NASA Technical Memorandum 104327

F/A-18A Inlet Flow Characteristics During Maneuvers with Rapidly Changing Angle of Attack

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NASA Contract NAS 3-26617
June 1997

National Aeronautics and
Space Administration

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Under NASA Dryden Flight Research Center
Contract NAS 3-26617

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Background

- **Inlet/engine compatibility**
  - **Inlet evaluation at steady aerodynamic conditions is the cornerstone of inlet/engine compatibility**
  - **Peak distortion descriptors are determined over a finite time span at fixed aerodynamic conditions**
  - **Wind tunnel testing is the primary data source of inlet assessments**
    - **Test configuration constraints**
      - **Fixed model position**
      - **Model-to-wind-tunnel size can limit AOA range**
      - **Limited maneuvering capability - slow rates**
- **New high AOA capabilities**
  - **Increased operating range of AOA and AOSS**
  - **Increased aircraft maneuvering rates**

Current inlet/engine compatibility testing separately determines inlet distortion generation and engine distortion tolerance characteristics during wind tunnel testing. The goal is to determine the inlet's pressure profiles at peak engine stall margin loss. The inlet evaluation is performed using wind tunnels. In general, wind tunnel test conditions consist of a matrix of discrete, steady aerodynamic conditions defined by Mach number, angle-of-attack (AOA), angle-of-sideslip (AOSS), and airflow. Testing is conducted at fixed model positions. Wind tunnel and aircraft model size can constrain assessments at high AOA. Maneuvering capability is limited to slow rates. The introduction of new high AOA capabilities are increasing aircraft maneuvering rates and the operating range of AOA and AOSS.

Objective

- **Determine whether current practice is adequate in describing inlet-generated total-pressure-distortion levels during maneuvers with rapidly changing AOA**
  - **Are distortion levels elevated during dynamic maneuvers?**
  - **Any limitations with steady aerodynamic condition testing?**
- **Flight test assessment required**

The objective of these analyses was to determine whether results obtained for steady aerodynamic conditions were adequate for describing the inlet-generated total pressure distortion levels that occur during rapid aircraft maneuvers. The evaluation focused on whether the constrained steady aerodynamic condition test matrix describes inlet trends in sufficient detail as currently practiced. If examination of the rapid maneuver results at any condition shows a significant increase in peak level distortion when compared with the steady-aerodynamic-conditions results, the inlet data would be analyzed to determine the source of these increased peak distortion levels. The effects of dynamic AOA maneuvers on inlet distortion levels could only be assessed during flight tests.

Aircraft/inlet/engine

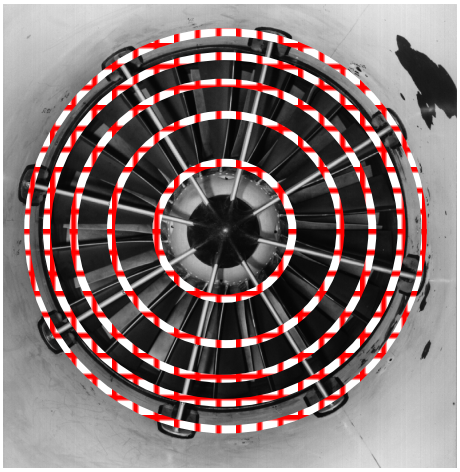
- **Aircraft**
  - **NASA F/A-18A High Alpha Research Vehicle with thrust vectoring paddles**
- **Inlet**
  - **Fixed geometry, side fuselage mounted, single ramp, external compression inlet**
  - **Right-hand inlet used**
- **Engine**
  - **General Electric F404-GE-400 afterburning turbofan engine**

HARV right-hand inlet

High alpha inlet research data were obtained using the NASA High Alpha Research Vehicle (HARV) at the NASA Dryden Flight Research Center. The aircraft is a preproduction F/A-18A with an externally-mounted thrust-vectoring paddle system. This modification allows the aircraft to fly at sustained high AOA conditions. The aircraft's inlet is a fixed geometry, side fuselage mounted, single ramp, external compression inlet. A pair of General Electric F404-GE-400 afterburning turbofan engines are installed in the aircraft. All inlet research testing was conducted using the right inlet/engine combination (aft-looking-forward).

