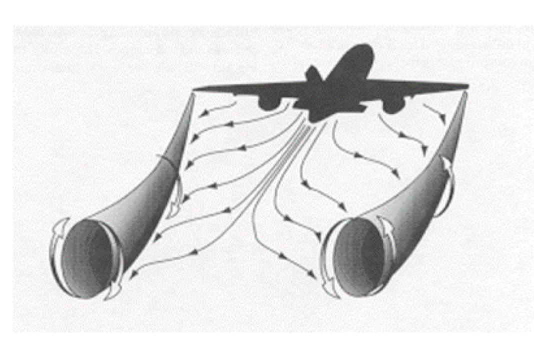
Wake Vortices 101

Presenter Michael Kelly
Date October 5, 2012

When aircraft travel through the atmosphere, wake vortices associated with the lift on the aircraft are shed from physical features.

Individual wake vortices "roll up" and merge with the largest vortices, which are shed from the wingtips.

- In a manner dependent on aircraft weight, geometry, altitude, and atmospheric conditions.
- Sequentially from outboard to inboard.
- Outboard engine exhaust plumes roll up.
- Horizontal tail vortices roll up.
- Inboard engine (if any) exhaust plumes roll up.



THE ROLLING UP PROCESS

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	Wake Vortices 101	Presenter Michael Kelly Date October 5, 2012

The aerodynamic lift distribution on a wing, which is determined by the wing's configuration, is known to affect the strength, span location, and behavior of the wing's rolled up vortices.

- Much of the available information applies to wings with flaps and slats deployed because research has been focused on wake vortex generation, rollup, behavior, and dissipation at altitudes near the ground, where airspace density is greater and the severity of an inadvertent wake encounter can be catastrophic .
- For elliptical wing loadings (as associated with a "clean wing" configuration with flaps up, slats retracted, and ailerons and spoilers faired), rolled-up wake vortices quickly migrate toward the theoretical location of approximately $\Pi/4 \approx 78$-percent wingspan location.

Wake vortex core (WVC) size, which determines peak tangential velocities, is commonly expressed in terms of "percent wingspan," for example, a "1-percent core size" for the DC-8 is about 1.5 ft in diameter.

Wake vortices persist behind aircraft for tens of miles.

Under certain atmospheric conditions, engine exhaust plumes are visible as ice particle contrails.

- When contrails roll up into wake vortices, the cores become visible.

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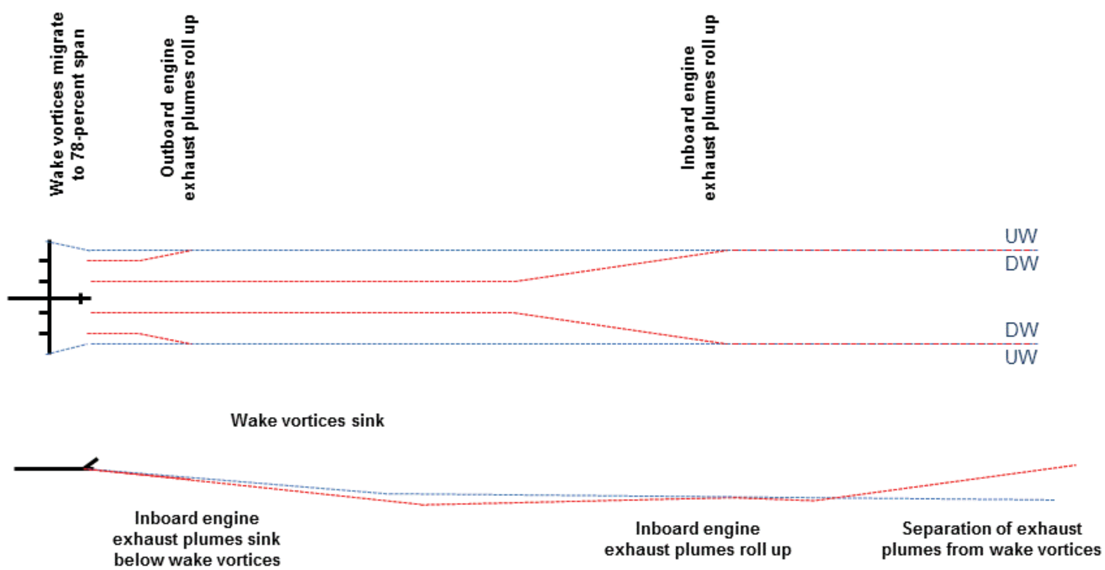
Wake Vortices 101

Presenter Michael Kelly

Date October 5, 2012

ACCESS near field and far field risk is a three-dimensional geometry problem; drawing is notional and not to scale.



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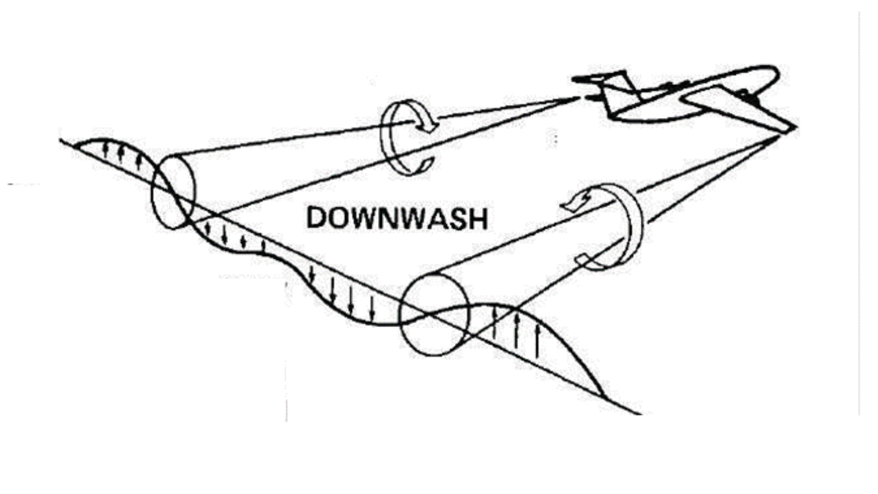
Wake Vortices 101

Presenter
Michael Kelly
Date
October 5, 2012

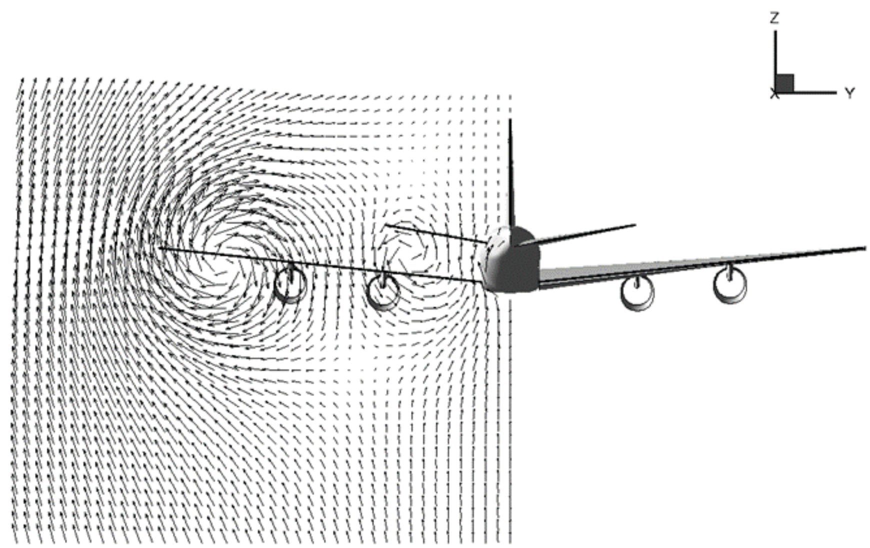
ACCESS flight test experiments will occur in complex upwash (UW) and downwash (DW) flow fields surrounding rolled-up wake vortices.



Wake Vortices 101

Presenter: Michael Kelly
Date: October 5, 2012

The horizontal tail also creates a counter-rotating flow field in the near field.



Representative Velocity Flow Field in Y-Z Plane Shown Directly Behind a Model Representation of a DC-8

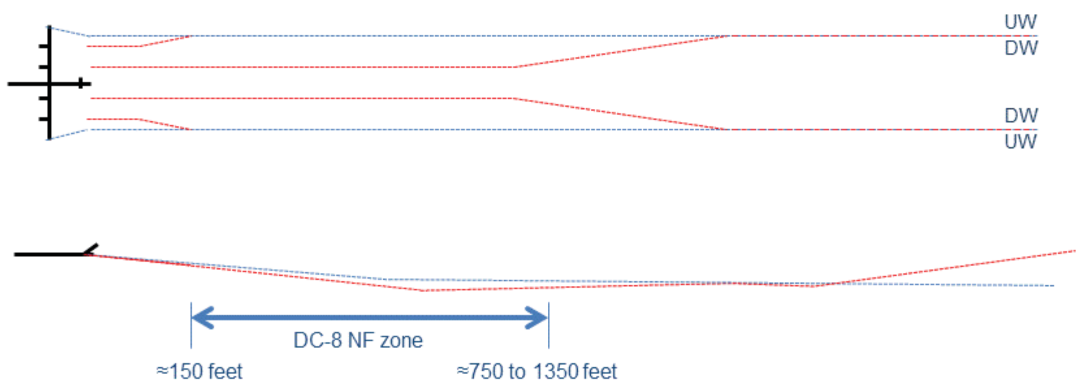
Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

The NF sample area is bounded by the DC-8 wing vortices with the outboard engine exhaust plumes rolled up around them.

- DLR pilots observed that outboard engine exhaust plumes from four-engine aircraft roll up around the WVCs within about one wing span length behind the aircraft tail.
- A practicable NF sample area was described by DLR Falcon 20 pilots to be between 1 and 5 wing span lengths behind lead aircraft with four engines.

The NESC team conducted photometric analysis of a small set of publicly available contrail images and observed that inboard engine exhaust plumes may roll up within about 9 wing span lengths.



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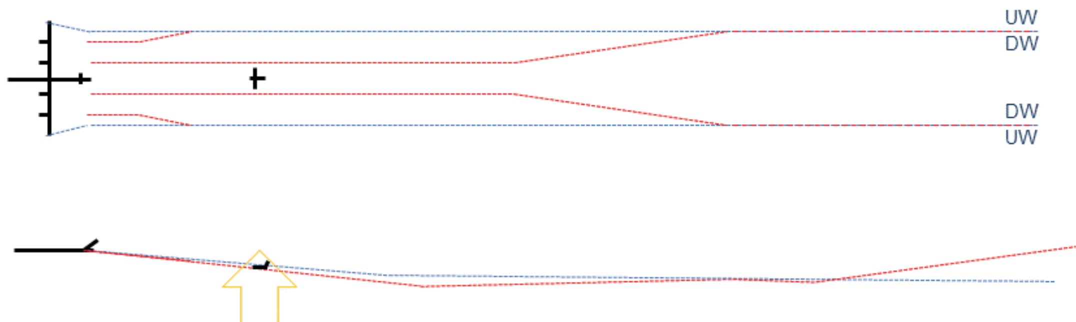
Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

To enter the NF sample area, the NASA Falcon 20 will climb from below and behind the DC-8 along its centerline, per in-flight refueling practices.

- Crew familiarity and visibility.
- In accordance with DLR experience.
- To facilitate inboard exhaust sampling.



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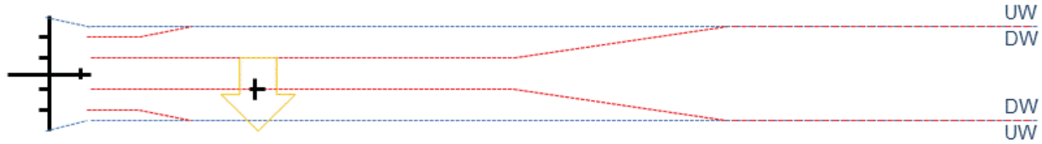
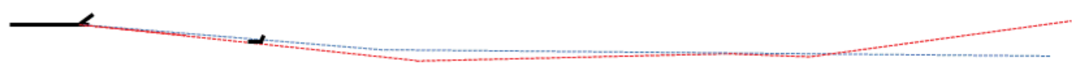
Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

To establish position to sample the DC-8 left inboard engine exhaust plume, the Falcon 20 will slowly translate to its left and stabilize behind the DC-8's left inboard engine.

- The Falcon 20 left wingtip will be about 5 to 6 ft away from the center of DC-8 left side wake vortex core, which can be assumed to be on the order of 1.5 ft in diameter.
- The Falcon 20 left wing will be experiencing more downwash than its right wing, requiring pilot roll and pitch inputs to maintain position.
- The pilot will use the outboard engine visual contrail cue to avoid encountering the wake vortex core.
- To exit from the NF sample area, the Falcon 20 will descend directly downward from the sampling location, as was the practice of the DLR pilots.





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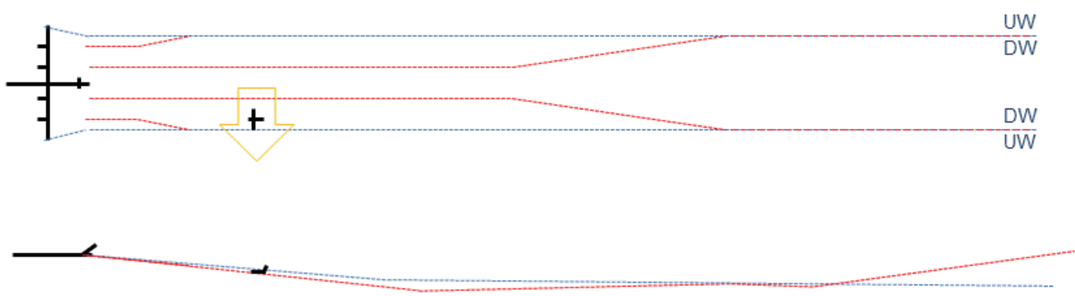
Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

Falcon 20 wingtip encounters the WVC.
- Load condition assessed.
- Dynamic simulation conducted.



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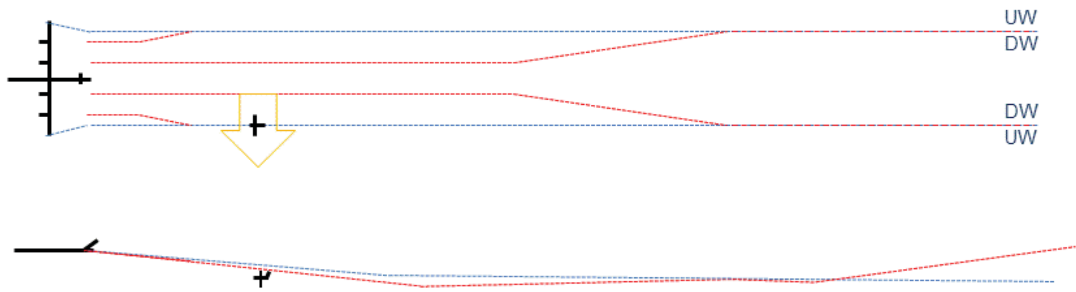
Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

Falcon 20 empennage encounters the WVC during rolling exit.
- Load condition assessed.



Near-Field ACCESS Experiment

Presenter Michael Kelly
Date October 5, 2012

DLR Falcon Sampling NF behind an A-320 (Unknown Variant)

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Near-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

DLR Falcon Sampling NF behind a VFW-Fokker 614 (WS 70.5 ft)

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Between Near Field and Far Field

Presenter: Michael Kelly
Date: October 5, 2012

Between the NF and the FF is a region 1 to 2 miles long where left and right WVCs can persist and display synchronized chaotic responses to atmospheric conditions.

Illustrations of Chaotic Nature of Single FF WVC Made Visible by Injecting Oil into Outboard Engine Exhaust Plume

Between Near Field and Far Field

Presenter: Michael Kelly
Date: October 5, 2012

Screen grab from NASA video showing chaotic WVC (737 encountering C-130 WVC).

