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**High-Lift Engine Aeroacoustics Technology
(HEAT) Test Program Overview**

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Outline

- Introduction
- HEAT 1 Test Overview
 - Objectives and Approach
 - Summary of Results
- HEAT 1A Test Overview
 - Objectives and Approach
 - Measurements and Test Techniques
- Additional Objectives to HEAT 1A Test
 - Large-Scale Geometric-Fidelity Objectives
- Summary

The outline of the presentation is as follows:

- Introduction
- HEAT 1 Test Overview
 - Objectives and Approach
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Introduction

Customers/Participants

NASA-Ames Research Center, Boeing, Douglas Aircraft Corp., Lockheed-Georgia, General Electric, NASA-Lewis Research Center

HEAT 40x80 ft. Wind-Tunnel Tests

- HEAT 1 Isolated Nozzle test
 - GE Gen 1 2-D mixer-ejector nozzle
 - Measured isolated aeroacoustic performance of nozzle for HEAT 1 Installed test
 - Summer '94

- HEAT 1 Installed Semi-Span Test
 - 13.5% Semi-Span Boeing Reference H model
 - Gen 1 2-D mixer-ejector nozzle
 - Feb. - May 1995

- HEAT 1A Isolated Nozzle test
 - GE Gen 1 2-D mixer-ejector nozzle

- HEAT 1A Installed Semi-Span Test
 - 13.5% Semi-Span Boeing Reference H model
 - Gen 1 2-D mixer-ejector nozzle

The NASA High-Speed Research program developed the High-Lift Engine Aeroacoustics Technology (HEAT) program to demonstrate satisfactory interaction between the jet noise suppressor and high-lift system of a High-Speed Civil Transport (HSCT) configuration at takeoff, climb, approach and landing conditions. One scheme for reducing jet exhaust noise generated by an HSCT is the use of a mixer-ejector system which would entrain large quantities of ambient air into the nozzle exhaust flow through secondary inlets in order to cool and slow the jet exhaust before it exits the nozzle. The effectiveness of such a noise suppression device must be evaluated in the presence of an HSCT wing high-lift system before definitive assessments can be made concerning its acoustic performance. In addition, these noise suppressors must provide the required acoustic attenuation while not degrading the thrust efficiency of the propulsion system or the aerodynamic performance of the high-lift devices on the wing. Therefore, the main objective of the HEAT program is to demonstrate these technologies and understand their interactions on a large-scale HSCT model.

The HEAT program is a collaborative effort between NASA-Ames, Boeing Commercial Airplane Group, Douglas Aircraft Corp., Lockheed-Georgia, General Electric and NASA - Lewis. The suppressor nozzles used in the tests were Generation 1 2-D mixer-ejector nozzles made by General Electric. The model used was a 13.5%-scale semi-span model of a Boeing Reference H configuration. The tests performed under the HEAT program are listed as follows:

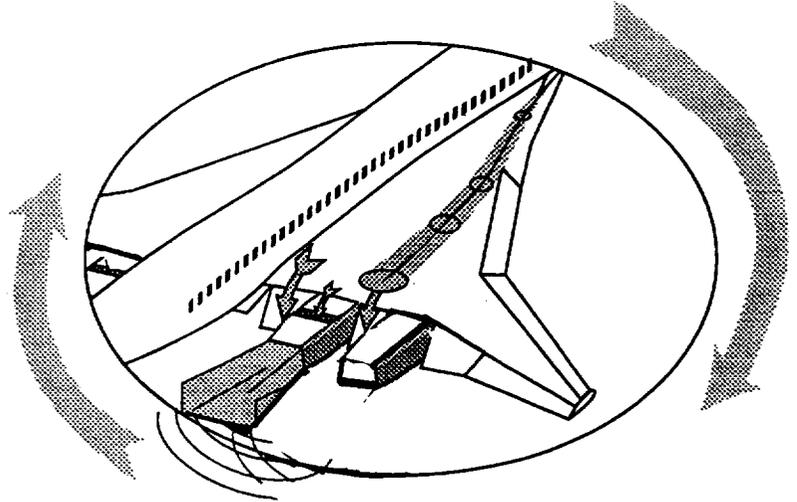
- HEAT 1 Isolated Nozzle test
- HEAT 1 Installed Semi-Span test
- HEAT 1A Isolated Nozzle test
- HEAT 1A Installed Semi-Span test

All the tests were performed in NASA-Ames' 40- by-80 ft. Wind-Tunnel Facility.

First HEAT Entry (HEAT 1)

Installation effects from inboard mixer-ejector nozzle

- Nozzle mixer-ejector entrained-flow effects on high-lift system performance
- Aerodynamic effects on installed noise suppressor performance
- Wing and Trailing-Edge Flap pressures
- Mixer-ejector inflow distortion
- Acoustic signature



HEAT 1 Test Overview

HEAT 1 was the first entry of the 13.5% Boeing Reference H semi-span model. The model was equipped with an inboard jet flow simulator (JFS) and fitted with GE's 2D suppressor, mixer-ejector nozzles. The outboard station was configured with a flow-through nacelle. The JFS system was supplied with high-pressure air and heated with a propane/burner system that provided high-temperature flows and representative nozzle pressure ratios. The Hot-Aeroacoustic Model (HAM) nozzle was used for the hot-flow aeroacoustic runs. The Cold-Aerodynamic Model (CAM) nozzle was used for the cold-flow aerodynamic runs. Also the CAM nozzle was instrumented with a higher density of static pressures, total pressures and temperature gages than the HAM nozzle.