Inlet total-pressure measurements

- **Descriptors defined from inlet rake measurements**
- **Inlet rake measurements**
  - **40 measurement probes**
  - **5 rings with 8 equally-spaced circumferential positions**
  - **High-response, absolute pressures with no significant time lag (2143 sps)**
- **Acquisition of data conforms to Society of Automotive Engineers ARP 1420 standards**

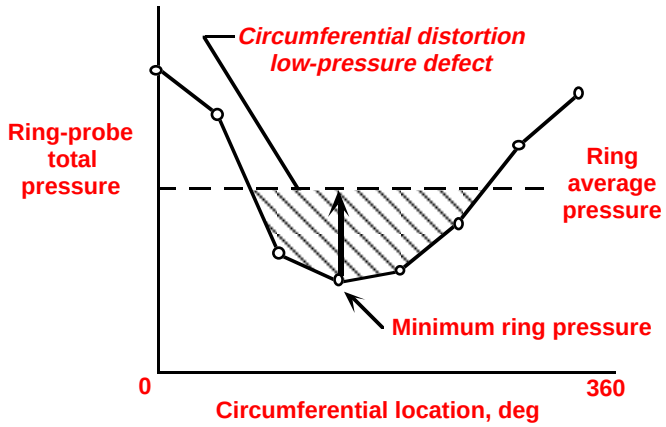


HARV inlet rake
with circumferential rings
superimposed

The inlet distortion descriptors require measurements from an inlet rake. The standard rake configuration is a 40-probe array consisting of eight equiangularly spaced rakes with five ports per rake located at the centroids of equal areas. This array provides 5 rings with 8 equally-spaced circumferential pressures. The HARV inlet rake provided high-frequency-response, absolute pressures with no significant timelag. This was a requirement for the dynamic maneuver assessment. Data recording was performed at 2143 samples per second. The acquisition of data conformed with the Society of Automotive Engineers Aerospace-Recommended-Practice (ARP) 1420 standards for total-pressure-distortion measurement.

Inlet total-pressure-distortion descriptors

- Inlet recovery
  - Face average total pressure referenced to the freestream total pressure
- General Electric F404 distortion methodology
- Dynamic circumferential distortion
  - Time-variant magnitude of the low-pressure defect for each ring (5 rings)
  - Average adjacent rings (4 calculated rings)
  - Select maximum value for one of the 4 averaged rings



This inlet research assessment used three inlet descriptors: inlet recovery, peak dynamic circumferential distortion, and peak dynamic radial distortion. Inlet recovery is defined as the face average pressure referenced to the freestream total pressure. The distortion descriptors used the General Electric F404 distortion methodology. Dynamic circumferential distortion is defined as the overall maximum value of adjacently-averaged rings of the time-variant magnitude of the low-pressure defect for each ring.