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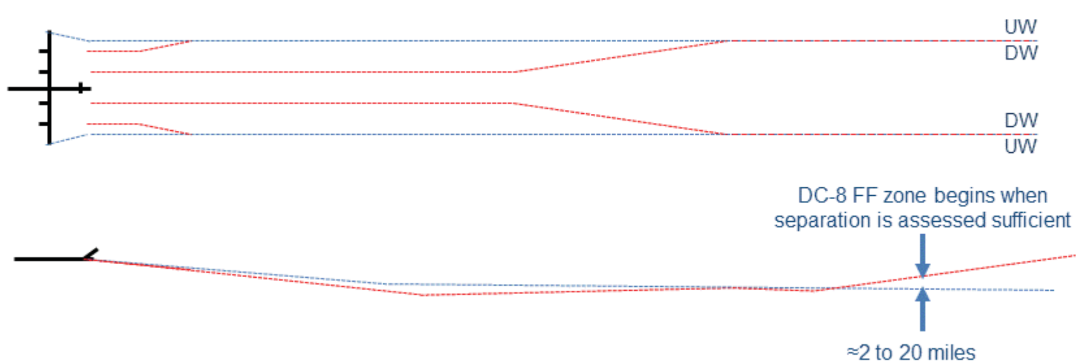
Far-Field ACCESS Experiment

Presenter
Michael Kelly
Date
October 5, 2012

The FF sample area is a diffuse exhaust contrail between 2 and 20 miles behind the DC-8 that has separated to an observable distance *above* its formerly associated WVC.

- Good physical models of separation physics do not exist, but thermal or species buoyancy may play a role where lighter gas constituents such as carbon monoxide might be overweighted in the top, while heavier constituents like carbon dioxide might be underweighted.
- Research suggests that the amount of separation between the upper diffuse exhaust plume and the lower formerly associated WVC may be smaller behind clean wings with elliptical lift distributions than behind wings with deployed surfaces.
- DLR observed 300-ft separation.



Far-Field ACCESS Experiment

Presenter: Michael Kelly
Date: October 5, 2012

Screen grab from DLR video showing FF separation: diffuse contrail above the WVC.

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Far-Field ACCESS Experiment

Presenter Michael Kelly
Date October 5, 2012

Screen grab from DLR video of Falcon 20 sampling diffuse contrail above an A-380 WVC.

Far-Field ACCESS Experiment

Presenter: Michael Kelly
Date: October 5, 2012

Screen grab from DLR video of Falcon 20 sampling diffuse contrail above an A-340 WVC.

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Far-Field ACCESS Experiment

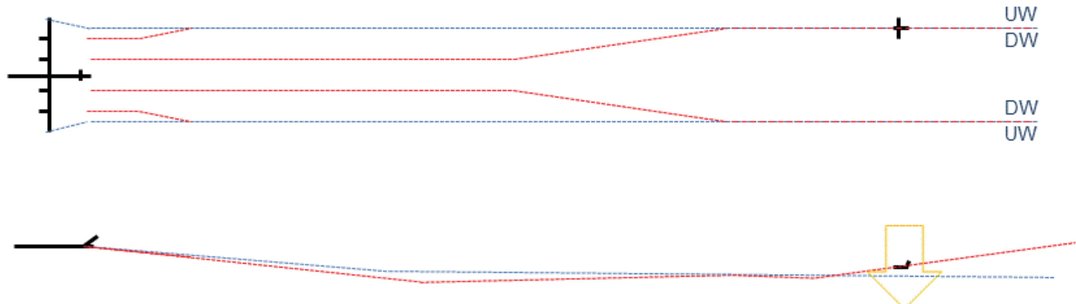
Presenter: Michael Kelly
Date: October 5, 2012

To enter the FF sample area, the Falcon 20 will descend from above and behind the DC-8 into one of the two visible, diffuse exhaust contrails.

- The clearance between the visible contrail and the visible WVC will have been noted before entry.
- DLR pilots reported clearance of at least 300 ft.
- The wake vortex may not be visible during entry (hidden below the contrail).
- The Falcon 20 crew will level off and maintain position within the separated chaotic contrail for TBD seconds.

DLR Falcon 20 pilots described the feel of flying in such conditions as being "on a washboard."

- Often lost visual references.
- "Washboard feel" provided positive feedback that they were in the correct sampling position.

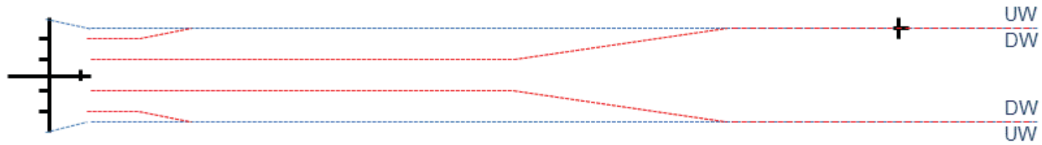


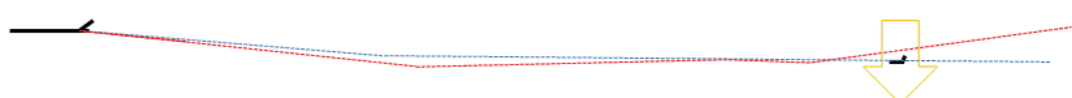
Far-Field ACCESS Experiment

Presenter: Michael Kelly
Date: October 5, 2012

Falcon 20 descends into WVC.

- Load condition assessed.
- Dynamic simulation conducted with conservative1-percent WVC model (assumes no decay).





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Aero Loads

Presenter
Michael Kelly
Date
October 5, 2012

The NESC team utilized an aerodynamic analysis tool proprietary to Nielsen Engineering and Research (NEAR) to predict the behavior of atmospheric vehicles in flight in proximity to one another.

- It has heritage usage for analysis of stores released from aircraft and has also been used for analysis of the release of experimental aircraft and rockets and missiles from carrier aircraft.
- It has been validated with flight data for previous applications.

Aero Loads

Presenter Michael Kelly
Date October 5, 2012

Key model aspects and assumptions:

NESC Model	ACCESS Team's Model
DC-8 weight = 280,000 lbs	DC-8 weight = 280,000 lbs
Falcon weight = 31,900 lbs	Falcon weight = N/A (not specified because no inertial loading was calculated)
Altitude = 25,000 ft	Altitude = 27,000 ft
1- to 3.5-percent core radii models	1-percent core radius model
No vortex decay	Linear rate of decay model
Wake modeled by multiple vortices from wing and tail	Wake represented by vortex pair from wing
Panel Method	Aerodynamic Strip Theory
Calculated wing distribution	Assumed elliptically loaded wing
Some computations with estimated aircraft inertia	All computations without inertial loads
Digitized Falcon geometry	Digitized Falcon geometry
Vortex loads in combination with level flight loads	Vortex loads in combination with level flight loads and possibly gust loads
Calculated tail load with the nose of the Falcon anywhere in the wake of the DC-8	Assumed worst case tail load was with vortex centered at the cruciform of the vertical and horizontal tails
Compared vortex loads to fin gust load and rudder load, but not in combination	Compared vortex loads to fin gust load and fin gust + rudder load

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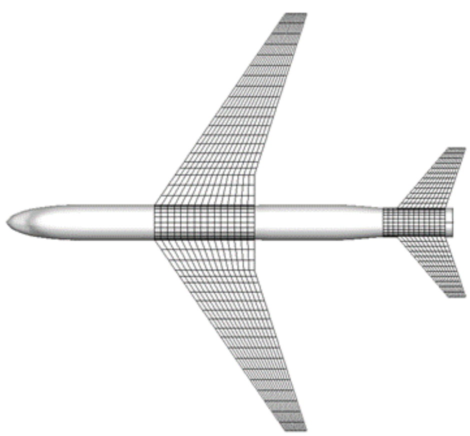
Aero Loads

Presenter: Michael Kelly
Date: October 5, 2012

Key model aspects and assumptions:

- Vortex Lattice Panel Model
  - More accurate span load distribution and vortex wake characterization
- Aerodynamic Strip Theory Model
  - Good first order estimate for loads and trailing vortex model



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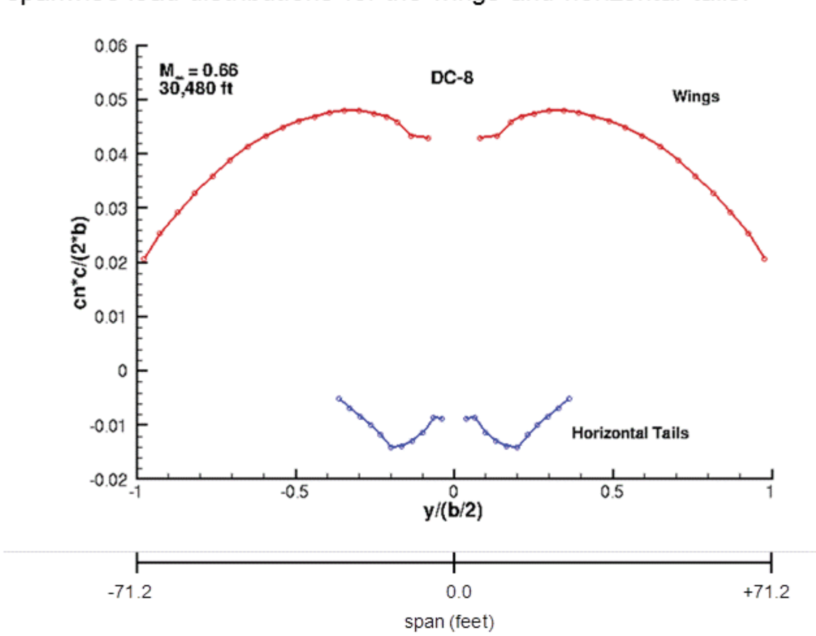
Aero Loads

Presenter
Michael Kelly
Date
October 5, 2012

DC-8 spanwise load distributions for the wings and horizontal tails.



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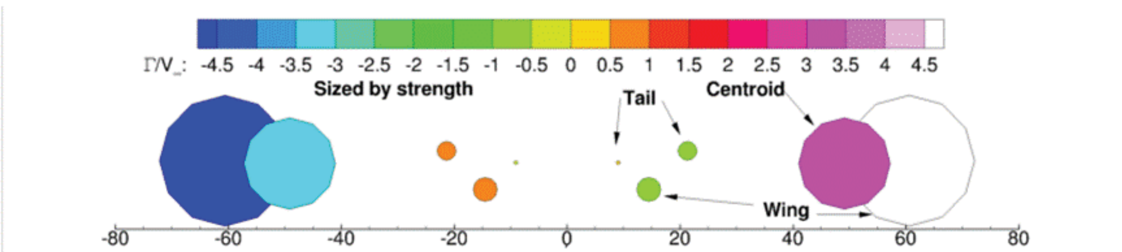
Aero Loads

Presenter
Michael Kelly
Date
October 5, 2012

DC-8 vortices are shown from the wingtips, inner wing regions, and horizontal tail surfaces. Engines and pylons were not modeled.

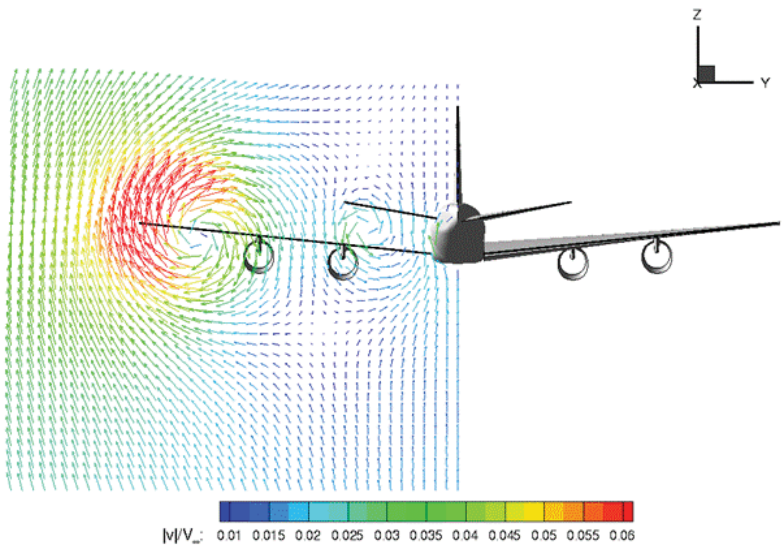
The centroid is the weighted average of all.



Aero Loads

Presenter
Michael Kelly
Date
October 5, 2012

DC-8 velocity field behind the aircraft is shown. Vector length and color indicate tangential velocity as a fraction of the free-stream velocity in the *Y-Z* plane. The results represent conditions at the aircraft tail location.



Aero Loads

Presenter
Michael Kelly
Date
October 5, 2012

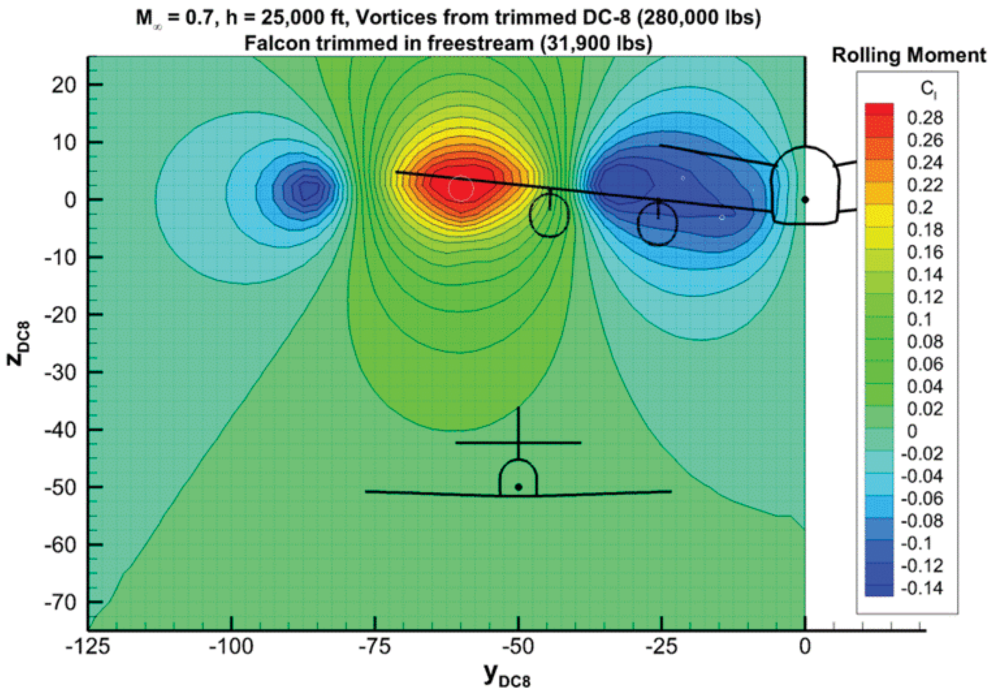
Two thousand production runs conducted with the Falcon 20 held in locations behind a DC-8 multi-vortex field with a 1-percent WVC size.

Maps created in the *Y-Z* plane for aircraft induced rolling moment, induced yawing moment, induced pitching moment, induced normal force, and induced side force.

Also generated C_p, maximum induced loads and moments, and induced component loads and moments for the vertical tail, horizontal tail, and wing.