The purpose of the HEAT 1 test was to examine the installation effects of the mixer-ejector nozzles integrated with the wing high-lift systems. Both the effects of the airframe flowfield on the acoustic performance of the suppressor nozzle and the effects of the nozzle's secondary inlet flows on the aerodynamic performance of the wing high-lift systems were the primary focus of the investigation. In addition, the local flowfield over the wing and flaps was closely examined. Static pressure taps over the wing and flaps were used to study the leading-edge vortex trajectories and trailing-edge flap flows. Boundary-layer rakes upstream of the nozzle's secondary inlets provided a measure of mixer-ejector inflow distortion.

HEAT 1 Objectives and Approach

Test Objectives

- Determine installation effects on high-lift system performance and noise suppressor performance
- Overwing pylon fin effects
- Acoustic fatigue and cabin noise measurements
- Horizontal tail effectiveness and plume impingement

Approach

- Isolated test of suppressor nozzles
- 13.5%-scale semi-span model of Boeing HSCT Ref H configuration
- Inboard nacelle powered by propane-fueled jet flow simulator
- Outboard flow-through nacelle
- Traversing microphones and acoustic array

Schedule

- February - May 1995 (385 runs)

The objectives of the HEAT 1 test were as follows:

- Determine installation effects on high-lift system performance and noise suppressor performance
- Overwing pylon fin effects
- Acoustic fatigue and cabin noise measurements
- Horizontal tail effectiveness and plume impingement

The approach of the test consisted of first measuring the noise suppression of the nozzles in isolation and then integrating the nozzles on to the 13.5%-scale Boeing HSCT Ref H semi-span model. The inboard nacelle was powered by a propane-fueled jet flow simulator. The outboard station was fitted with a flow-through nacelle. Traversing microphones and an acoustic array were used to measure the near-field and far-field acoustic signatures.

The HEAT 1 test was performed during Feb-May 1995 and gathered data for 385 runs.

Summary of HEAT 1 Results

Key Aero-Performance Findings

- Beneficial Aero-Performance installation effect
 - Favorable effect on drag for most configurations (up to 20 counts at nominal conditions)
 - Positive increment on L/D varying from 0.3 to 0.15 DL/D at nominal conditions (3.6% to 1.8% of L/D at $\alpha=10^\circ$)
- Data repeatability was $\Delta C_D=\pm 0.0015$ and $\Delta L/D=\pm 0.115$
- Local flowfield pressure data also revealed supporting evidence of this beneficial effect on aerodynamic performance
- Flow-visualizations tufts showed dramatic increase in flow angularity at outboard secondary inlet location for $10^\circ < \alpha < 14^\circ$

Key Acoustics Findings

- 1 to 2.3 EPNdB installation effect
- Jet noise shows to be function of flap deflection

Summary of Results

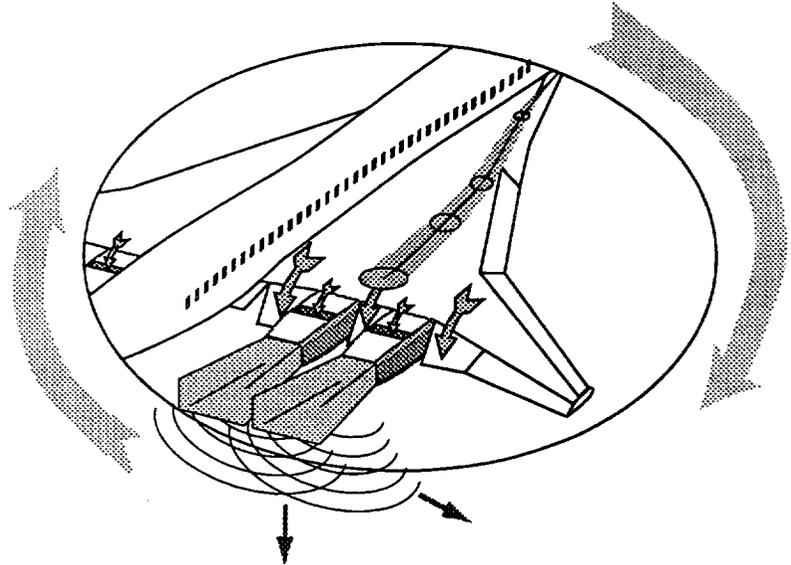
The HEAT 1 test results showed a beneficial aerodynamic performance installation effect for most configurations. This beneficial effect showed a decrease in drag of up to 20 counts and an increase in lift-to-drag ratio of 0.3 to 0.15 at nominal conditions. Further evidence of this beneficial effect on aerodynamic performance was supported by examination of the local flowfield pressure data. The installation effect on acoustic suppression showed a loss in suppression on the order of 1 to 2.3 EPNdB. A complete description of these results can be found in Brian Smith's et al paper entitled, "Summary of HEAT 1 Aeroacoustics Installation Effects", presented at last year's HSR Configuration Aerodynamics Workshop, Feb. 27-29, 1996.