Inlet total-pressure-distortion descriptors

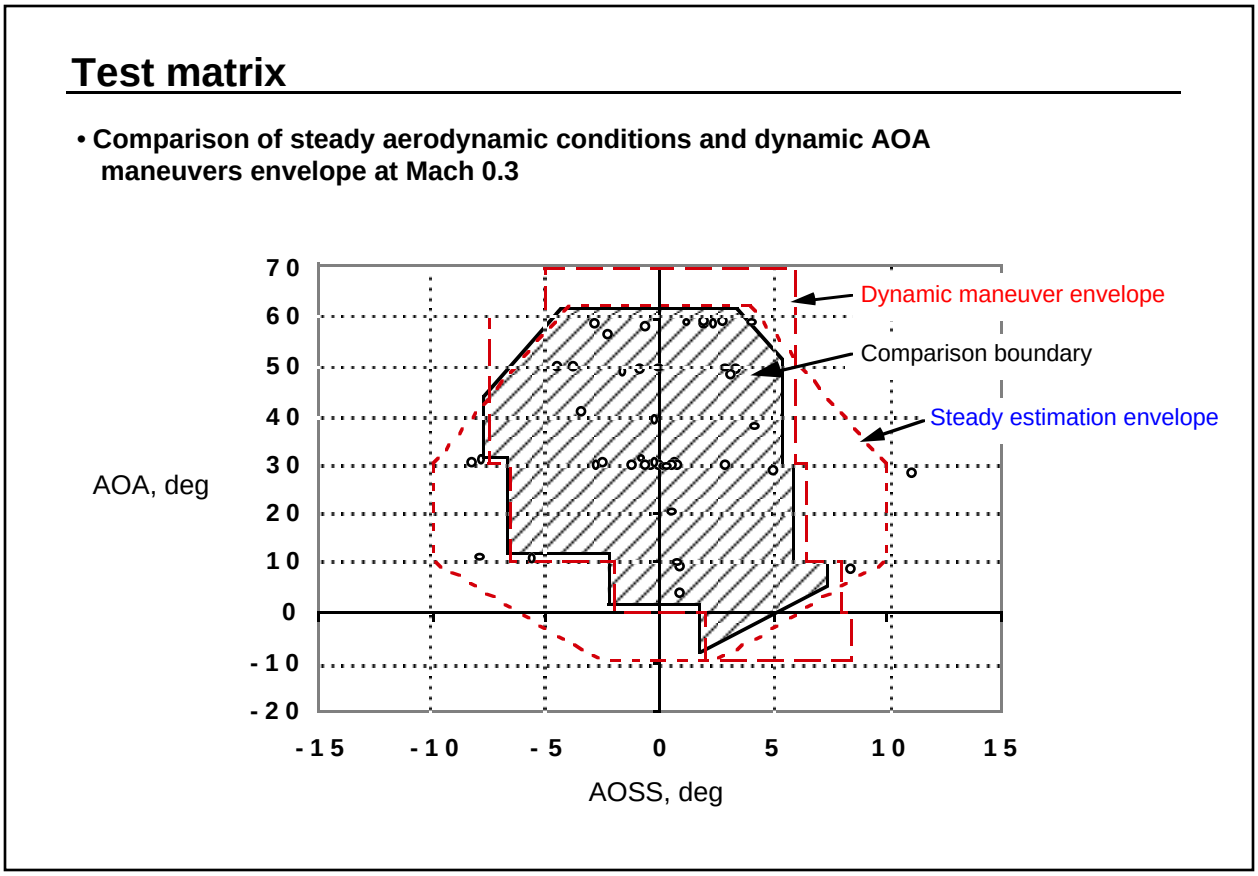
- **Dynamic radial distortion**
  - **Time-variant magnitude of the difference between the ring average pressure and the face average pressure for the tip and hub ring (2 rings)**
  - **Select maximum value of either ring**
- **Peak value determination of circumferential and radial descriptors**
  - **Maximum observed magnitude computed for a finite period of time at steady aerodynamic conditions**
  - **Randomness of pressure fluctuations in an inlet requires a statistically significant data sample**
  - **HARV steady data used 4–6 sec**

Dynamic radial distortion is defined as the maximum value of either the tip or hub ring for the time-variant magnitude of the difference between the ring average pressure and the face average pressure. The circumferential and radial distortion descriptors are both referenced to the face average pressure. The circumferential and radial distortion descriptors require further reduction to determine their peak values. For steady aerodynamic conditions, the maximum observed magnitude is determined over a finite period of time. This time period needs to be a statistically significant period because of the randomness of inlet pressure fluctuations. The HARV steady aerodynamic conditions were held to obtain a 4 to 6 second data sample.

Test matrix

- **Steady aerodynamic conditions**
  - **79 conditions at maximum corrected airflow of 144 lb/sec**
  - **Mach 0.3 and 0.4**
  - **–10° to 60° AOA and –8° to 12° AOSS**
- **Rapid AOA maneuvers**
  - **46 maneuvers at maximum corrected airflow of 144 lb/sec**
  - **Initial conditions**
    - **10°, 25–30°, and 60° AOA at 0°, ±5° AOSS (Mach 0.3)**
    - **10°, 12–15°, and 40° AOA at 0°, ±5° AOSS (Mach 0.4)**
  - **AOA sweeps**
    - **Low-to-high AOA, 46 deg/sec maximum rate**
    - **High-to-low AOA, –37 deg/sec maximum rate**

Two databases were required for this research: one based on steady aerodynamic conditions and the other using rapid AOA maneuvers. In brief, the steady aerodynamic conditions consisted of 79 test points at Mach 0.3 and 0.4 with AOA from –10° to 60° and AOSS from –8° to +12°. Conditions typically were held for 6 seconds. The rapid AOA maneuvers consisted of 46 maneuvers. The initial setup (at steady aerodynamic conditions) was, for Mach 0.3 at 10°, 25–30°, and 60° AOA with 0° and ±5° AOSS; and for Mach 0.4 at 10°, 12–15°, and 40° AOA with 0° and ±5° AOSS. Once the initial steady conditions were held for 2 to 3 seconds, the dynamic maneuver was performed. Both positive and negative AOA rates were performed with maximum rates of –37 deg/sec and 46 deg/sec being attained. Both databases required that the engine be held at maximum corrected airflow of about 144 lb/sec.