Induced Rolling Moment

Presenter
Michael Kelly
Date
October 5, 2012



Vortex core size - 1% of span "white" symbols - DC8 vortices scaled by strength

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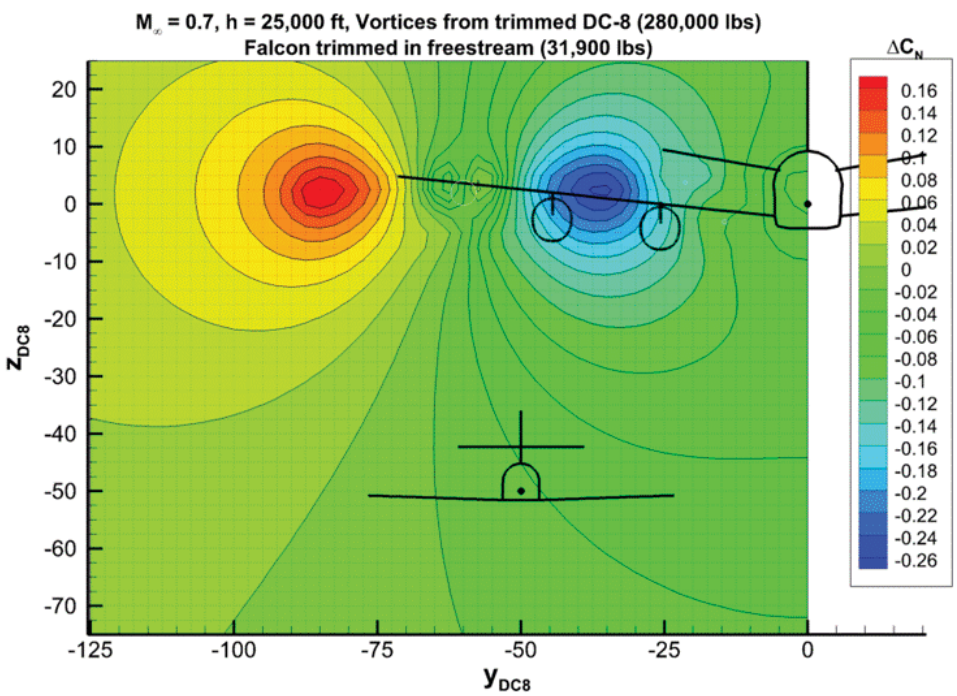
Induced Normal Force

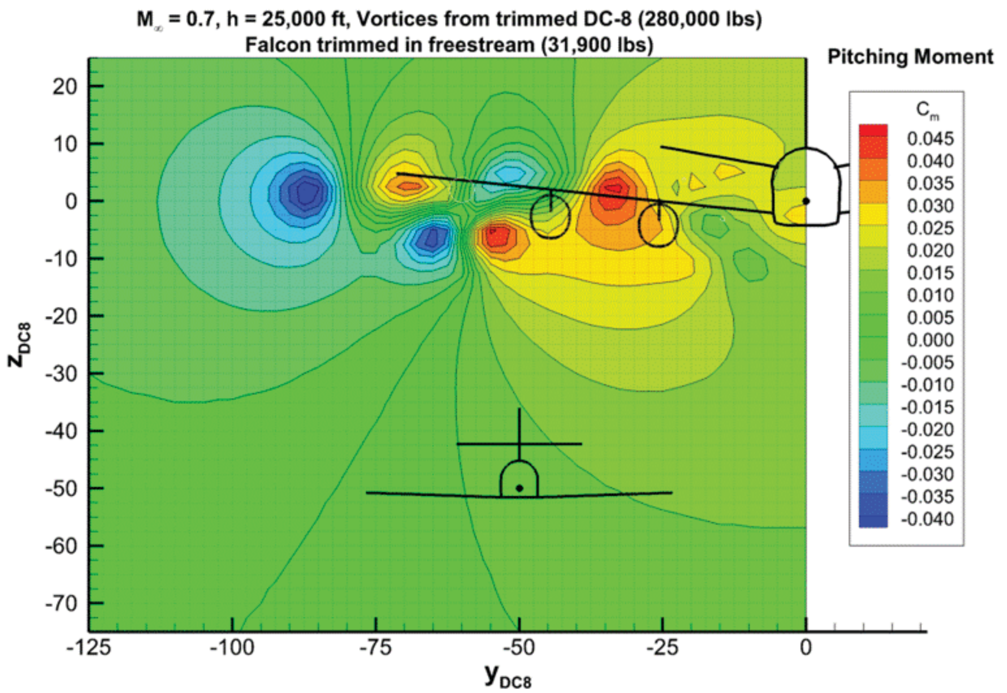
Presenter Michael Kelly
Date October 5, 2012



Vortex core size - 1% of span
"white" symbols - DC8 vortices scaled by strength

NESC Request No: TI-12-00822 This briefing is for status only and does not represent complete engineering data analysis 66

Induced Pitching Moment	Presenter Michael Kelly
	Date October 5, 2012



Vortex core size - 1% of span

"white" symbols - DC8 vortices scaled by strength

NESC Request No: TI-12-00822

This briefing is for status only and does not represent complete engineering data analysis

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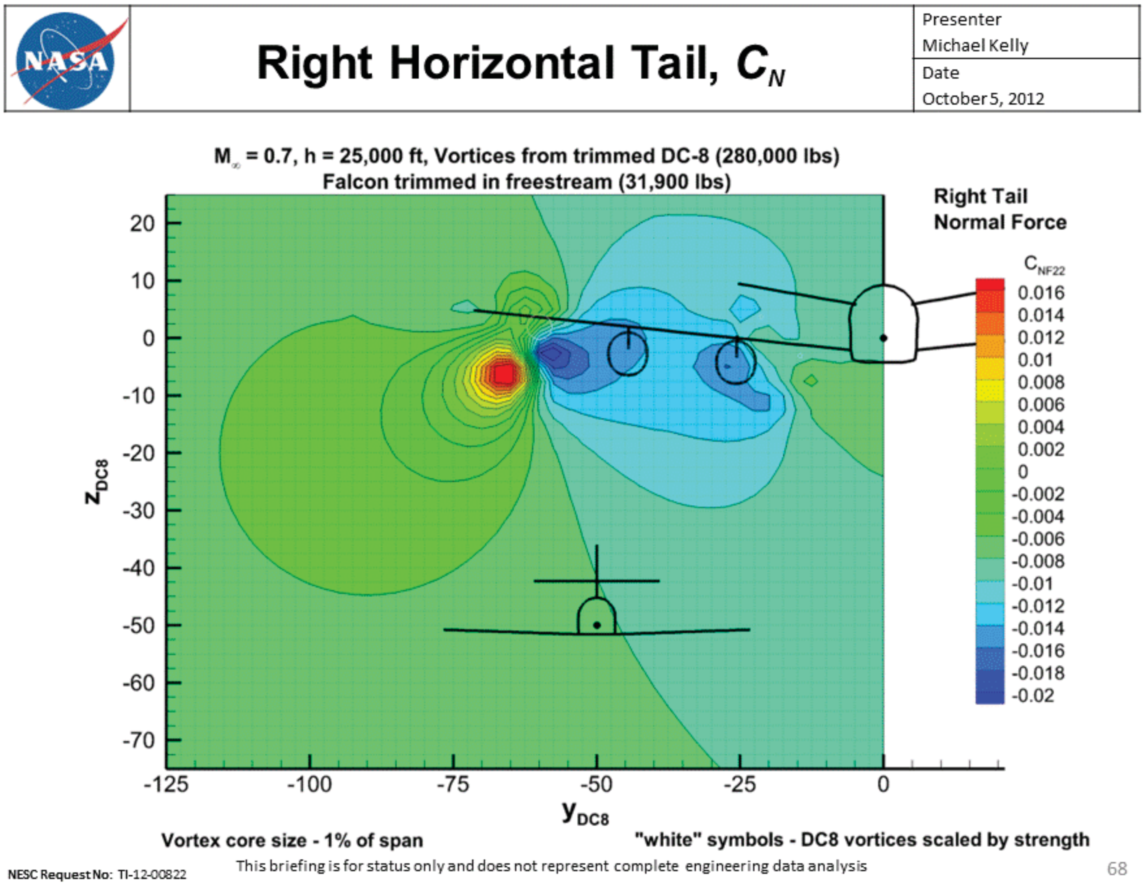
Right Horizontal Tail, C_N
Presenter
Michael Kelly
Date
October 5, 2012
M∞ = 0.7, h = 25,000 ft, Vortices from trimmed DC-8 (280,000 lbs)
Falcon trimmed in freestream (31,900 lbs)
Right Tail
Normal Force
C_{NF22}
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
-0.018
-0.02
z_{DC8}
y_{DC8}
20
10
0
-10
-20
-30
-40
-50
-60
-70
-125
-100
-75
-50
-25
0
Vortex core size - 1% of span
"white" symbols - DC8 vortices scaled by strength
NESC Request No: TI-12-00822
This briefing is for status only and does not represent complete engineering data analysis
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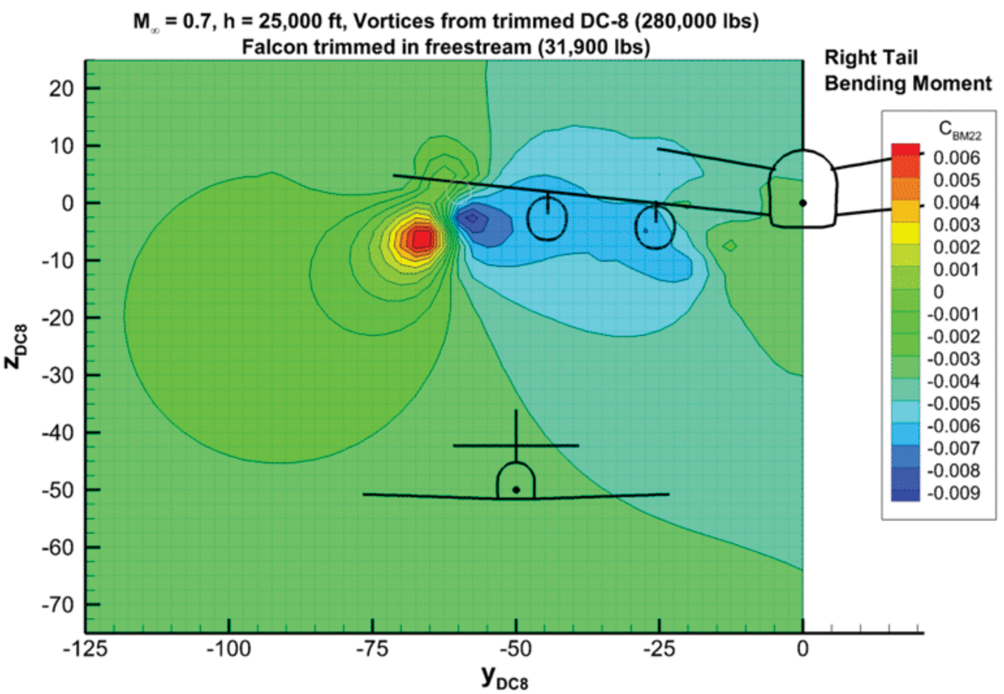
Right Horizontal Tail, C_{BM}

Presenter Michael Kelly
Date October 5, 2012



Vortex core size - 1% of span
"white" symbols - DC8 vortices scaled by strength

NESC Request No: TI-12-00822

This briefing is for status only and does not represent complete engineering data analysis

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Aero Loads Comparison

Presenter Michael Kelly
Date October 5, 2012

Compared computed aero loads for 1-percent core size encounter with design load conditions documented in Dassault document number DTX-37713 (parts 1 and 2), titled "Mystère (Falcon) 20 Series With Fairings, Calculation of Loads," dated April 1966.

- Treated these conditions as if they were "design limit load" (DLL) conditions.

	Documented Maximum Design Condition	Documented Maximum Design Shear, lbs	Documented Maximum Design Bending Moment, ft-lbs
Right Wing	Vertical Gust	46,247	485,441
Left Wing	Vertical Gust	46,247	485,441
Vertical Tail	Lateral Gust	4,737	14,331*
Right Horizontal	Vertical Gust	–10,043	–50,213*
Left Horizontal	Vertical Gust	–10,043	50,213*
Differential Horizontal Load	Unsymmetric Vertical Gust	–2,008	–10,040*

* Design bending moments are calculated based on the reported shear loads.

Aero Loads Comparison

Presenter: Michael Kelly
Date: October 5, 2012

NESC and ACCESS teams' computed vortex-induced loads for a 1-percent wake vortex core.

	Documented Maximum Design Condition	NESC TEAM Computed Vortex Induced Shear (1% Core Radius)		ACCESS TEAM Computed Shear	NESC TEAM Computed Vortex Induced Bending Moment (1% Core Radius)		ACCESS TEAM Computed Bending Moment
		lbs	Percent DLL	Percent DLL	ft-lbs	Percent DLL	Percent DLL
Right Wing	Vertical Gust	30,321	65.6	N/A	335,771	69.2	N/A
Left Wing	Vertical Gust	29,943	64.7	N/A	286,988	59.1	N/A
Vertical Tail	Lateral Gust	3,769**	79.6	18	13,278**	92.7	**327*** **
Right Horizontal	Vertical Gust	–2,678	26.7	184	–10,702	21.3	**180**
Left Horizontal	Vertical Gust	–4,413	43.9	184	16,817	33.5	**180**
Differential Horizontal Load	Unsymmetric Vertical Gust	–2,887	**144.**	N/A	–10,969	**109.**	N/A

Red font denotes that the "inferred" design limit loads were exceeded.

** Vertical bending moment includes differential horizontal tail loads.
***Location used to take the moment about at the root is not known. Could potentially differ from point used by NESC team.

Core Size Parametric Study

Presenter
Michael Kelly
Date
October 5, 2012

The core size parametric study was conducted to provide a tool for the stakeholder to assess various core decay models.

Decay model choice may lead to up to a 40-percent variance in decay. Larger cores have smaller induced velocities and, therefore, induce smaller aircraft roll responses.

- Two thousand production runs conducted with the Falcon 20 held in locations behind a DC-8 multi-vortex field with a 1-percent (1.5-ft diameter) WVC size.
- Two thousand production runs conducted with the Falcon 20 held in locations behind a DC-8 multi-vortex field with a 2-percent (3.0-ft diameter) WVC size.
- Two thousand production runs conducted with the Falcon 20 held in locations behind a DC-8 multi-vortex field with a 3.5-percent (5.25-ft diameter) WVC size.

Core Size Parametric Study

Presenter: Michael Kelly
Date: October 5, 2012

Falcon Component	Maximum	Falcon Baseline*	DC-8 Vortex Core Radius (% span)** 1%	2%	3.5%
Right Wing	Normal Force, lbs	14,999	30,321	26,762	23,425
	Bending Moment, ft-lbs	151,921	335,771	287,860	243,776
Left Wing	Normal Force, lbs	14,999	29,943	25,145	21,914
	Bending Moment, ft-lbs	151,921	286,988	253,704	223,424
Vertical Tail	Normal Force, lbs	0	3,769	2,486	1,559
	Bending Moment, ft-lbs	0	12,005	7,332	4,379
	Total* Bending Moment, ft-lbs	0	13,278	9,120	6,180
Right Horizontal Tail	Normal Force, lbs	–864	–2,678	–1,948	–1,862
	Bending Moment, ft-lbs	–3,891	–10,702	–7,970	–7,641
Left Horizontal Tail	Normal Force, lbs	–864	–4,413	–3,067	–2,191
	Bending Moment, ft-lbs	–3,891	–16,817	–12,153	–8,876

* Falcon baseline = free air loads on a trimmed aircraft in 1G flight given weight, Mach number, and altitude.
** Total loads shown are baseline + vortex-induced loads.

Dynamic Simulations

Presenter Michael Kelly
Date October 5, 2012

To assess trajectories of Falcon after WVC encounter.

The team applied methods described in *Roskam's Airplane Design Part V: Component Weight Estimation* to *estimate* Falcon 20 moments of inertia for use in dynamic simulations.

- The Cessna 550 was chosen as the aircraft most similar *in configuration* to the Falcon 20.
- An FAA safety oversight group uses this same method to determine the critical parameter roll moments of inertia for WVC encounter safety assessments and has found it to be accurate to within 20 percent where manufacturer data are available.

Comparison Between Aircraft					
	MTOGW	Span	Length	Height	Wing Area
HU-25	32,000 lbs	53' 6"	56' 3"	17' 7"	450 ft^2
Cessna 550	13,500 lbs	51' 8"	47' 3"	15'	323 ft^2

Cessna 550

Dynamic Simulations

Presenter
Michael Kelly
Date
October 5, 2012

To assess trajectories of Falcon after WVC encounter, conducted 6 degree of freedom (DOF) dynamic simulations and generated trajectories for three key conditions:

1. Beginning with Falcon 20 nose in a 1-percent WVC.
   - Applicable to inadvertent FF descent into WVC.
2. Beginning with Falcon 20 wingtip near the WVC.
   - Applicable to inadvertent NF lateral drift toward WVC.
3. Beginning with Falcon 20 in sampling position behind the inboard DC-8 engine.
   - Benign condition.

Dynamic Simulations

Presenter
Michael Kelly
Date
October 5, 2012

Results:

1. Beginning with Falcon 20 nose in a 1-percent WVC; applicable to inadvertent FF descent into WVC.
   - Aircraft rolled away naturally, with maximum roll rate and angle consistent with DLR experience (90-degree maximum roll, 60-degree-per-second maximum rate).
   - See Sim_1.

2. Beginning with Falcon 20 wingtip near the WVC; applicable to inadvertent NF lateral drift toward WVC.
   - Results pending, to be described in the final report.