Although the results of the test showed much evidence of a beneficial installation effect on aerodynamic performance, these results were hampered by the large uncertainties in the balance data. Repeat runs of the data showed uncertainties in the data of ± 15 counts in drag coefficient and ± 0.115 in lift-to-drag ratio. It was concluded that in order to verify the results of the first test, a second entry of HEAT model should be performed and the accuracy of the drag measurements should be improved. In addition, the flow-visualization tufts showed a dramatic increase in flow angularity at the outboard secondary inlet location for angles-of-attack greater than 10 deg. This increase in flow angularity could lead to greater installation effects at the outboard nacelle station. Therefore, it was justified that the installation effect at the outboard nacelle should be further examined during the second entry of the HEAT model.

Second HEAT Entry (HEAT 1A)

Installation effects from 2 mixer-ejector nozzles

- Nozzle mixer-ejector entrained-flow effects on high-lift system performance
- Wing and Trailing-Edge Flap pressures
- Mixer-ejector inflow distortion



The second entry of the HEAT model or the HEAT 1A test will examine the installation effects from two mixer-ejector nozzles integrated with an HSCT wing and high-lift system. Similar to the first entry, the main purpose of the test is to determine the effects of the nozzle mixer-ejector entrained flow on aerodynamic performance. However, unlike the first test, there will be no acoustic measurements taken in this test. This was decided based on the lack of technical justification, program priority and budget limitations.

HEAT 1A Test Objectives

- Improve accuracy of drag/thrust measurements
- Evaluate high-lift performance increments due to jet flow entrainment from 2 powered mixer/ejector nozzles
- Determine the nozzle aerodynamic performance effects due to interactions between the high-lift system and jet suppressors
- Investigate the local flowfield in the vicinity of the secondary inlets to better understand the interactions between the two flowfields
- Measure hinge-moments on key high-lift system control surfaces

The objectives of the HEAT 1A test are as follows:

- Improve accuracy of drag/thrust measurements
- Evaluate high-lift performance increments due to jet flow entrainment from 2 powered mixer/ejector nozzles
- Determine the nozzle aerodynamic performance effects due to interactions between the high-lift system and jet suppressors
- Investigate the local flowfield in the vicinity of the secondary inlets to better understand the interactions between the two flowfields
- Measure hinge-moments on key high-lift system control surfaces

HEAT 1A Test Approach

Hardware

- Use existing image plane and HEAT 1 semi-span model
- Add a second jet flow simulator to the outboard station of the HEAT model
- Use existing HAM/CAM nozzle hardware at inboard and outboard stations, respectively

Measurement Accuracy

- Refurbish and re-calibrate model support system
- Repeat isolated nozzle thrust performance test of HAM/CAM nozzles to improve accuracy of thrust-removed L/D
- Add instrumentation to image plane to improve aero calibration (buoyancy, blockage and upwash)
- Improve test techniques (add more repeat runs, improve calibration techniques, etc.)

The approach of the HEAT 1A test will be similar to the first entry. The existing image plane, model and HAM and CAM nozzles will be used again in this test. The only change in hardware will be the addition of the outboard jet flow simulator and internal high-pressure air plumbing.

The isolated nozzle thrust performance test will be repeated to improve the accuracy of the thrust-removed lift-to-drag ratios. These lift-to-drag ratios are subtracted from the installed data to give a net installation effect. Therefore, in order to improve accuracy on the net results, it is necessary to repeat the isolated test with the newly refurbished and re-calibrated model support system. In addition, the change in hardware for the outboard JFS system can also lead to changes in isolated thrust. Therefore, it is justified to repeat this test in an effort to improve accuracy as best possible.

In order to improve the aerodynamic calibration of the buoyancy, blockage and upwash of the test section, instrumentation will be added to the image plane and the calibration for the test section with the image plane will be recomputed. The overall test techniques for aerodynamic calibration and repeatability will also be improved in an effort to improve accuracy.

HEAT 1A Test Approach (cont.)

Systems

- Remotely actuate trailing-edge flaps
- Upgrade high-pressure system to deliver required mass flow rates for 2 JFS systems

Measurements

- Add boundary-layer rakes to outboard nacelle station
- Add hinge-moment instrumentation to outboard flap #3
- Add pressure taps to outboard flaps #3 and #4 to determine hinge-moments and evaluate spanwise loading
- Add five-hole probe to measure downwash angle at tail station during tail-off runs

Flow-Visualization

- Pressure-Sensitive Paint
- Fluorescent Mini-Tufts

There will be two systems added to the HEAT 1A test. These will include: (1) remote actuation of the trailing-edge flaps, and, (2) an upgraded high-pressure system to deliver required mass flow rates for the 2 JFS systems.