This AOA-AOSS envelope shows the extent of the comparisons performed in this study. Three envelopes are shown for the Mach 0.3 database. The first envelope is the steady aerodynamic estimation envelope with limits at about –10° to 60° AOA and ±10° AOSS. The second envelope is the dynamic maneuver envelope which shows the extent of the AOA-AOSS excursions reached during maneuvers. The intersection of these two envelopes forms the third envelope and shows the extent of the comparison performed at the Mach 0.3 conditions. A similar set of envelopes exists for the Mach 0.4 database with an upper AOA limit near 40°.

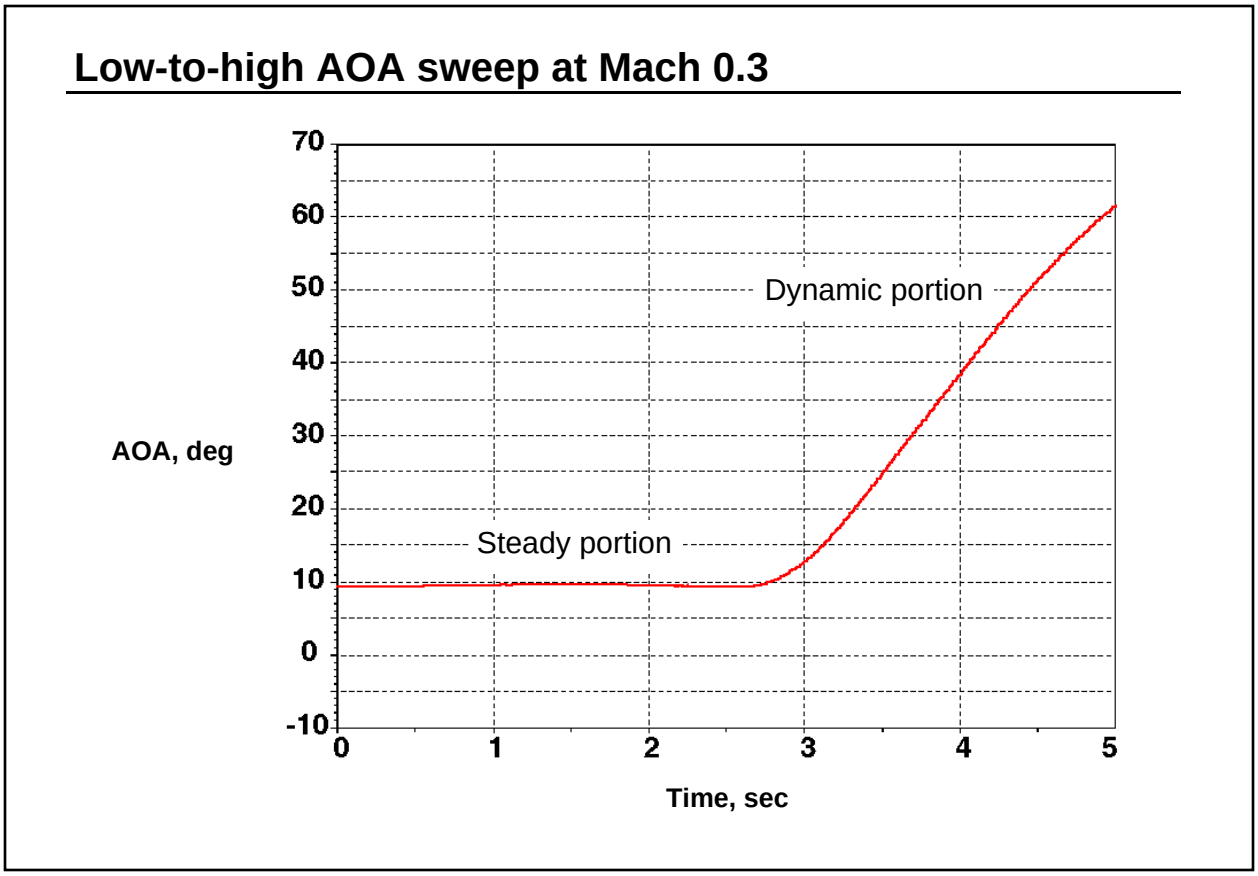
Analysis

- **Steady aerodynamic conditions**
  - **Inlet characteristics processed, peak values found, and models created**
  - **Reduced to tabular format**
  - **Function of AOA, AOSS, and Mach number**
- **Dynamic maneuvers**
  - **Time-variant inlet characteristics calculated**
  - **Airdata analyzed to remove measurement errors**
- **Dynamic Aircraft Maneuvers Program (DAMP)**
  - **Computes descriptors based on steady aerodynamic conditions for comparison with dynamic maneuver values at equivalent conditions**