3. Beginning with Falcon 20 in sampling position behind the inboard DC-8 engine; benign condition.
   - Results pending, to be described in the final report.

Appendix I. ACCESS Pre-Experiment Technical Briefing (To DFRC Independent Review Team) February 8, 2013

The ACCESS team presented to a Dryden IRT. The NESC team participated to stay abreast of ACCESS test plans prior to beginning their experimental flight tests.

NESC pre-meeting "input" for each IRT question can be seen in the following spreadsheet. The ACCESS team's briefing charts are also included.

All questions were answered satisfactorily.

ACCESS Tech Briefing

31-Jan-13

RFA ID	IR Team Request	ACCESS Team Response	NESC Team Input
FRR-001	During near field testing a KIO is called when the coherent wake rolls up with the outer contrail, but that occurs aft of the HU-25. How visible is that location from the cockpit? Have any additional considerations for chase or exterior cameras been explored?	Video from the T-39 SUCCESS program showed that exhaust contrail and wingtip vortex rollup is visible in front of the aircraft before it is fully developed. ACCESS team intent is to KIO from pilot/copilot visual references before it is fully developed. The team has video from the SUCCESS program which shows how this technique will be used. SUCCESS used a B-757, the DC-8 differs in that there should be some outboard engine exhaust evidence that precedes inboard exhaust to provide an earlier observation to the pilots. The primary observer for reaching KIO visual criteria will be the PNF.	Unknown, have to be in cockpit to gauge field of view.
FRR-002	A KIO is called for if >50% sustained control input in the HU-25 in the wake. How is this monitored, and who is responsible for making the KIO call?	It is qualitatively monitored by the two pilots. Pilot flying would be the primary person responsible for recognizing over 50% sustained inputs. The PNF can also call KIO if he thinks inputs have reached that point. The aircraft has no control position sensors to allow any other crew member to know if this point has been reached.	Pilot Flying has best idea of % of control input; Pilot monitoring can back up if "following along" or "riding" controls. Consider IP defensive positioning by PM to block rapid, extreme movements.

FRR-003	Where is the specific required action during a KIO documented? In the near field is it a descent or is it based on visual cues based on the location of the contrails and the wake?	KIO exit maneuver will be situation dependent based on aircraft position to the vortex, visibility of the DC-8 and contrails, and existing control inputs when the KIO call is made. The expected action for near field will be to move down and towards centerline and for far field it will be to move up and then laterally outboard either side. A specific required action cannot cover every situation so it has not been written down but is understood to be based on pilot flying's judgment at the time, more than likely fitting into the descriptions above. Inadvertent wingtip vortex penetration and out of control recovery procedures are documented in the mission rules.	That's up to the project's mission rules. There could be an ascending level of responses based on what the crew evaluates they've experienced. Down and out in near field or up and out in far field seem to be the German practices. Post-KIO evaluation of possible damage or crew injury should be included to decide whether to resume research or abort.
FRR-004	What are the Handling qualities of the HU-25? Does it permit precise formation control without undo pilot work load? Is it used in a precision tracking mission in an operational environment?	The HU-25 operational mission has required formation flying with aircraft that range from USCG helicopters during SAR to airliners during air intercept missions. NASA LARC pilots have talked to USCG pilots regarding formation flying, but that conversation with operational pilots will never yield an answer to a Cooper-Harper like evaluation. Pitch sensitivity is mentioned in the flight manual, so LARC pilots have discussed techniques and will remain aware of PIO or high workload possibilities. There will be a TPS grad at all times in the cockpit who is knowledgeable in C-H evaluation and will remain	DAR and LaRC have the knowledge. LaRC answer is good. Since the primary concern is relative position to the wake, DC-8 position is secondary. Airspeed will be a factor in control sensitivity, there will be a best speed for control that will likely differ from the required speed for collection. As long as the PF can focus on outside scan primarily, the PM should handle everything else--navigation, comms, checklists. Each should advise the other if they feel they are getting behind the situation.

		cognizant of excessive workload when accomplishing the tasks.	
FRR-005	Is chase required or desired for helping with visual references?	Chase aircraft has never been either discussed or desired. A chase aircraft adds complexity and coordination for limited expected gain.	Concur with LaRC. Risk outweighs benefit.
FRR-006	How is aircraft relative position measured and monitored between the DC-8 and the HU-25?	Pilot visual references. Post flight analysis will provide precise positioning information for research purposes, but in-flight test conduct will be solely by visual reference to the aircraft and/or contrails.	Concur with LaRC. There is a brief learning curve for each new formation encounter, between different aircraft and pilot handling characteristics. Normally the wingman can quickly adjust without need for communication, as long as the lead is predictable and communicates airspeed/altitude/heading changes. In this case, contrail characteristics will change with density altitude and humidity, so there will be a brief learning curve there as well.
FRR-007	Where are the limits for what constitutes an RTB documented? If you get a flame out is that an RTB, what about if you accidently fly through the wake is it an RTB if you exceed 2.5g's or 65 degrees of bank and how would you know if you exceeded those limits?	We will be establishing exceedence criteria for maneuver KIO as well as exceedence criteria for RTB. This will be presented in the team brief to the IRT and documented in the test cards.	See my input to FRR-003

FRR-008	Has the communication protocol been documented? Are you going to say “Knock it off”, or “Abort”, are there multiple radio calls and what do all of them mean and what is the required action for each aircraft when the calls are made?	Protocols for formation and aircraft internal communications will be documented in the flight cards and briefed as part of the flight crew and formation briefing. The comm plan will be presented to the IRT during the team presentation.	Project owns this. It matters most that everyone involve AGREE to and USE the protocol, rather than the exact nature of the protocol.
FRR-009	Have you considered Hot Mic for the HU-25 to increase situational awareness to the DC-8 crew?	Hot mic between aircraft has not been considered. It is technically not feasible with the HU-25 current configuration. If DC-8 desires specific calls for SA, PNF can accomplish over radio.	LaRC answer is good. Hot Mic is voice-actuated rather than finger-actuated. Unless the pilot is familiar with the fraction-of-a-second delay in voice actuation (think of using your cell phone in speaker mode), the first word in a call may be lost using Hot Mic. In this situation, clarity is preferable over speed.
FRR-010	For laser operations is there a ground test hazard, and what are your mitigations? How powerful is the laser?	The DLH laser beam is not eyesafe within 2 meters of the window port. Ground hazard mitigation is denial of access to that area except by trained personnel wearing approved laser safety eyewear. The laser output power is nominally ~25 mW, but in practice we emit less than 20 mW through the window. Beam divergence renders the beam eyesafe by 2 meters. References are the Langley laser safety permit and the HU-25 specific hazard package. Dryden Laser Safety personnel have been provided the DLH laser specifics. Upon their review if they determine we need a separate permit for Dryden/DAOF one will be issued. The DLH laser is not required and will not be active during ground testing.	LaRC answer is good.

FRR-011	How much clearance between the measurement locations and the wake vortices is there? Just looking for rough magnitudes. Is it one HU-25 wing span is it 10 ft? How precise does the HU-25 have to be to stay out of the "dangerous" locations?	HU-25 wingspan = 54', DC-8 wingspan = 148'. Inboard engine is 26' off centerline and outboard engine is 45' off centerline. The HU-25 sampling the inboard engine would have some of the outboard wingtip in the outboard engine exhaust. The HU-25 outboard wingtip would be 47' from the DC-8 outboard wingtip. A receiver with precise visual references is able to maintain +/- 10' laterally while in contact. I'd expect our references won't be as good, and thus not as precise, but in close we would have to move 50' (about one HU-25 wingspan) laterally to get the vertical fin directly behind the wingtip.	I defer to LaRC. The contrail will put them in a slightly different position than the engine, and the wingtip vortex of course has some diameter based on distance from the aircraft. The clearance will be less than 50', but well within the ability to position the aircraft nonetheless. I estimate an experienced formation pilot will be able to maintain position in clear air within a 5 foot radius of the desired point in clear air, in close to the DC-8. In the exhaust, this will degrade due to buffeting, and I don't know how much. Looked like the DAR pilots concentrated more on following the exhaust pattern rather than staying in one spot.
FRR-012	In the far field sampling if you can see the separated exhaust plume but not the vortices would you still sample the plume?	It is a pre-requisite to observe separation between the wingtip vortex and the exhaust plume prior to sampling, therefore we would not begin far field exhaust sampling if we couldn't see the vortices below. Sampling in the exhaust does limit visibility, but knowledge of altitude separation has already been achieved. Visibility returns gradually when exiting the exhaust plume with enough visible warning to remain clear of the wingtip vortices. See DLR far field videos.	Good LaRC answer. They've adopted the DAR criteria which I believe is sound.

FRR-013	For dual engine failure (HR 2), how does a dual engine failure affect the other aircraft systems? Cabin pressurization, hydraulic feel system, electrical systems? Would it be critical to preserve battery backup to power down all the instrumentation system components or are they isolated from the battery backup by design? Any other considerations?	Note: APU cannot be run at these high altitudes, consideration is given to operating on battery power only until APU or engine relight. Cabin pressure will begin to increase as there will be no more inflow, outflow valves will close when cabin pressure can't be maintained. The leak rate will be investigated during our CFP flights. Hydraulic flight controls will revert to battery powered STBY pump, the feel is slightly sluggish but very controllable, without the STBY pump manual reversion is possible with greatly increased control forces. Electrical power will be from two batteries with a recent battery capacity check. There is an auto load shed function. Additional systems can be shed as well to reduce battery drain until an APU or engine is relit. Windmilling RPM was found in simulation to be over 300 KIAS so it is expected to need battery power for starter assist if at best glide speed. Instrumentation power is run through the load shed function and project acknowledges loss of research system power with loss of one or both engines. Battery power preservation is imperative as the APU and engines cannot be immediately started due to altitude restart limitations; auto load-shed, manual load shed and research power shutoff will be used to	I cannot overemphasize the benefit of practicing a total engine failure/loss of hydraulics/electric power in the simulator. I have direct knowledge of a P-3 crew that saved itself in this highly unique situation in March 1995. The copilot was an experienced instructor I had flown with in the P-3 training squadron, who had practiced this in the sim and prompted all the right actions in time (they regained control at 2,500 feet, otherwise would have had about 30 seconds to ground impact). Knowledge of what to do is good, but practicing the skills of doing it makes all the difference in time and preventing the situation from becoming uncontrollable.

		preserve battery power for APU/engine relight or flameout landing. The standby horizon Jetpack battery also powers the VHF1 radio usable through the handheld microphone. Battery capacity checks of the stby horizon and both aircraft batteries was accomplished week of 4 Feb 2013.	
FRR-014	What is your altitude tolerance for getting the data you want? If you have conditions for contrails at a different altitude can you test there instead for that day?	Our only requirement is to sample at altitudes where contrails form. We will be reviewing meteorological data and model predictions prior to flight to determine whether contrail-forming conditions exist over the Edwards AFB complex and if so, what the most likely altitudes are. When we arrive on site, we will have one or both aircraft spiral from 30 to 39 kft to determine the altitude range where the heaviest contrails form. Once established, we'll conduct a series of flight legs at those altitudes. If we find that contrails do not form anywhere within our experiment box, we will terminate the mission.	I'm glad they are not tying themselves to R-2508 airspace. This tendency for contrails to form or not should be identified as early as possible (like starting this month) to plan for the best location. On the day of the mission, there should be no doubt where the best conditions exist, just verification.

FRR-015	What are the rules for crew movement in the HU-25 during near and far field sampling? Can the instrumentation operator reach all of the racks/systems without getting out of their seat? Maybe it's considered standard aircraft operations, but I would have expected to see a mission rule or discussion in one of the hazards about it. Any PPE they should be wearing or gear they should carry?	Research crew will be securely belted into their seats with 4-point harnesses during all exhaust and contrail sampling. Instrument controls are arranged so that operators can control and make all necessary adjustments/calibrations while seated. Aircraft would need to stop sampling for any out-of-seat requirements. Researchers are required to wear flight suits by LARC policy. 100% oxygen is available at each seat position in addition to the passenger drop down masks. There are other specifications called out in the LaRC specific Hazard Package.	I don't know the internal arrangement of the HU-25 as modified, but if there are sharp-edged racks around, Nomex MILSPEC flight gloves provide a good ability to grip things without injury. Whenever researchers unstrap they should keep "one hand for yourself and one for the ship" as they move about. Each Center does what it approves, but I've found it's a good practice to simulate Fire of Unknown Origin in the cabin so the crew is familiar with that aircraft's procedure and knows how to assist when necessary, knows when to stay seated and quiet.
FRR-016	How was the HU-25's air data calibrated post mod, and how accurate do you expect it to be in the wake? Was this considered when discussing how the formation tolerances are maintained?	All modifications are outside the RVSM critical areas. We expect fluctuations in airspeed and altitude while in the exhaust. Once sampling, altitude is maintained visually and airspeed is no longer critical as we need to move aft to provide samples at multiple distances. There is no tolerance to maintaining a specific altitude or airspeed.	LaRC answer is good.
FRR-017	What g and vibration specifications were the racks and instrumentation systems on the HU-25 tested to? Are we confident that they are not likely to come loose during an upset, or have parts vibrate off while being buffeted in the DC-8's wake? I assume they are designed to the crash	The racks were designed to meet or exceed the crash load certification of the HU-25. FAR 25 crash load certification is 9 G forward, 2 G up, 4.5 G down and 1.5 G sideways. The rack weight and CG locations to meet the above crash loads were complied with. Additionally, installation of all components are inspected by Flight QA for compliance	LaRC answer is good.

	loads limits for the HU-25 which would be well above the limits for a wake encounter. What about other loose equipment that could fly around during an upset?	with processes, procedures and best practices. Crew will stow all loose items prior to start of sampling. All research additions will be inspected after each CFP flight.	
FRR-018	Is intercom on the HU-25 a mission critical requirement? If the intercom on the aircraft fails for whatever reason is that an RTB? It happens and I just wanted to make sure the team has discussed it.	IAW mission rule go/no-go list, intercom is a requirement between all crew/QNC.	LaRC answer is good.
FRR-019	Va = 220 KCAS for the HU-25 but there is a desire to get data at >mach = 0.7. That is pretty constraining from an altitude perspective. How is the decision made to go above Va for a test? Is there a buildup approach (didn't see any test point sequencing in the test plan).	It is not too constraining at the sampling altitudes of FL310-390. Va is 220 KIAS and T-storm penetration speed is 250 KIAS/.75M. If we can't maintain below Va, then flying up to gust penetration speed is allowable with reduced control inputs. For reference: FL310 .7M = 257 KIAS and we'll sample slightly slower than .7M and remain below gust penetration speed but at FL390 .7M is 214 KIAS and we can sample at .7M and also be below Va. There is no buildup approach mentioned because of such a small overlap of speeds between the DC-8 and HU-25. Build up in one area often conflicted with safety aspects of another (i.e. max altitude best for engine out glide but worst for FQ). The build up approach we are using is to have a practice sortie before a data sortie.	LaRC answer is good. The faster you fly, the smoother and gentler you need to be with control inputs. They know this, but one actually has to get bounced around at high speed to internalize it. Most pilots upon first encountering moderate buffet in formation react by 'holding what they've got' at first, which is good for the airplane. Going through a buildup will get their muscle and long-term memory in good shape for this.

FRR-020	I would recommend a mini-tech after the pre-experiment build up flights to access the workload of the vortex avoidance procedures, and show pictures/video of the regions you intend to test in.	Pictures and videos exist from T-39 SUCCESS and DLR FA-20 sampling activity. Our procedures are built upon these techniques and lessons learned. Test team has a responsibility to terminate testing based on any safety issue which will include a lack of correlation to expected visual cues. Any safety termination would generate a new briefing to the board. This includes safety issues discovered during the pre experiment sortie.	LaRC answer is good. I would recommend a structured crew and test team debrief after every flight to compare inflight findings and impressions of controllability, new environmental knowledge…does the test plan or procedures need any changes? I'm sure they're already planning to do this.
FRR-021	In the far field how is it determined that the vortices are ~300 ft below the sampling aircraft?	By flying abeam the contrail, we intend to vary HU-25 altitude so as to provide an assessment of the altitude difference between the exhaust trail and the remaining vortices. By looking aft when laterally positioned, HU-25 crew can determine that the separation continues to increase with aft distance.	LaRC answer is good.
FRR-022	Are the altitudes specified in the test plan for the lead aircraft or the trail aircraft? Will the lead aircraft be asked to maneuver to allow the sampling aircraft to sample at particular altitudes?	The specified altitudes are for the lead aircraft. The contrail system can either descend or ascend, depending on meteorological conditions, so the Falcon will have to adjust its altitude to sample exhaust emissions while avoiding the trailing vortices. The lead aircraft will only be asked to change altitudes once a successful run for both JP-8 and Blended fuels is accomplished. During any run, the DC-8 will remain fixed at the same altitude.	LaRC answer is good. As I recall they'll elevate to save fuel if they can remain in contrail conditions or get to better conditions.