The measurements of this test will include all the existing instrumentation of the HEAT 1 test and additional instrumentation as follows:

- boundary-layer rakes on outboard nacelle
- hinge-moment instrumentation on outboard flap #3
- dense number of pressure taps on outboard flaps #3 and #4 to determine hinge-moments and evaluate spanwise loading
- five-hole probe at tail station to measure downwash angle during tail-off runs

Flow-visualization requirements will include the use of pressure-sensitive paint (PSP) and fluorescent mini-tufts. The PSP will be used as another technique to evaluate the hinge-moments on the outboard flaps and tail. PSP will also be applied over upper and lower surfaces of the wing along with the mini-tufts to examine the leading-edge vortex trajectories and trailing-edge flap flows.

Additional Test Objectives

Large-Scale Geometric-Fidelity Objectives

- Leading-Edge Hingeline Step and Gap Size Sensitivity Study
- Wing Crank Flap Gap Sensitivity Study
- Flap Edge/Nacelle Gap Study

Propulsion/Airframe Interaction Objective

- Main Engine Inlet Distortion Measurements

Additional test objectives are being proposed to be merged on to the HEAT 1A test. These objectives are being proposed by the High-Lift ITD team as a result of their survey with Tech Integration, Configuration Aero, Propulsion Airframe Integration and Environmental Impact ITD teams. This survey was conducted to determine what additional technical objectives can be met by large-scale testing and are needed by the technical community to reach the HSRP technology readiness level of 6. This survey was conducted as part of the 4 Engine Propulsion Airframe Integration Configuration (4EPIC) feasibility study. From these efforts, it was concluded that there was not enough technical and program justification for the 4EPIC test but that the program would merit technically by adding on more objectives to the HEAT 1A test.

As a result of this process, the following are a list of technical objectives that can potentially be added on to the HEAT 1A test. They can be categorized as large-scale geometric-fidelity objectives and propulsion/airframe interaction objectives as listed below:

Large-Scale Geometric-Fidelity Objectives

- Leading-Edge Hingeline Step and Gap Size Sensitivity Study
- Wing Crank Flap Gap Sensitivity Study
- Flap Edge/Nacelle Gap Study

Propulsion/Airframe Interaction Objective

- Main Engine Inlet Distortion Measurements

Leading-Edge Hingeline Step and Gap Sensitivity Study

Objective

Determine sensitivity of configuration L/D to details of the leading-edge hingeline geometry especially for outboard wing

Approach

- Generate geometry of representative leading-edge hinge line
- Fit thin upper surface gloves to the leading edge of the wing
- Gather baseline data for smoothly, faired flap-to-wing surface
- Test at two different step sizes
- Obtain aeroperformance data at constant JFS power level and at Re number sweeps and alpha sweeps

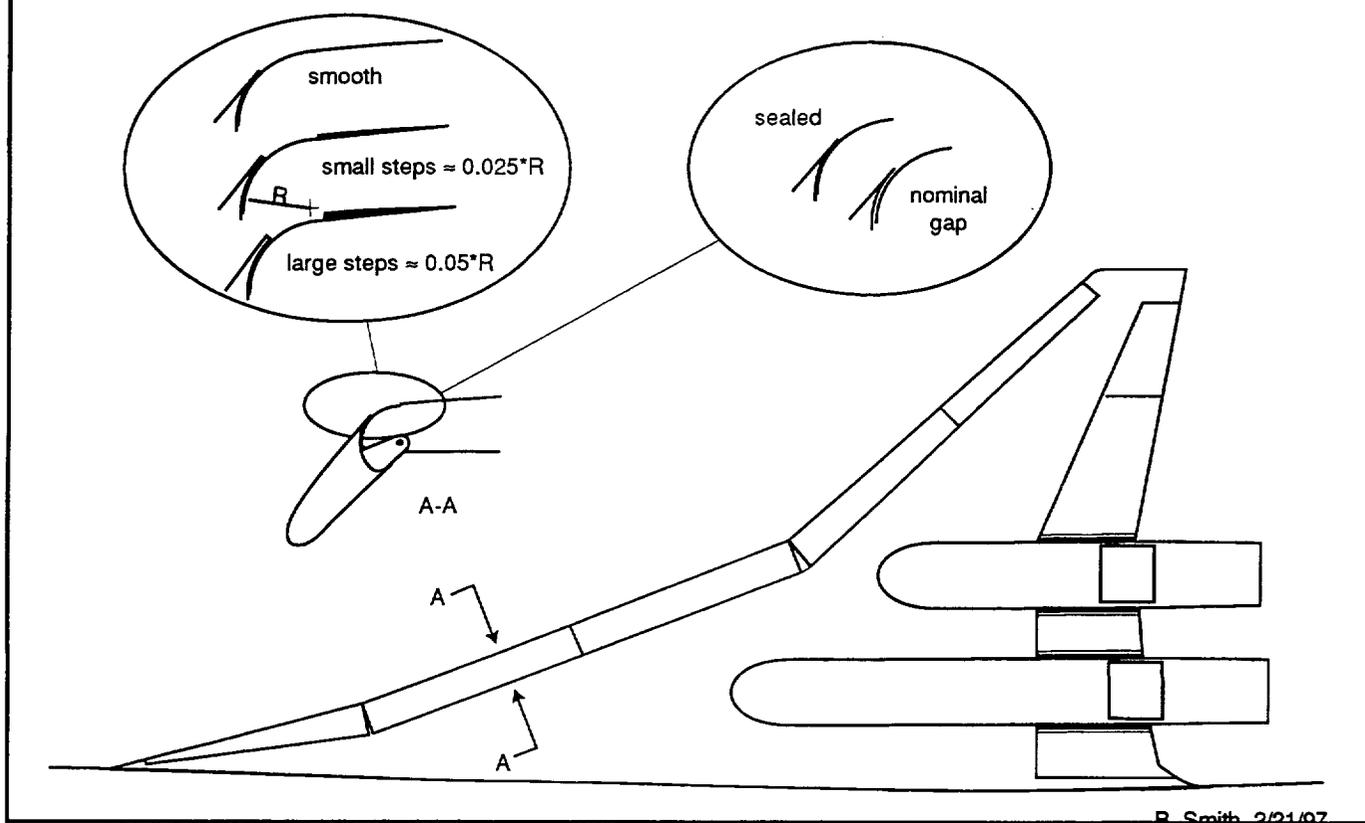
Requirement

Determine the sensitivity of configuration L/D to the details of the leading-edge hingeline geometry especially for the outboard wing panel. Maintaining flow attachment on the upper surface may be critical to the outboard wing panel. Vortical structures and local flow separations arising from chordwise leading discontinuities at the hinge line may significantly affect the overall high-lift performance and the flow on the outboard wing panel.

Approach

The geometry of representative leading-edge hinge line details on the upper surface will be generated in consultation with industry flap kinematics and structures personnel. Thin upper surface gloves will be fitted to the leading edge of the wing so that the model can be tested with two step sizes in addition to a smoothly faired, idealized flap-to-main-wing panel surface. If hinged flaps are fabricated for the model, it may be possible to evaluate the effects of gap flows between the slat and main element. L/D and drag polar runs will be made in each configuration at a constant jet-flow simulator (JFS) power level. Since Reynolds number may effect these results, alpha sweeps will be made at a variety of tunnel airspeeds.

HEAT IA Leading Edge Hingeline Step & Gap Size Sensitivity Study



B. Smith, 2/21/07

Figure 1 - Leading Edge Hingeline Geometry Effects.

Figure 1 above illustrates the HEAT wing planform and the step and gap areas to be examined during the leading-edge hingeline step and gap size sensitivity study. The sizes shown are potential sizes to be tested.

CFD Support Activities

The Low-Speed Aerodynamics Branch here at Ames is working closely with the Applied Computational Aerodynamics Branch to define basic CFD research using generic swept-wing configurations to investigate step (forward- and aft-facing) and cavity effects on curved, accelerating flow fields characteristic of realistic leading edge flap/slat hingeline geometries. Figure x depicts candidate geometries for this area. It is felt that calculations using simplified geometries will provide insight to the physics of these types of flows and will develop CFD technologies applicable to HSCT-class vehicles.

Wing Crank Flap Gap Sensitivity Study

Objective

Evaluate changes in high-lift performance due to effects from leading edge flap-to-flap gaps and discontinuities along span

Approach

- Simulate geometry of the flap-to-flap interface at the wing crank junction
- Test with a smoothly faired, idealized juncture
- Test with simulated “production” gap fairing geometry
- Test with completely unported geometry
- Obtain aeroperformance data at constant JFS power level