FRR-023	Any WATR support requirements? Radar, video …	No.	I understand this to be Western Aeronautical Test Range, which has extensive tracking capability.
FRR-024	What format is the data from the DC-8 given to the LARC team?	Post mission data from the DC-8 should be in the standard "REVEAL", 1-second averaged format. Needed parameters include: Static Air Temp, Static Air Press, Mach #, True Air Speed, Palt, GPS_alt, horizontal winds, GPS Lat and Lon, pitch, roll, true heading, platform heading, etc.	LaRC answer is good.
FRR-025	How does our pod design differ from the DLR design, and the AFFTC pod design? It sounds like AFFTC departed their vehicle in part due to a pod design.	The departure from controlled flight during AFFTC's testing (full rudder SHSS) was attributed to the Side Looking Airborne Radar (SLAR). This SLAR pod was very large and attached well forward of the CG on the right fuselage below CL and stretched from the wing leading edge to the copilot's window. Our configuration has no SLAR pod and the wing pylons and stores will be different. The USCG stores are much larger, heavier and had more drag that the CAPS probe being installed in the NASA HU-25. The DLR Falcon can carry up to 5 pylons, one centerline and two-each wing pylons. The stores they carry are similar to our CAPS probe. For drag reduction, we intend to fly with one pylon only as FQ reports for varying pylon configs (one vs. two) did not result in any negative FQ	LaRC answer is good. I don't have their buildup plan, but I expect they'll evaluate how the HU-25 handles differently in critical situations (engine loss after takeoff, just prior to landing).

		properties (ref AFFTC P&FQ test report).	
FRR-026	Do the HU-25 onboard research instruments contain any hazardous chemicals that could present a risk during ground operations that ground crews should be aware of? I assume that the flight hazards have been addressed by the LARC process.	The payload includes small amounts of butanol (contained within instruments), several high-pressure calibration gas cylinders, and a small alpha-particle radiation source sealed within a metal cylinder. MSDS sheets for these items are available onboard the aircraft. All chemical hazards have been reviewed by the ASRB, an industrial safety engineer and aircraft inspectors. Mitigations are in place to prevent harm to flight and ground crews. All high pressure gas cylinders were below the max permissible exposures (MPE 8hr).	LaRC answer is good.
FRR-027	According to the discussion transcript, DLR had a wake encounter at 20 nm which almost departed the vehicle and caused a roll departure beyond the published aircraft limit. They also had a single engine failure/flame out. I would consider these to be “close calls”, were any procedures modified to minimize the probability of this occurring during	The Joint Flight Test Planning team was chartered specifically to evaluate these risks and develop specific mitigations and procedures. The result is the 11 joint hazards and mission rules document. Since DLR did not have any hazards analysis or written procedures, no DLR procedures were modified but NASA procedures were developed with as many mitigations that were	LaRC answer is good. A Boeing test pilot barrel-rolled a 707 at low g and proved it to everyone.

	the NASA test missions?	deemed feasible. Dassault does not publish a bank angle limit, so DLR did not go beyond a published limit, recovery from their event was natural and G-load was never an issue. The bank angle limit can only be found in the USCG Dash-1. NASA LARC has eliminated the bank angle limit via our NASA flight manual supplement in order to be consistent with Dassault documentation. As long as the G-limit is adhered to, bank angle need not be limited. Intentional aerobatics are not authorized. The aircraft has a G-meter to monitor G-loads during any unintentional encounter or recovery.	
FRR-028	DLR communicated that they feel these tests would be dangerous if they were to use their G-550, which is a similar class airplane, due to its T-tail configuration, suggesting that there is some residual risk even with the procedural mitigations in place. Their testing used at European Falcon 20, are there any configuration differences between NASA's HU-25 and DLR's Falcon 20 that could cause any additional concerns, such as airframe hours, other modifications done to our airframe, different engines …	There are configuration differences between their Falcon-20E and our Falcon-20G but the cruciform tail is similar in size and shape. The G-model has higher thrust engines, higher GW allowable, auto-slats, dual environmental control units, a different APU, greater slat span, smaller mid-wing stall fence, an autoslat function, more rudder authority and a higher maneuver speed. It is also similar to the FA-200 series aircraft. Our G-model is about 5-8 years younger. It has 15,500 hrs. The one difference that has been discussed and evaluated during simulator recoveries is that the engines have special throttle limitations above 28,000' which require slow and deliberate action,	LaRC answer is good. Should be able to leave power alone at first during most recoveries, just reduce it if in a dive. Lots of altitude to play with.

		there is no specific mitigation we can determine that alleviates this high altitude engine behavior.	
FRR-029	DLR noted that there is decreased visibility when in the exhaust plume of the lead aircraft. Does this present any additional risk to our ability to see and avoid the aircraft wake?	Lower visibility in the contrail will affect ability to see the DC-8, but at that point we will be aft, and trending further aft. The wingtip vortex characteristics will be visible in front of the HU-25 in the contrail prior to it being fully entrained. This is clearly visible in the videos with adequate cues to terminate sampling prior to reaching a state of full entrainment.	I think you really don't know this until you try it. Sun angle, etc.
FRR-030	What speeds are the near field tests planned? Are there any mission rules for KIO's when relative speeds between the two aircraft are too great (drifting aft quickly would make seeing and avoiding the wake vortex more difficult)?	We are targeting .7M. The aft drift rate will be a natural result of the exhaust velocity with limited power available in the HU-25 to compensate. There are no mission rules for KIO due to relative airspeed. Minimum sample time is 10 sec, and T-39 video shows 30-45 sec of sampling before reaching a vortex KIO criteria. Formation briefing will include breakaway procedures to quickly change a forward closure rate to prevent mid-air collisions. Formation briefing will also require DC-8 pilot to call any airspeed changes >5 kts.	LaRC answer is good.

FRR-031	In the dash-1 (pg 204) the aircraft has OAT limitations (low temp) I assume that we have looked at those temperatures and compared them to the temperatures at altitude for EDW.	EDW high altitude temperatures rarely impact jet flight operations. The DC-8 and HU-25 have very compatible temperature limits at high altitude, nearing -70 deg C. Feb 5th's temp at FL420 was -55 deg C. Both aircraft have successfully operated in the arctic and and/or Antarctic regions at much colder temperatures than anticipated at Edwards.	LaRC answer is good.
FRR-032	Is there a cooling cart requirement for the com/nav system of the HU-25 for ground testing? Pg 750 of the dash-1 gives a 5 minute limit without cooling. What about for the experiment systems, how are they going to be cooled during ground ops? Is there a concern for how hot the cabin of the HU-25 would be without cooling? I know it's cool outside at EDW in the winter, but I'm just wondering should we have a hot day, are there any concerns?	There is no requirement to cool the Falcon during ground operations since aircraft avionics are not required and will be off. The limitation is due to the enclosed aircraft avionics rack and not the research equipment. Ground tests of the DC-8 will be conducted in early morning under cold conditions. If hot conditions are encountered during pre-flight, research instruments will not be turned on until after takeoff.	LaRC answer is good.
FRR-033	What are the expected effects of the wake on the airdata system? Has the effect on the artificial feel system been considered?	Expected air data effects in the exhaust are that of gusty wind conditions. The Arthur-Q system is either in a high speed or low speed feel. The effect on the artificial feel system is that a gust could interrupt a transition from one setting to the other and be mismatched. Lingering at speeds near the transition point (approximately 260 and 180 kts) during normal cruise can produce this mismatch.	LaRC answer is good. Buildup program important to this.

		It is expected most sampling speeds will be below the transition speed and if the Q-units are stuck in high speed mode, control forces would be higher. There are procedures in the Dash-1 that allow for continued flight only if the mis-match can be eliminated, otherwise an RTB fully understanding the remaining HQ changes is prudent.	
FRR-034	Does engine failure cause a hydraulic failure on 1 or more systems? A hydraulic failure puts the feel system into landing/low q configuration which makes the aircraft more sensitive to pilot commands. The dash-1 mentions PIO risk on pg 709 in the horizontal stabilizer section.	Engine failure causes the corresponding side hydraulic system to be inop. There is a standby electric pump that can give 2,000 psi vs. the normal 3,000 psi to either side as required. This is enough to operate all systems to recover to a normal landing. The procedure for Q-unit failure is to get below 260 KIAS/.76M, which is where most of our sampling speeds will be. Thus, if an engine failure occurs, it is likely we are already at a safe airspeed and if not, we would not be able to maintain high airspeed and desire would be to slow to 180 kts and drift down until restart is attempted.	LaRC answer is good. My FRR-013 input is germane.
FRR-035	Does flying in the contrail increase the likelihood of an airdata failure on the HU-25? Icing/feel system considerations?	Control feel considerations mentioned above. Icing not anticipated due to the dry nature of any ice particle at those altitudes. Pitot/Static heat is meant for much greater icing accumulation hazards. Easy to exit those conditions if they were present and would recover fine for landing. The changes in feel do not change aircraft stability	LaRC answer is good.

		characteristics but pilots are cognizant of PIO possibilities if there is a Q-unit mismatch.	
FRR-036	In the event of a dual engine failure does the battery power the electric trim actuator for the horizontal stabilizer?	Yes.	LaRC answer is good.
FRR-037	Autostart for the engines is mentioned in the dash-1. What is the autostart mode? Is this a mode that can be turned on for testing where engine outs are more likely? 747's (SOFIA) have an igniter that can be turned on when we are doing reduced normal acceleration maneuvers that during normal aircraft operations was left off.	One ignition select switch provides the continuous ignition and autostart modes. Autostart mode simplifies pilot duties during a ground or flight start and is the normal flight position unless contaminated runways, turbulence or icing is present in which case continuous ignition is used. A single press of the start button when in autostart mode motors the engine with throttle in cutoff, provides ignition with throttle out of cutoff and disengages the starter and ignition upon idle RPM. The mode we will use during sampling is "Ignition Select - ON" so that a flameout has the best chance of relighting on its own. There is no time limit for continuous ignition (the windmilling airstart position), but the pilot will physically need to move this switch for a starter assisted airstart. "Ignition Select - Autostart" (middle position) would be used if a flameout actually happened and a pilot initiated relight was required.	LaRC answer is good.

FRR-038	Pg. 642 of the dash-1 says to "land as soon as practical" after a compressor stall even if the engine recovers, and land as soon as possible if it does not. Is it an RTB for us if a flameout/compressor stall recovers, and would you land away from the DAOF if it did not? Do we have procedures in place for offsite landings (this is probably more of a normal ops kind of thing for DC-8 and the HU-25 than Dryden's research F-18's and F-15's)?	We would terminate sampling upon any compressor stall and RTB for a compressor stall/flameout that required pilot action in order to recover/relight. If both engines are operating, we would land at DAOF. If an engine has flamed out/been shut down and cannot be restarted, the landing field will be at the PIC's discretion based on current altitude, SE driftdown altitude, and dual engine out gliding distance. An actual SE scenario might require landing at China Lake, Mojave or Edwards if more appropriate (i.e. fire, winds aloft). The Falcon 20 was designed to operate from fields with limited support, thus no HU-25 specific offsite landing procedures are needed. The R-2508 alternate fields (KBIH, KNID, KMJV, KEDW) have been evaluated for suitability (runway length, width, crash/fire, etc.).	
FRR-039	Does the fuel state affect the probability of an engine stalling or affect the ability relight it? Should considerations be made for when in a flight to do the maneuvers with the highest risk of upsets?	There is no flight manual information on fuel state vs. engine behavior or relight capability. Fuel is normally moved automatically from AUX - WING - FEEDER tanks by electric pumps and valves and/or differential pneumatic pressure. The feeder tanks can be selected at either mid or full with mid-level as the normal position for HU-25 flight. The feeder tanks directly feed the engine with adequate transfer from either boost pump or	fuel state vs. aircraft attitude matters

		pneumatic air with crossfeed option from the opposite boost pump. The risk of upset is similar regardless of when a data run is performed in the profile.	
FRR-040	Are the auto slats going to be on or off? The dash-1 says to pull the CB for the auto slats if an air data failure is suspected and you are above 220KCAS. Could the wake cause what looks like an airdata failure	Autoslats are normally on. The "air data failure" referenced in the question is a loss of slat sensor redundancy. The note allows for continued flight with the CB pulled if above 220 KIAS so as not to have the slats come out at high speed and cause damage. This can happen if another sensor fails. Caution is needed with the CB pulled as the clean stall speed is now about 10 kts higher. This would be a satisfactory configuration for sampling since we'll be at speeds well above stall and have sufficient altitude to recover. Slat/Speed Protection light is common with the HU-25 fleet and has happened with our HU-25. Sampling with this CB pulled will be allowable, our checklist ensures that it is reset for landing.	LaRC answer is good.
FRR-041	Mission rules for ground tests are not captured in the mission rules document. Any procedural items counted on for hazard mitigation for ground operations should be captured in place where they are sure to be highlighted in all crew briefs.	The unsigned draft reviewed by the IRT only had TBD under hazards. All the hazards associated with the ground test are now incorporated in the signed Ground Test Document as well as the approved hazard forms. There are no Mission Rules associated with the ACCESS Ground	LaRC answer is good.

		Tests. Pre-Test briefing for the Ground Test will focus attention to the hazards, safety, and communication plans. The Ground test procedure has captured all hazard mitigations.	
FRR-042	What are the standards used for COTS equipment acceptance for the HU-25 aircraft environment?	COTS research equipment is evaluated as part of the LARC engineering review process for safety but not mission assurance. Mechanical attachment provisions are evaluated against the FAR 25 emergency landing loads by mechanical/structural engineer and inspected by QA. Electrical provisions external to COTS equipment are designed by electrical engineers and inspected by QA. Provisions for circuit protection and emergency research equipment power cut-off are provided by the aircraft's research system infrastructure and controlled by the pilot through a power enable switch.	Who accepts the risk? Permit?
FRR-043	Where is emergency equipment located in reference to onboard personnel?	Walk-around 100% oxygen bottle and quick-donning mask is located by the forward researcher seat, all other seats have 100% crew oxygen available. Passenger cabin also has 5 drop down masks. Fire extinguisher by exit door and cockpit. Crash axe in cockpit. Grab-n-go survival bag containing life support equipment by exit door. A first aid kit is in the cabin. Removable ELT affixed to aux tank accessible to crew from cabin.	LaRC answer is good.

FRR-044	Are the aircrew solely responsible for addressing onboard emergencies aft of the cockpit, or are other personnel also trained for that duty?	Researchers will be briefed on crew communication, emergency egress and emergency equipment operation. Onboard emergencies are the pilots' responsibility, but recovery from an in-flight emergency is enhanced by research crew awareness of emergencies and how to assist the PIC if directed.	Good to brief and practice the inflight cabin fire and emergency egress on the deck.
FRR-045	Is there any intent to modify the ACCESS systems while at the DAOF?	We will not modify ACCESS system design while in the field. Failures or malfunctions may require removing instruments from the HU-25 (or Mobile Laboratory) and bringing them into the DAOF for troubleshooting and repair. The instruments will then be reinstalled and inspected by HU-25 crew before flight. The Dryden manager assigned to the ACCESS project (Chris Jennison) has Payload Information Forms (PIFs) for both the Falcon and Mobile Laboratory and should be aware of all equipment that could potentially be brought to the DAOF. The Falcon payload is a subset of the equipment Langley installed on the DC-8 for the recent DC3 experiment.	LaRC answer is good.
FRR-046	For the JP-8 and Blended Fuel tests, where are the separate tanks located? And which fuel is in which tank?	DC-8 Center AUX tank has the blended fuel. All other tanks will have JP-8. HU-25 will always fly with JP-8.	LaRC answer is good.