Requirement

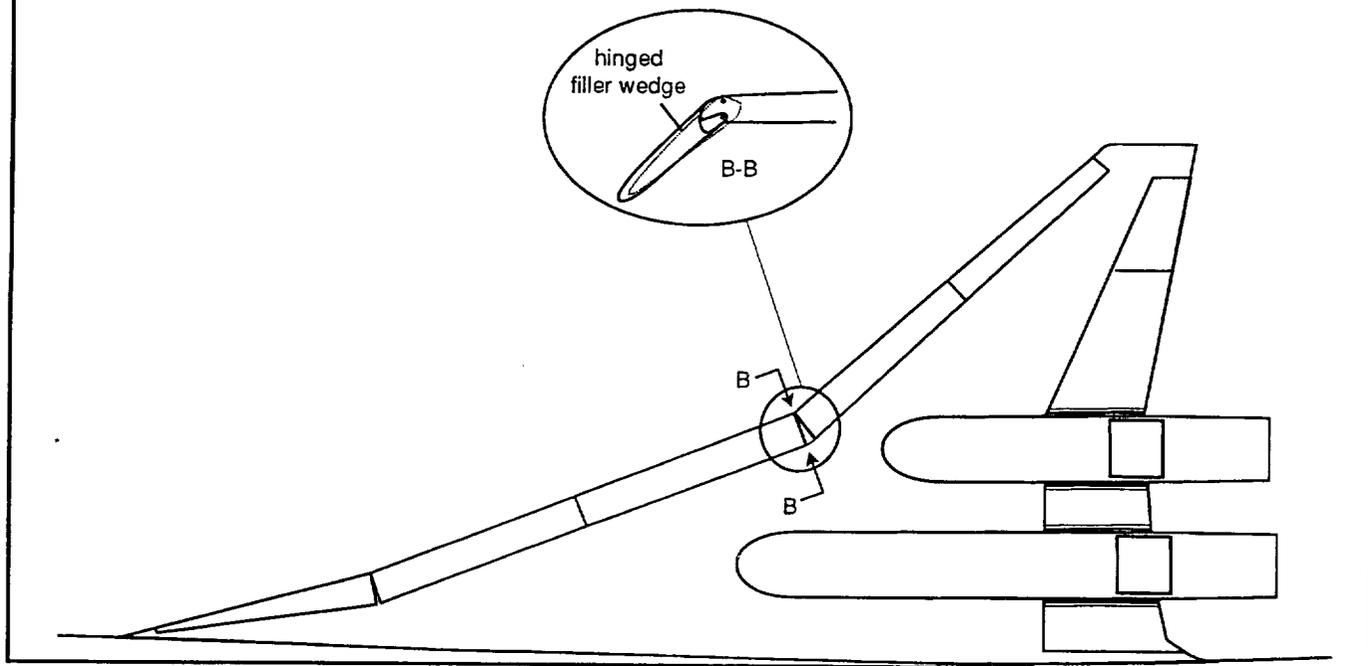
Evaluate changes to high-lift performance and vehicle drag due to vortical structures and local flow separations arising from leading edge flap-to-flap gaps and discontinuities which exist along the span where the sweep angle changes.

Approach

Accurate modeling of the spanwise discontinuities can be achieved with the large-scale HEAT IA model. An attempt will be made to simulate the geometry of the flap-to-flap interface at the wing crank junction between the inboard and outboard wing panels. This geometry will be generated in consultation with industry flap kinematics and structures engineers. The model will be tested with 1.) the simulated “production” gap fairing geometry, 2.) a smoothly faired, idealized juncture, and 3.) a completely unported geometry which may produce the worst-case performance. In addition to documenting the crank gap effect, candidate mechanization and fairing schemes can be evaluated with the model if the individual leading edge flaps are each hinged separately. L/D and drag polar runs will be made in each configuration at a constant jet-flow simulator (JFS) power level.

**HEAT IA Wing Crank
Flap Gap Sensitivity Study**

**Effect of gaps/fillers arising between adjacent
flap elements due to finite thickness**



B. Smith, 2/21/97

Figure 2 - Effect of Spanwise Discontinuities Along Leading Edge

Figure 2 above highlights the area to be examined in the wing crank flap gap sensitivity study. The size of the gap in this area will be adjusted to determine the effects of gaps/fillers between these adjacent flap elements.

CFD Support Activities

NS calculations of the full HEAT IA geometry may be able to include studies of the flap-to-flap gap effects. Figure x depicts candidate geometries for this area of the vehicle.

Flap Edge/Nacelle Gap Study

Objective

- Determine sensitivity of configuration L/D to the sizes of gaps between trailing-edge flap edges and nacelles
- Determine critical gap size

Approach

- Use spacer plates between flap edges and nacelle to adjust gap sizes for three inboard flaps
- Obtain aeroperformance data at JFS power level sweeps

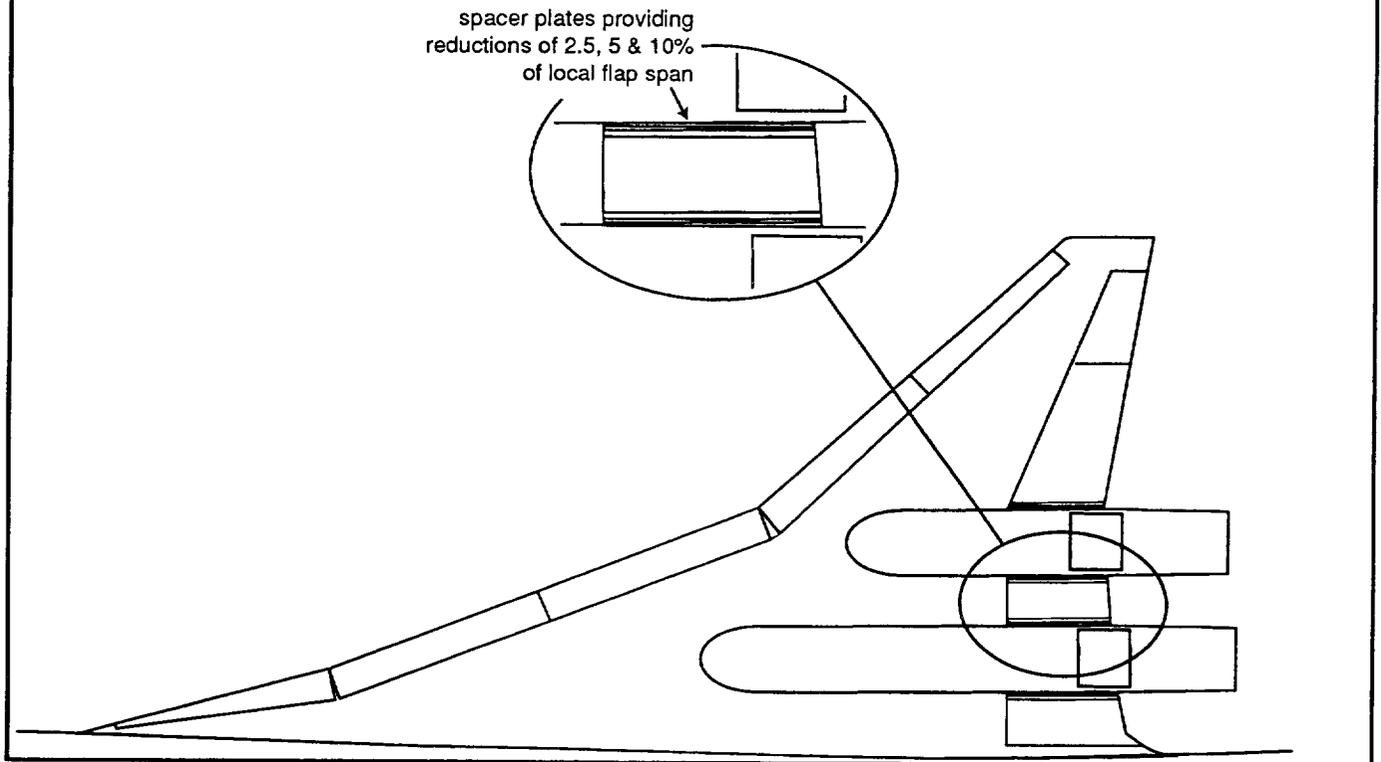
Requirement

Determine the sensitivity of configuration L/D to the size of gaps between the streamwise edges of the trailing-edge flaps and vertical sidewalls of the adjacent nacelles. The overall high-lift performance may be significantly degraded and vehicle drag may increase when these gaps are above a certain size. Determining this critical gap size will be crucial to design of candidate high-lift systems for the Technology Configuration.

Approach

The trailing-edge flaps of the HEAT model were designed with this type of system performance study in mind. Thin plates can be bolted to the streamwise edges of the inboard three flaps to produce gaps of various sizes. The configuration tested during the first HEAT entry used a set of plates which produced a minimal gap. L/D and drag polar runs will be made in each gap configuration at a constant jet-flow simulator (JFS) power level. Because of the close proximity of the flap edges to the suction of the ejector suppressor nozzle inlets, it will be instructive to perform some NPR sweeps with the various gap sizes at constant angle of attack and airspeed.

HEAT IA Flap Edge/Nacelle Gap Study



B. Smith, 2/21/97

Figure 3 - Effects of Flap Edge/Nacelle Gaps_

Figure 3 above highlights the area to be examined in the flap edge/nacelle gap study. Spacer plates will be used to adjust the gaps between the flap edges and nacelle walls to determine the effect of these gaps.

CFD Support Activities

A basic building block approach using generic, simplified configurations will be used to determine the incremental effects on lift and drag of the gaps between streamwise flap edges and adjacent vertical nacelle surfaces. The attached figure depicts candidate geometries for this area. The principal CFD investigator at Ames, Ching-Mao Hung, who will be working the HEAT IA problem feels that generic research on this topic will generate technology which can be applied not only to HSRP configurations but also to other aerodynamic problems. The full NS calculations using the complete HEAT IA geometry may be able to investigate these gap effects for select configurations:

Main Engine Inlet Distortion Measurements

Objective

Measure total pressure deficits and flow angles at the inboard and outboard main engine inlet

Approach

- Add 5-hole probe rake arrays upstream of the main engine inlets
- Replace JFS nacelles with flow-through nacelles
- Obtain total pressure and flow angularity distributions at varying angle of attack, airspeeds and leading-edge flap deflections