FRR-047	Explain the communication plan between aircraft when airborne for these evaluations.	The comm plan will be presented in the ACCESS IRT brief by the project team.	OK
FRR-048	Who leads the tests?	The HU-25 is the test aircraft and the DC-8 is the support aircraft. In flight card management and test conduct will be maintained by the HU-25 crew and principal investigator. DC-8 will be the formation lead and have navigation and ATC communications responsibilities.	LaRC answer is good.


National Aeronautics and Space Administration
NASA
ACCESS Flight Experiment
Independent Review Team Briefing
Dr. Bruce Anderson, Principal Investigator
Brian Beaton, Integration Manager
Greg Slover, Falcon Pilot
Troy Asher, DC-8 Pilot
Clint St. John, Chief Engineer/DRFC
Matt Berry, Operations Engineer/DRFC
Michelle Berger, Safety Engineer/DRFC
Gary Martin, Project Manager/DRFC
February 8, 2013

IRT Briefing Agenda

- Objectives of the proposed flights
- Flight Plan CONOPS
- HU-25 Configuration
- Control Room Operations
- Mandatory Requirements
- Accepted Risk List
- Open Items

2

ACCESS Flight Experiment

ARD

- The purpose of the Alternative Fuel Effects on Contrails and Cruise EmiSSions (ACCESS) Flight Experiment is to characterize fuel effects on aircraft contrails and cruise missions.
- Ground based tests have shown that alternative fuels greatly reduce emissions parameters. However, there is very little data to relate ground-based emission parameters to cruise altitude emissions. Data from this flight experiment will help address whether alternative fuels similarly reduce emissions at cruise altitudes and affect contrail formation/properties.
- The DFRC DC-8 will be the lead aircraft burning standard and alternative fuel blends and either an instrumented LaRC Falcon HU-25C will fly behind the DC-8 taking detailed emissions measurements.
- A Joint Flight Operations Planning Team has been formed to develop concept of operations, experiment test plans, and identify safety hazards/ mitigation plans.
- Developing Experiment Implementation Plan to be presented to GRC PRB and LaRC CMC.

3

Previous Airborne Emissions Tests

NASA – all same PI as ACCESS

- Subsonic Assessment Near-Field Interactions (SNIF-1), Summer 1995
  - Sabreliner sampled NASA B737, P-3B, and C-130 over east coast
- Subsonic Assessment Near-Field Interactions (SNIF-2), Winter 1996
  - Sabreliner sampled MD80, B757, B747 in east coast flight corridors
- Subsonic Assessment Cloud and Contrail Effects Special Study (SUCCESS), Spring 1996
  - Sabreliner sampled NASA DC-8 and B757
- Subsonic Assessment Near-Field Interactions (SNIF-3), Summer 1997
  - Sabreliner sampled ANG F-16s over Vermont and New Jersey

German Aerospace Agency (DLR)

- SULFUR flight series, mid 1990's , Falcon 20 sampled ATTAS, A310, A340, B707, B747, B737, DC8, DC10
- Pollution from aircraft emissions in the North Atlantic (Polinat), Falcon 20, late 1990's
- CONCERT—Falcon 20, various aircraft, 2009-2011
- **Lufthansa flight experiment, Falcon 20 sampled an A380 with bio fuel, Spring 2012**

NRC Canada

- Wake/Vortex Dynamics Measurements — T-33 sampling commercial and military A/C
- Alt Fuel effects — T-33 chasing military A/C burning biofuel

ACCESS Flight Experiment

ARD

Lead Aircraft: DC-8

Weight: 280,000 lbs

Wing-span: 148 ft

Engines: four turbofans, wing mounted

Sampling Aircraft: HU-25C Guardian

Weight: 28,000 lbs

Wing-span: 53 ft

Engines: two turbofans, fuselage mounted

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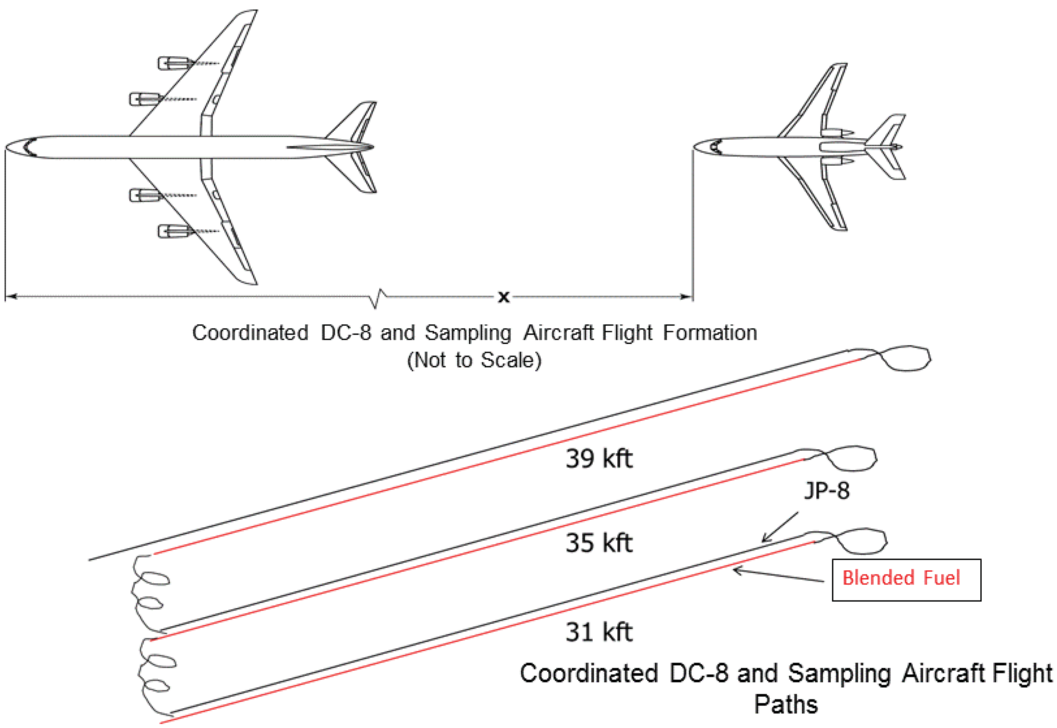
Flight Operations

- Project flight test plan per Langley's Flight Test Operations and Safety Report (FTOSR)
  – Instrument check flight per Langley ASRB
  – Calibration flight per Langley ASRB
  – Build-up practice flight per DFRC Tech Brief
  – Sampling flights per DFRC Tech Brief

- Sampling and practice sortie CONOPS
- Flight Test Techniques
- Lessons Learned & Past Videos

6

Joint Flight Operations



DC-8 non-normal Operations

- Fuel Loading Checklist
  - Created a fuel loading checklist to cover the upload of JP-8 Fuel and HEFA/JP-8 Fuel mixture to minimize cross contamination
  - Checklist also assist the FE with the Pre-flight checks
- Fuel Switching Checklist
  - Created a Fuel Switching Checklist to get us “on and out of condition” during the Flight Phases
  - This is also ensures we use JP-8 for Takeoffs, Landings, and during transitions between test points

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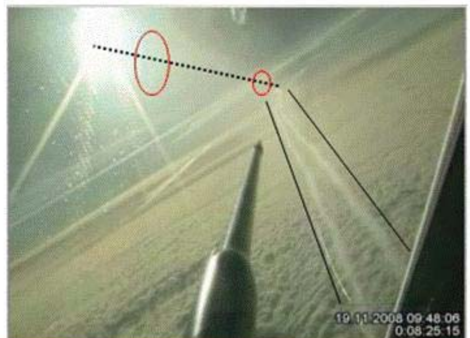
Flight Test Techniques

- Near Field
  - Sample DC-8 inboard engine only, maneuver IAW air refueling techniques
  - Start when exhaust contrail visible and safe nose/tail clearance obtained
  - Sample in exhaust for 10-sec minimum, 20-sec desired
  - Speed < gust penetration speed (250 KIAS/.75M) required, < maneuver speed (220 KIAS) desired
  - Knock-it-off when:
    - Contrail no longer visible
    - Flight control authority requires 50% sustained input (any axis) for station keeping
    - Visible evidence of start of wingtip vortex roll-up on inboard contrail
    - Aircraft systems malfunction
    - Turbulence moderate or greater in free air
  - Exit by climb or descent until clear of vortex, then move laterally when safe

- Far Field
  - Sample any residual exhaust from any/all engines
  - Start from lateral position when exhaust plume separation from visible vortices is present and ~300 ft vertically (expected ~ 1.5 - 2 nm in trail)
  - Sample at multiple distances as long as conditions permit
  - Speed < gust penetration speed (250 KIAS/.75M) required, < maneuver speed (220 KIAS) desired
  - KIO criteria same except visible roll-up not present during far field
  - Exit by climb up and away from contrail, then laterally to side

Lessons Learned from DLR Pilots

Within the contrail



Exiting the contrail

Close in, no wake turbulence developed

Credits to pilots Roland Welser and Stefan Grillenbeck, DLR

In-Flight Video

- T-39 near-field video
- DLR far-field video

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HU-25 Configuration

- External Modifications
- Internal Modifications and Arrangement

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ACCESS HU-25 additions

ARD

External Modifications Made to the HU-25:

1. Crown Installation
   a) HIMIL Aerosol Probe
   b) Cloud Droplet Probe
2. Nadir Plate Installation
   a) Venturi Assembly
   b) Diode Laser Hygrometer (DLH) "Shark Fin" Assembly and associated wing target
   c) Fast Response Temperature Probe
3. Wing Pylons
   a) Droplet Measurement Technologies Cloud, Aerosol and Precipitation Spectrometer (CAPS) probe

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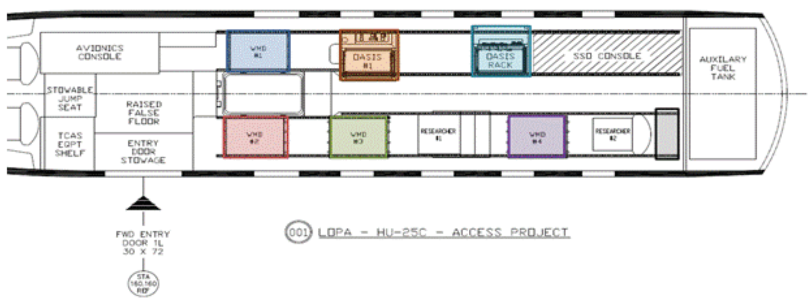
ACCESS HU-25 additions

ARD

Internal Modifications Made to the HU-25Aircraft:

1. Six (6) Research Equipment Racks
2. Rack-mounted components associated with the NASA Langley Aerosol Research Group Experiment (LARGE)
3. Gas cylinders (5) and Diaphragm Pump
4. Video Camera
5. Research power upgrade
6. Ballard Technologies Avionics Bus Box
7. Applanix 510 unit



Control Room Ops

- No control room required or used

Mandatory Requirements

- Mission Rules
- Operating Limitations
- Weather Constraints
- Calls
- Required Documentation
- Go/No-Go List
- Hazard Reports

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Mission Rules

(hazard mitigations during test execution)

HU-25 basic mission rules:

- Flight shall not be conducted if severe weather (LARC-027, 030)
- Flight planned for no greater than forecasted moderate turbulence (LARC-009, 015)
- Icing Restrictions (LARC-028)
  - Plan missions to:
    - Avoid forecast or reported icing conditions when practical.
    - Do not plan to cruise in forecast or reported moderate or greater icing;
    - Do Not plan to climb through forecast moderate icing for more than 5-min. or to climb through reported moderate icing.
    - Do not plan any flight segments in forecast or reported severe icing or freezing rain.
  - If ice accumulation occurs in flight, the following restrictions apply
    - Trace – no restrictions.
    - Light – no more than 30 minutes, exit light icing conditions when practical.
    - Moderate or greater – immediately exit the icing conditions.
- Researchers shall wear seat belts whenever aircraft in motion unless cleared by PIC (LARC-009, 029)
- Notify pilots if smoke/fumes are detected (LARC-012), if NO/CO/CO2 bottle failure suspected (LARC-039, 040, 041) or if alcohol is smelled or liquid observe (LARC-013) and don oxygen if directed.
- No filling of the alcohol reservoir in flight (LARC-013)
- Non DC-8 formation (calibration flight)(LARC-038):
  - Pre-mission formation briefing shall include at least one pilot from each aircraft conducted either in person or by telephone.
  - Flights shall be in Day/VMC.
  - Altitude and airspeeds shall be planned within performance capabilities of both aircraft
- Sampling of non-participating aircraft (LARC-037):
  - Sampling of non-participating aircraft shall be at or greater than standard IFR separation;
  - Pilots shall comply with see and avoid requirements of 14 CFR, section 91.113;
  - During research flight operations pilots shall have communications available with ATC having jurisdiction over airspace during operations

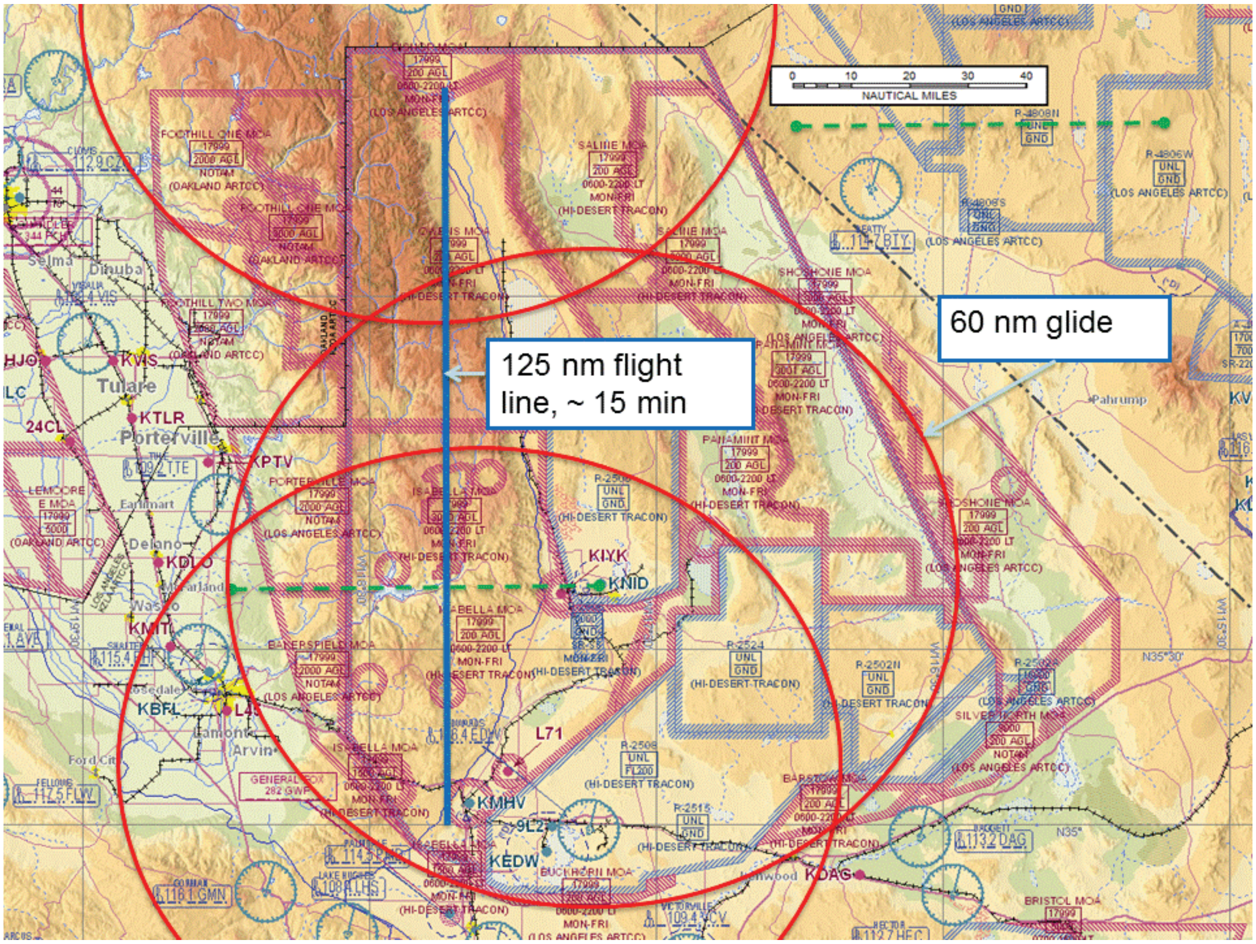
Mission Rules (cont'd)

- Joint HU-25/DC-8 mission rules (summarized):
  - Fly at or above engine restart envelope
  - Safe altitude above cloud ceiling tops to allow for recovery from departure
  - VMC with discernible horizon
  - HU-25 min crew when in close proximity to wake
  - Do not intentionally penetrate wingtip vortex
  - Visible contrails required to allow for visual acquisition of wingtip vortex
  - Gliding distance of suitable landing surface when wingtip vortex encounters are possible
  - No greater than light turbulence as determined in free air
  - Formation crews qualified and briefed
  - Far field sampling < Va when practical
- HU-25 Pilot responsibilities
  - PF: terminate sampling if self-acknowledging any KIO criteria, comm w/ DC-8
  - PNF: monitor systems, monitor visual contrail vs. vortex, back-up on control deflections, comm w/ ATC
- DC-8 crew responsibilities
  - ATC communication, rendezvous, monitor free air turbulence, monitor divert field weather

R-2508 Suitable Airfields

- HU-25 min runway length required – 5,000’
  - Dual engine flameout emergency ~7,500’
  - Gliding distance from FL310 ~ 62nm, up to 85nm at FL390

- Palmdale (KPMD)
  - RWY 07/25 – 12,000 x 200’
- Edwards (KEDW)
  - RWY 04.22 – 15,000 x 300’
- Rogers Dry Lake (KEDW)
  - Multiple runways exceeding 15,000’
- Mojave (KMHV)
  - RWY 12/30 – 12,500’ x 200’
- China Lake (KNID)
  - RWY 03/21 – 10,000’ x 200’
- Bishop (KBIH)
  - RWY 12/30 - 7,500’ x 100’


125 nm flight line, ~ 15 min
60 nm glide
0 10 20 30 40
NAUTICAL MILES
KMHV
KEDW
KNID
KIYK
KBFL
KDAG
KTLR
KVIS
Tulare
Porterville
L71

Operating Limits and RTB/KIO criteria

1. System Limits: KIO and RTB if an inoperative system is included in the mission rule go/no-go list even if Dash-1 states "continue flight as appropriate" in Section III.

2. Engine Limits: We will KIO if compressor stalls occur while sampling. If a compressor stall self clears without pilot action and has normal throttle response, it will not require an RTB. Any compressor stall that requires pilot action to recover or throttle response is abnormal will require an RTB. Any flameout will require an RTB.

3. Maneuver Limits: KIO and RTB in event of inadvertent wingtip vortex encounter as determined by the HU-25 pilot(s). Regardless, KIO and RTB for excursions exceeding 0.0 to +2.0 G, 135 deg bank, 10 deg pitch change or +/- 2,000' of altitude deviation prior to pilot initiating a controlled recovery. Note: mission rules drive a non aggressive response to any upset, recovery should not force an aggressive technique in order to remain within tight limits for RTB.

4. Flight Control Limits: KIO and RTB in event of full control deflection used above Va during any phase of flight.

5. Emergencies: KIO and RTB if EP exists where Dash-1 direction is to land immediately, as soon as possible or as soon as practical (except for self clearing engine stalls during sampling).

6. Flight Manual Limits: KIO and RTB in event of exceeding any flight manual operating limit. Note: 65 deg angle of bank is not a NASA flight manual limit.

Weather Constraints

IAW both LARC and JOINT hazard packages, summary below.

1. Sampling airspace must be day only with discernible horizon and VMC conditions above any broken cloud deck to allow for VMC recovery from unusual attitude or upset (planning 10,000').
2. VFR conditions for planned flameout landing fields.
3. Crosswind limit of 20 kts at KPMD and planned divert fields.
4. Basic HU-25 flight will avoid severe weather and greater than moderate turbulence. Sampling is limited to light turbulence only (excludes exhaust induced turbulence).
5. Icing restrictions as below:
   1. Plan missions to:
      a) Avoid forecast or reported icing conditions when practical.
      b) Do not plan to cruise in forecast or reported moderate or greater icing;
      c) Do Not plan to climb through forecast moderate icing for more than 5-min. or to climb through reported moderate icing
      d) Do not plan any flight segments in forecast or reported severe icing or freezing rain.
   2. If ice accumulation occurs in flight, the following restrictions apply
      a. Trace – no restrictions.
      b. Light – no more than 30 minutes, exit light icing conditions when practical
      c. Moderate or greater – immediately exit the icing conditions

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Radio/Intercom Calls

IAW Draft DFRC control room communication plan; modified for intra- & inter-plane communications

- Hold – Researcher to HU-25 pilot to hold conditions or either aircraft to request the other to hold conditions
- Copy – response acknowledging radio or intercom call (alternatively "Roger")
- Acknowledge – speaker's request for formal response
- Terminate (state reason) – Stop test using normal means, if in exhaust exit exhaust; call made by any crewmember of either aircraft for data quality, weather, traffic conflicts, loss of go/no-go criteria, aircraft system malfunctions or other non-vortex issues
- Knock-it-off (state reason) – Immediately exit the exhaust/wake/vortex using normal or EP recovery control protocol as appropriate; instruction transmitted by any HU-25 crew or QNC, used for exiting any inadvertent wingtip vortex encounter or reaching any KIO criteria

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Radio/Intercom Calls (cont'd)

- Recover – PNF call to PF that HU-25 is clear of wingtip vortex hazard and normal smooth recovery controls can be used
- Breakaway – Action for DC-8 to increase thrust to MCT and accelerate in level flight and HU-25 to decrease thrust to idle and use airbrakes to decelerate until a safe longitudinal distance is achieved and descend (near field) or climb (far field) until safe altitude is achieved; called by any crew in either aircraft for collision avoidance or onboard emergency
- Breakout – Action for HU-25 to break out of wing formation; called by DC-8 crew to direct a breakout or by HU-25 crew to announce action already taken
- On conditions – Either DC-8 or HU-25 pilot stating they are in the briefed position with all pre-sampling checklist steps complete
- Cleared to sample – DC-8 crew authorization to HU-25 to begin sampling
- (Near/Far field) complete – HU-25 crew communication indicating when either near field or far field sampling is complete for any run
- UnderRun- Either DC-8 or HU-25 pilot; called by the DC-8 crew to command an underrun or by the HU-25 pilot to advise of an underrun on a rendezvous
- Cleared(or Request) Rejoin (Position)- DC-8 crew authorization for the HU-25 to join in formation in the specified position. Requested by the HU-25 to specify the position for the DC-8 crew

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Required Documentation

- Ground Test Plan
- FTOSR
- Flight Cards w/ EP/recoveries included
- DC-8 fuel loading and in-flight DC-8 switching procedures
- Joint Mission Rules
- Joint Hazards
- Langley HU-25 Hazards
- Flight manuals and NASA supplements

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Go/No-Go List

- Decisions: Safety (PIC), Science (PI), Programmatic (PM)
- Go/No-Go Instrumentation List
  - HU-25 G-meter, Altimeter, ADI
  - No Flight Safety research instrument are Go/No-Go items
  - Mission Critical Go/No-Go (real time decision by PI in aircraft)
  - Aircraft Systems per Mission Rules Document

Parameter Classification		
MC	Mission Critical –	
No.	**Falcon-20G Systems**	**Class**
1	Fuel Computer Operational	MC
2	All electrical power generation systems operational and batteries charged	MC
3	APU operational	MC
4	Positive communications with DC-8/ATC	MC
5	Oxygen with 100% capability for all crew and QNC positions	MC
6	Intercom to all crew/QNC operational	MC
7	No flight control or trim degrades	MC
8	No hydraulic system degrades	MC
No.	**DC-8 Systems**	**Class**
1	Both Center Aux Pumps on DC-8 are operational	MC

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Emergency Procedures

All Engines Out Condition:

1.Both Batteries – ON (CP)
2.Aux Bus – SHED (CP)
3.Throttles – CUTOFF (CP)
4.Start Select – NORM (CP)
5.Ignition Select Switches – AUTO-START (assisted) or ON (windmilling 10% N3) (CP)
6.Airstart Envelope – establish, pg. 3-24 (P)
7.Start Button – Pressed (if assisted start) (CP)
8.Throttle(s) – Idle (when 10% N3 RPM) (CP)
9.Review clean-up items in applicable airstart checklists

IF NO ENGINE CAN BE RELIGHTED:

10.Best Glide Speed (180 kts) – Set
11.Standby Elctro-Pump – Full Left
12.High Key (over touchdown zone) 3,000' AGL - Clean
13.Low Key (abeam touchdown zone) 1,500' AGL – Flaps 10 deg
14.Base Key (90 deg remaining) 750' AGL – Flaps 20 deg, Gear down
15.Short Final 300' AGL – Flaps 40 deg if energy allows

IF OFF-AIRPORT LANDING ANTICIPATED:

16.Prepare for Ditching (pg 3-65) / Forced Landing (pg 3-67)

Incorporated into NASA's HU-25 flight manual supplement

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Emergency Procedures (cont'd)

HU-25 recovery control inputs following departure from controlled flight:

- Upon wake vortex encounter recognition - avoid recovery inputs until after the aircraft naturally exits the wake vortex, then apply appropriate recovery controls.
- Initial encounter controls as required, limiting aileron and rudder unless below Va.
- If encounter develops into an out of control departure, pilot action will be IAW AFFTC test report recommendations to rapidly neutralize controls.
- If departure develops into a spin, recovery controls will be IAW flight manual pg 6-5.

Simulator workups involved upset recoveries, engine restarts, flameout landings, compressor stall recognition, and stall recoveries

Accepted Risk List

- No accepted risks
- Forty-two (42) hazards written up for HU-25 only hazards, all are RAC 3 (low risk)
- Eleven (11) Joint Hazards
  - Residual risk has been mitigated to the project manager approval level

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ACCESS Joint Hazard #1

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Single engine malfunction of probing aircraft	a) Ingestion of distorted inlet flow in the wake of lead aircraft b) Fuel flow interruption due to unusual attitudes in a non-aerobatic aircraft c) Compressor stall d) Abnormal engine indication e) Engine flame-out	1) Loss of mission 2) Damage to asset	NA	IIID	1) Follow safe operating limits and plan for recovery altitude for abnormal aircraft attitudes 2) Follow systems config and go/no-go requirements 3) Practice engine restarts in sim, tabletop discussion, and/or aircraft 4) Min crew on probing aircraft 5) Probing aircraft will not intentionally penetrate the wake vortex 6) Only fly in visible contrail conditions 7) Limit ops to day/VMC with discernible horizon 8) Engine restart possible at or below all test point altitudes 9) Practice malfunctioning engine procedures 10) Instrumentation data will be reviewed post-flight if warranted

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ACCESS Joint Hazard #2

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Dual engine flame-out of probing aircraft	**a) Ingestion of distorted inlet flow in the wake of lead aircraft** **b) Fuel flow interruption due to unusual attitudes in a non-aerobatic aircraft**	**1) Loss of mission** **2) Loss of or damage to asset** **3) Loss of or injury to personnel**	**IE**	**IE**	**1) Follow safe operating limits and plan for recovery altitude for abnormal aircraft attitudes** **2) Plan riskier events within gliding distance of emergency landing surface** **3) Follow systems config and go/no-go requirements** **4) Practice engine restarts in sim, via tabletop discussion, and/or in aircraft** **5) Follow flameout landing procedure for dual engine flame-out landing** **6) Min crew on probing aircraft** **7) Probing aircraft will not intentionally penetrate the wake vortex** **8) Only fly in visible contrail conditions** **9) Limit ops to day/VMC with discernible horizon** **10) Engine restart possible at or below all test point altitudes** **11) Instrumentation data will be reviewed post-flight if warranted**

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ACCESS Joint Hazard #3

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Structural failure of probing aircraft due to near field sampling	a) Flow conditions in wake of lead aircraft b) Pilot overcontrol or abrupt release c) Turbulence coupled with wake effects	1) Loss of mission 2) Loss of or damage to asset 3) Loss of or injury to personnel	IE	IE	1) Only fly in visible contrail conditions 2) Probing aircraft will not intentionally penetrate the wake vortex 3) Turbulence limited to light 4) Min crew on probing aircraft 5) Follow pre-penetration checklist prior to start of test points 6) Limit ops to day/VMC with discernible horizon 7) Lead aircraft will only be fueled to a level necessary for conduct of each flight 8) Avoid aggressive maneuvers in wake of lead aircraft 9) Instrumentation data will be reviewed post-flight if warranted

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ACCESS Joint Hazard #4

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Structural failure of probing aircraft due to far field sampling	a) Inadvertent wake crossing of lead aircraft b) Pilot overcontrol or abrupt release c) Turbulence coupled with wake effects	1) Loss of mission 2) Loss of or damage to asset 3) Loss of or injury to personnel	IE	IE	1) Probing aircraft will remain below maneuvering speed when practical (i.e. far field sampling) 2) Turbulence limited to light 3) Min Crew on probing aircraft 4) Probing aircraft will not intentionally penetrate the wake vortex 5) Only fly in visible contrail conditions 6) Limit ops to day/VMC with discernible horizon 7) Follow pre-penetration checklist prior to start of test points 8) Lead aircraft will only be fueled to a level necessary for each flight 9) Avoid aggressive maneuvers in wake of lead aircraft 10) Instrumentation data will be reviewed post-flight if warranted

ACCESS Joint Hazard #5

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Probing aircraft controllability/ operability at unusual attitudes	a) Encounter with wake vortex of lead aircraft	1) Loss of mission 2) Loss of or damage to asset 3) Loss of or injury to personnel	IE	IE	1) Implement loss of control and spin recovery procedures 2) Limit ops to day/VMC with discernible horizon 3) Practice flight at unusual attitudes in simulator, via tabletop discussion, and/or in the aircraft 4) Min crew on probing aircraft 5) Probing aircraft will not intentionally penetrate the wake vortex 6) Only fly in visible contrail conditions

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ACCESS Joint Hazard #6

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Toxic fumes to crew in probing aircraft (ground testing)	**a) Sensor hull penetration** **b) Mounting structure, mounting, or seal fails**	**1) Loss of mission** **2) Damage to asset** **3) Injury to personnel**	**IVE**	**IVE**	**1) Probe on test stand outside of probing aircraft so that aircraft can be positioned out of the lead aircraft exhaust** **2) Research power supplied from ground cart so that probing engines or APU do not need to be run** **3) Sample air will be vented outside the cabin of the probing aircraft**

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ACCESS Joint Hazard #7

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Toxic fumes to crew in probing aircraft (flight testing)	**a) Sensor hull penetration** **b) Mounting structure, mounting, or seal fails** **c) Air intake ingests exhaust fumes**	**1) Loss of mission** **2) Damage to asset** **3) Injury to personnel**	**Non-credible**	**Non-credible**	**1) Oxygen masks on board probing aircraft for all personnel** **2) Oxygen monitor** **3) Crew shall use oxygen masks if toxic fumes are detected** **4) Sample air shall be vented outside the cabin** **5) Knock off test point**

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ACCESS Joint Hazard #8

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Mid-air collision during formation or rendezvous	**a) Loss of visual contact b) Loss of situational or positional awareness c) Excessive closure rate d) Excessive turbulence e) Uncontrollable roll rate when in ahead of nose-tail clearance**	**1) Loss of mission 2) Loss of or damage to aircraft 3) Loss of or injury to personnel**	**Non-credible**	**Non-credible**	**1) Rendezvous will use best practices from air refueling rendezvous techniques 2) Mission briefing will emphasize rendezvous, terminology, formation emergencies, contingencies, and formation breakup 3) Formation/receiver experienced and qualified crew 4) Min crew on probing aircraft 5) Limit ops to day/VMC with discernible horizon 6) Probing aircraft will not intentionally penetrate the wake vortex 7) Only fly in visible contrail conditions 8) Turbulence limited to light**

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ACCESS Joint Hazard #9

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Excessive heat on probing aircraft	**a) Probing aircraft in exhaust of lead aircraft engines**		**Non-credible**	**Non-credible**	**1) Thermal analysis of in-flight conditions 2) Ground – Probe on test stand outside of probing aircraft so that probing can be positioned out of the lead aircraft exhaust 3) Probing aircraft exits exhaust plume if high temperatures are detected in excessive duration**

ACCESS Joint Hazard #10

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
Personnel or equipment damage from lead aircraft exhaust (ground testing)	**a) FOD** **b) Exhaust velocity (engine blast)** **c) High engine sound levels**	**1) Damage to asset or GSE** **2) Personnel injury**	**IIE**	**IVD**	**1) Test procedure** **2) Keep out zones** **3) Positive control by crew chief** **4) Probing aircraft positioned outside of exhaust** **5) Pre-test briefings** **6) Covers on engines of probing aircraft** **7) FOD sweep** **8) All vehicles parked well away from aircraft** **9) All participants located inside of vehicles during test runs (except safety tech)** **10) Ground personnel monitoring sensors and rigs during test** **11) Proper PPE worn during engine runs (ear plugs)** **12) Comm. plan established**

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ACCESS Joint Hazard #11

Hazardous Condition	Causes	Effects	Human	Asset/ Mission	Mitigations
DC-8 engine flameout	a) Disruption in fuel flow during transfer of fuel from center aux. tank to all four engines	1) Damage to engines or airframe	NA	IIE	1) Procedure developed by DFRC's most experienced Instructor FE 2) Procedure will be tested using a build-up approach (high power ground run and flight crew only flight) 3) Crew will verify center aux pumps operational, engine igniters on, and crossfeed valves open before beginning procedure 4) Procedure will only be performed at or above 27k 5) High demand thrust settings will be avoided 6) EP for engine flameout in QRH

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ACCESS
Human Safety Hazard Action Matrix (HAM)

	Probability [Pr] Estimations				
Injury Severity Classifications	A: Expected to occur (Pr > 10^{-1})	B: Probable to occur ($10^{-1} \geq$ Pr > 10^{-2})	C: Likely to occur ($10^{-2} \geq$ Pr > 10^{-3})	D: Unlikely to occur ($10^{-3} \geq$ Pr > 10^{-6})	E: Improbable to occur ($10^{-6} \geq$ Pr)
I: Catastrophic					2, 3, 4, 5
II: Critical					10
III: Minor					
IV: Negligible					6

	Human Safety Primary Risk acceptance requires Center Director approval and will normally require higher authority approval. These are "**Accepted Risks**"
	Risk acceptance requires Center Director approval. These are "**Accepted Risks**".
	Risk acceptance requires Project Manager approval.