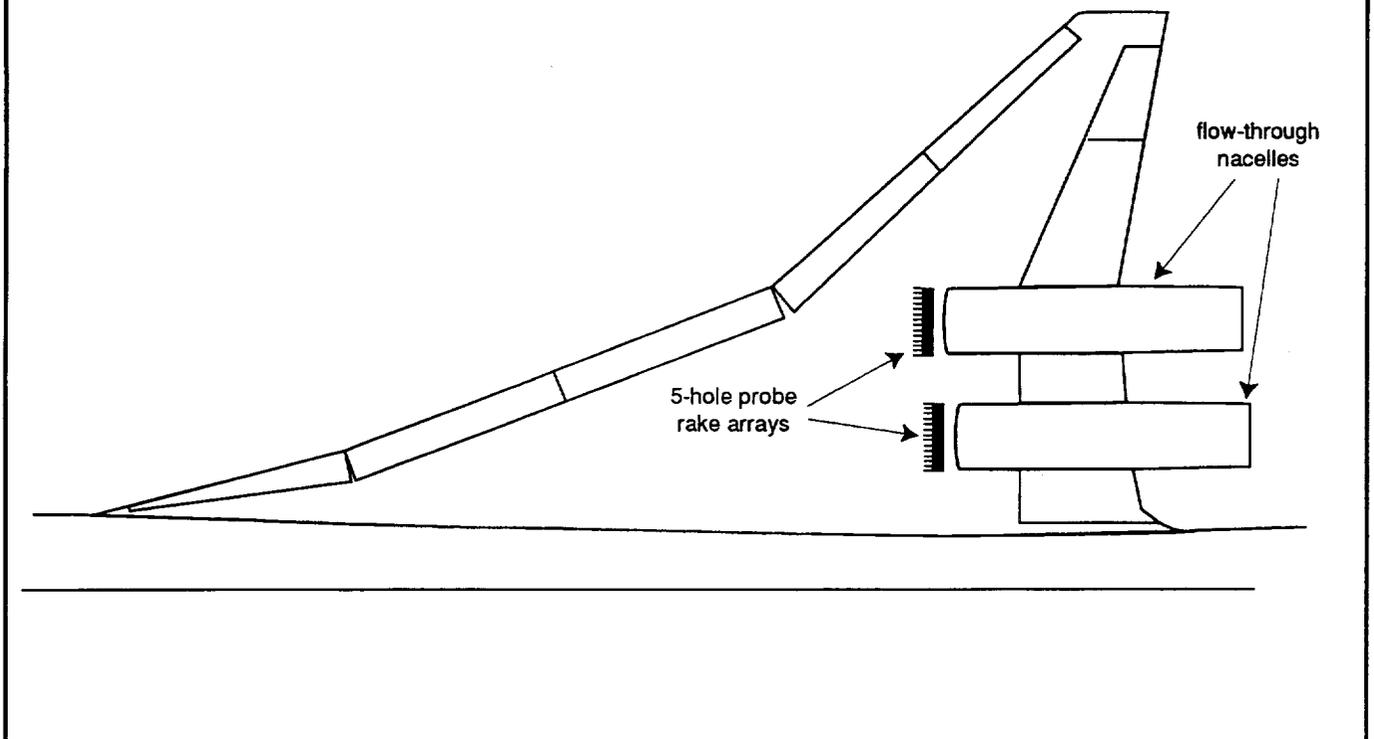
Requirement

Distortion levels at the location of the main engine inlets due to cross flow on the lower surface of the wing at low-speed, high-alpha, high leading-edge flap deflection conditions may be significantly greater than at the cruise design point. The objective of this investigation will be to measure total pressure deficits and flow angles in a plane at the location of the inboard and outboard main engine inlets.

Approach

Detailed mappings of the total pressure and flow angularity distributions at the locations of the main engine inlets will be made using either a fixed or traversing array of five-hole probes. Flow-through nacelles will be fabricated for use during this portion of the test. The powered nacelle interface with the wing will be redesigned to accept the flow-through nacelles. Surveys of the flowfield at the inlet faces will be made at a variety of angles of attack, airspeeds and leading edge flap deflection angles.

HEAT IA Main Engine Inlet Distortion Measurements



B. Smith, 1/16/97

Figure 4 - Main Engine Inlet Exterior Flowfield Assessments_

Figure 4 above shows the approximate location for the 5-hole probe rake arrays to be added to measure the flow angularity and total pressure deficits at the inboard and outboard main engine inlets.

CFD Support Activities

It may be possible to utilize the NS calculations of the full HEAT IA configuration to predict first-order flow angularities and total pressure deficits downstream of the deflected leading edge flaps with the model at the low angles of attack which might be expected to generate distorted main engine inlet flows.

Summary

- HEAT 1A main objectives and approach have been set
- Measurements and Test Techniques have been reviewed to give improved accuracy on drag/thrust measurements
- Additional large-scale geometric-fidelity objectives are being merged into HEAT 1A test plan where advantageous to program
- Additional Propulsion/Airframe Interaction objective(s) are being examined as potential HEAT 1A objectives

In summary, the justification and motivation for the HEAT 1A test has been presented. The objectives and approach for this test has been reviewed along with the measurements and test techniques to be used in the HEAT 1A test. The importance of improving the accuracy of the drag/thrust measurements for this test was also explained and justified.

The potential additional objectives to be merged in with the HEAT 1A test objectives were presented. The additional objectives were categorized as large-scale geometric-fidelity objectives and propulsion/airframe interaction objectives. These additional objectives are still being reviewed and therefore, the final decision to incorporate them into the test is still pending completion of the review process.