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Loss of Asset / Mission Hazard Action Matrix (HAM)

	Probability [Pr] Estimations				
Asset/Mission Severity Classifications	A: Expected to occur ($Pr > 10^{-1}$)	B: Probable to occur ($10^{-1} \geq Pr > 10^{-2}$)	C: Likely to occur ($10^{-2} \geq Pr > 10^{-3}$)	D: Unlikely to occur ($10^{-3} \geq Pr > 10^{-6}$)	E: Improbable to occur ($10^{-6} \geq Pr$)
I: Catastrophic					2, 3, 4, 5
II: Critical					11
III: Minor				1	
IV: Negligible				10	6

	Primary Risk acceptance requires Center Director approval and may require higher authority approval. These are "**Accepted Risks**"
	Risk acceptance requires Center Director approval. These are **"Accepted Risks"**.
	Risk acceptance requires Project Manager approval.

Open Items

- Remaining work that must be closed prior to the test/flight operation
  - DLH installation
  - Communication Plan
  - Falcon CFP & ICF
  - F-15 or F-18 Photo Chase aircraft

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Action Items

- IRT Questions on team responses
- IRT Briefing

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Back-up Slides

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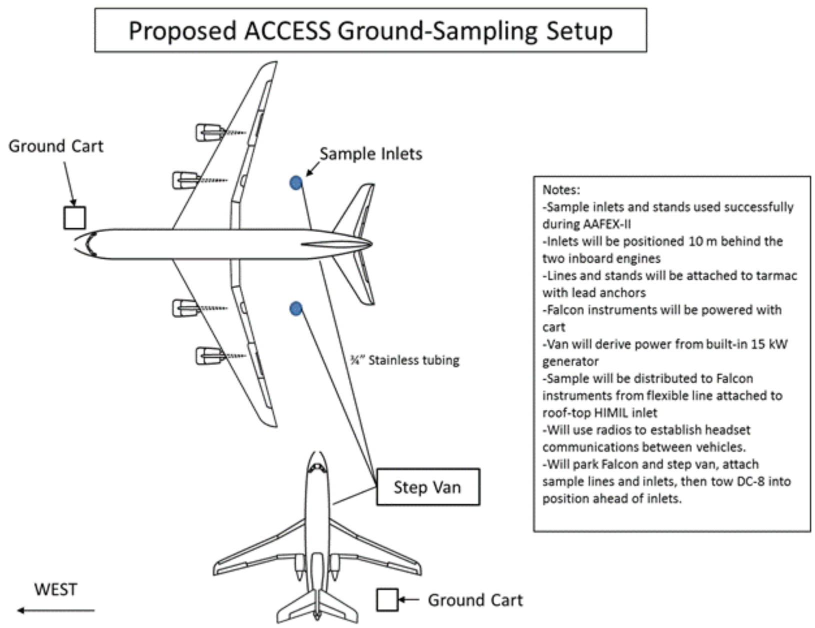
Mission Rules (hazard mitigations during test execution)

- 42 hazards written up for HU-25 only hazards, all are RAC 3
- HU-25 basic mission rules:
  - Challenge and response between laser operator and ground safety coordinator
  - Only designated crewmember shall remove laser cover
  - Comply with CFP restrictions (if any)
  - Pilots provide advanced warning to cabin crew when turbulence is expected
  - Avoid severe weather
  - Icing limits are: trace (none), light (30-min max), mod-severe (exit immediately)
  - Seat belt use mandatory
  - Researchers notify pilots if smoke/fumes detected
  - Formation briefing and altitude/airspeeds match each aircraft's performance

Ground Test Plan & Operations



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Ground Test Plan & Operations

Safety Equipment
- IAW ACCESS Ground Test Procedure document

Communication plans
- Lead by test conductor, Matt Berry
  - DC-8, Dan Bulzan
  - Falcon, Bruce Anderson
- IAW ACCESS Ground Test Procedure document

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Hazard Probability Estimation

- **HAMs Probability [Pr] Estimations:**

- **A: Expected to Occur**
  - Likely to Occur Immediately on the order of (Pr > 10-1)
  - Expected to occur often in the life of the program/item. Expected to be experienced continuously in on-going programs.

- **B: Probable to Occur**
  - Probably will occur on the order of (10-1 > Pr > 10-2)
  - Will occur several times in the life of a program/item.

- **C: Likely to Occur**
  - May occur on the order of (10-2 $\geq$ Pr > 10-3)
  - Likely to occur sometime in the life of a program/item, but multiple occurrences are unlikely. Controls have significant limitations or uncertainties.

- **D: Unlikely to Occur**
  - Unlikely but possible to occur on the order of (10-3 $\geq$ Pr > 10-6)
  - Unlikely to occur in the life of the program/item, but still possible. Controls have minor limitations or uncertainties.

- **E: Improbable to Occur**
  - Improbable to occur on the order of (10-6 $\geq$ Pr)
  - Occurrence theoretically possible, but such an occurrence is far outside the operational envelope. Typically robust hardware, operational safeguards and/or strong controls are put in place with mitigation actions to reduce risk from a higher level to an improbable state (probability E).

Hazard Severity Classifications

- **Human Safety Hazard Severity Classifications**

- **CLASS I (CATASTROPHIC)**
  - A condition that may cause death or permanently disabling/life-threatening injury, or loss of crew.
- **CLASS II (CRITICAL)**
  - A condition that may cause severe/lost time injury or occupational illness.
- **CLASS III (MINOR)**
  - A condition that may cause medical treatment for a minor injury or occupational illness (no lost time).
- **CLASS IV (NEGLIGIBLE)**
  - A condition that could cause the need for minor first aid treatment (though would not adversely affect personal safety or health).

- **Loss of Asset/Mission Hazard/Risk Severity Classifications**

- **CLASS I (CATASTROPHIC)**
  - A condition that may cause the destruction of facility on the ground, major system, vehicle, termination of project, or loss of the only opportunity for critical data. Recovery/replacement cost equal to or greater than $2M.
- **CLASS II (CRITICAL)**
  - A condition that may cause major loss/damage to facility, system, equipment, flight hardware, vehicle, long term project delay, or loss of major project critical data. Recovery/replacement cost equal to or greater than $500K, but less than $2M.
- **CLASS III (MODERATE)**
  - A condition that may cause loss of mission (sortie, flight, return-to-base, test shut-down, etc…), loss of minor project critical data, minor loss/damage to facility, system, equipment, or flight hardware. Recovery/replacement cost equal to or greater than $50K, but less than $500K.
- **CLASS IV (NEGLIGIBLE)**
  - A condition that may cause loss of non-critical data, subjects facility, system, or equipment to more than normal wear and tear. Recovery/replacement cost greater than $1K, but less than less than $50K.

Appendix J. 2013 Pilot Proficiency Practice Flight Tests Lessons Learned

On March 1, 2013, the ACCESS team provided an outbriefing to the NESC team describing pilot proficiency flight tests that had been accomplished in accordance with NESC recommendations R-1 and R-2. Videos were shown on a WebEx teleconference and the ACCESS pilots described lessons learned. No written material was received or reviewed by the team.

NESC pre-meeting questions (verbatim) included:

- -Location, altitude, KIAS, humidity?
- -Number of wingspans estimated aft of lead aircraft for each run?
- -Turbulence level before and after establishing position in a contrail?
- -Sun angle looks like 090 degrees relative. Other angles tried? What is best sun angle for contrail visibility?
- -I tried to ID wingtip vortices rolling up the outboard contrail edges but couldn't. Can they see the vortices from above, below, and directly aft?
- -What was the maximum rolling and pitching force perceived on the controls in pounds?
- -How many nautical miles did it take to rendezvous, get established, do a run, and exit?

Post meeting comments (verbatim) among the NESC team included:

- They have the right combination of crew, aircraft, environment, and planning to do their mission safely.
- They had a good tec. Brief… so I expected everything to go well … everything went even better that I expected.
- My measure of comfort is whether or not I'd get in the back of the Falcon and feel comfortable. I think they have demonstrated that there is a comfort level there. Something unexpected could occur, but they have mapped out safe operating regions that probably have generalized validity.
- I have no problem with their continued cautious flying. As to the vortex encounter -- it's kinda hard to know where that cliff really is, since you don't have to be in the core to have upset forces applied to the Falcon.
- In the near field, things appeared exactly as expected, with outboard contrails rolling up quickly and making the vorticity very apparent. The inboard contrails were sunk to an altitude below the vortices allowing them to sample an inboard exhaust plume safely

keeping the Falcon wingtip clear of the vortex. The Falcon roll control appeared very easy.

- In the far field, the separation phenomenon was not clearly visible on the videos. The hazard of inadvertent descent into a vortex remains but is mitigated by the ACCESS flight rules and the experience gained by the pilots.
- I am actually kinda surprised that the Falcon didn't experience more unusual forces than they did. It's counter to my experiences. Good for them.
- I don't disagree with anything we heard this morning. I think they have done a good job and have a prudent approach to avoid vortex encounters. I do think there is a window of opportunity here to validate the methods that we and others used to estimate the effect of the trailing vortex on the Falcon. For example, they could measure the aileron input required to maintain the Falcon at wings level and correlate that with position with respect to the DC-8 and its wake similar to our color maps of Falcon rolling moment. I realize the project is not interested in this aspect for their science project, but it could be very useful to know if the tools are useful and accurate for future projects.
- I was a little put off on the question about the accel/INS/strain data. In better times NASA would be interested in those data.
- My concerns are to the project science goals; not safety. .... These are briefly what I'd wonder about. I have never been convinced that the farfield sampling is a complete known. What are we really sampling in this "upper layer." If I were the science Program Manager I wouldn't go forward without a complete aerochemical multi-species CFD simulation to see what this stuff is. Sure they see exhaust, but is this the "whole" exhaust or is there a gravitational or buoyancy or thermal separator in play here? For the farfield cases they showed in the video, there are two visible trails. The inboard and outboard exhaust are mixed at this distance. How do you interpret the data if just the inboard engine has the "different" fuel?

NASA Press Release:

March 1, 2013

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NASA BEGINS FLIGHT RESEARCH CAMPAIGN USING ALTERNATE JET FUEL

WASHINGTON -- NASA researchers have begun a series of flights using the agency's DC-8 flying laboratory to study the effects of alternate biofuel on engine performance, emissions and aircraft-generated contrails at altitude.

The Alternative Fuel Effects on Contrails and Cruise Emissions (ACCESS) research involves flying the DC-8 as high as 40,000 feet while an instrumented NASA Falcon HU-25 aircraft trails behind at distances ranging from 300 feet to more than 10 miles.

"We believe this study will improve understanding of contrails formation and quantify potential benefits of renewable alternate fuels in terms of aviation's impact on the environment," said Ruben Del Rosario, manager of NASA's Fixed Wing Project.

ACCESS flight operations are being staged from NASA's Dryden Aircraft Operations Facility in Palmdale, Calif., and will take place mostly within restricted airspace over Edwards Air Force Base, Calif.

During the flights, the DC-8's four CFM56 engines will be powered by conventional JP-8 jet fuel, or a 50-50 blend of JP-8 and an alternative fuel of hydroprocessed esters and fatty acids that comes from camelina plants.

More than a dozen instruments mounted on the Falcon jet will characterize the soot and gases streaming from the DC-8, monitor the way exhaust plumes change in composition as they mix with air, and investigate the role emissions play in contrail formation.

Also, if weather conditions permit, the Falcon jet will trail commercial aircraft flying in the Southern California region, in coordination with air traffic controllers, to survey the exhaust emissions from a safe distance of 10 miles.

The flight campaign began Feb. 28 and is expected to take as long as three weeks to complete.

ACCESS follows a pair of Alternative Aviation Fuel Experiment studies conducted in 2009 and 2011 in which ground-based instruments measured the DC-8's exhaust emissions as the aircraft burned alternative fuels while parked on the ramp at the Palmdale facility.

A second phase of ACCESS flights is planned for 2014. It will capitalize on lessons learned from the 2013 flights and include a more extensive set of measurements.

The ACCESS study is a joint project involving researchers at Dryden, NASA's Glenn Research Center in Cleveland and NASA's Langley Research Center in Hampton, Va.

The Fixed Wing Project within the Fundamental Aeronautics Program of NASA's Aeronautics Research Mission Directorate manages ACCESS.

Figure J-1. Pilot Proficiency Practice April 2013: Approaching the Near Field Zone, Chase Plane Point of View

Figure J-2. Pilot Proficiency Practice April 2013: Approaching the Near Field Zone, Falcon Point of View

Figure J-3. Pilot Proficiency Practice April 2013: In Near Field, Between Inboard Exhaust Plumes

Figure J-4. Pilot Proficiency Practice April 2013: Immersed in Right Inboard Exhaust Contrail; Left Wingtip Vortex is Made Visible by the Rolled Up Left Outboard Exhaust Contrail; Located to the Left and "Centerline At Least One Core Diameter (~6 feet) Above" the Centerline of the Left Inboard Exhaust Contrail; Right Wingtip Vortex Obscured

Figure J-5. Pilot Proficiency Practice April 2013: Approaching the Far Field

Figure J-6. Pilot Proficiency Practice April 2013: Approaching the Far Field; Exhaust Gases Separated Above Vortices are not Apparent in Images

Figure J-7. Pilot Proficiency Practice April 2013: Approximately 300 ft Above the Vortices in Far Field; Both Cores are Made Visible by Rolled up Exhaust Contrails

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14. ABSTRACT
The Alternative Fuel Effects on Contrails & Cruise Emissions (ACCESS) Project Integration Manager requested in July 2012 that the NASA Engineering and Safety Center (NESC) form a team to independently assess aircraft structural failure hazards associated with the ACCESS experiment and to identify potential flight test hazard mitigations to ensure flight safety. The ACCESS Project Integration Manager subsequently requested that the assessment scope be focused predominantly on structural failure risks to the aircraft empennage (horizontal and vertical tail). This report contains the Appendices to Volume I.

15. SUBJECT TERMS
ACCESS; NASA Engineering and Safety Center; Wake vortices; Engine exhaust plumes; Near field; Far field

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