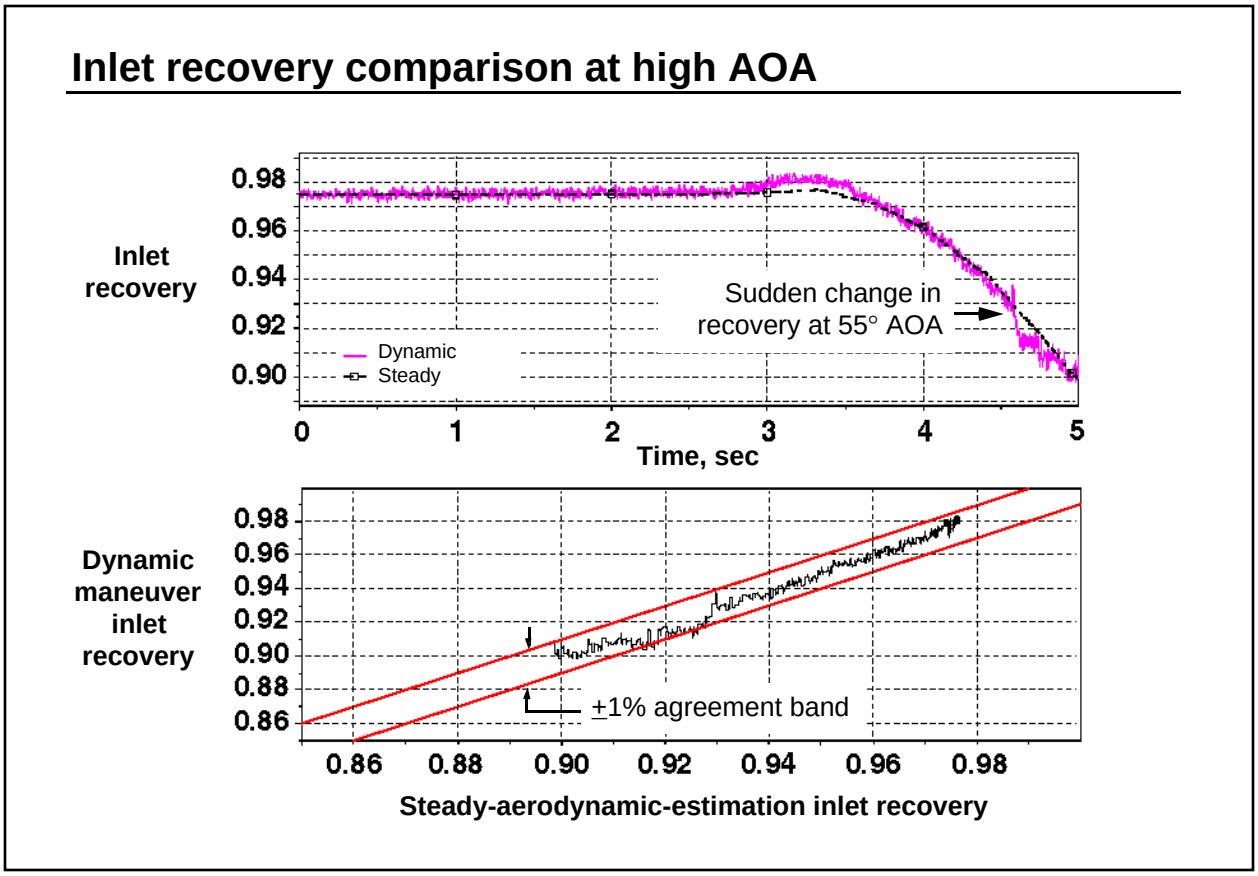
Each database was analyzed in order for calculations and comparisons to be performed. For each aerodynamic condition inlet descriptors were calculated. These descriptors included average recovery and peak distortion values. Further analysis reduced these data into tabular format which provided each descriptor as a function of AOA, AOSS, and Mach number.

Each dynamic maneuver had the time-variant inlet characteristics calculated. Special data review was performed to remove any known measurement errors from the AOA and AOSS signals. These errors included the effects of wing bending frequency on the airdata wing-tip-mounted vanes and the averaging of divergent AOSS vanes at high AOA (greater than 60°).

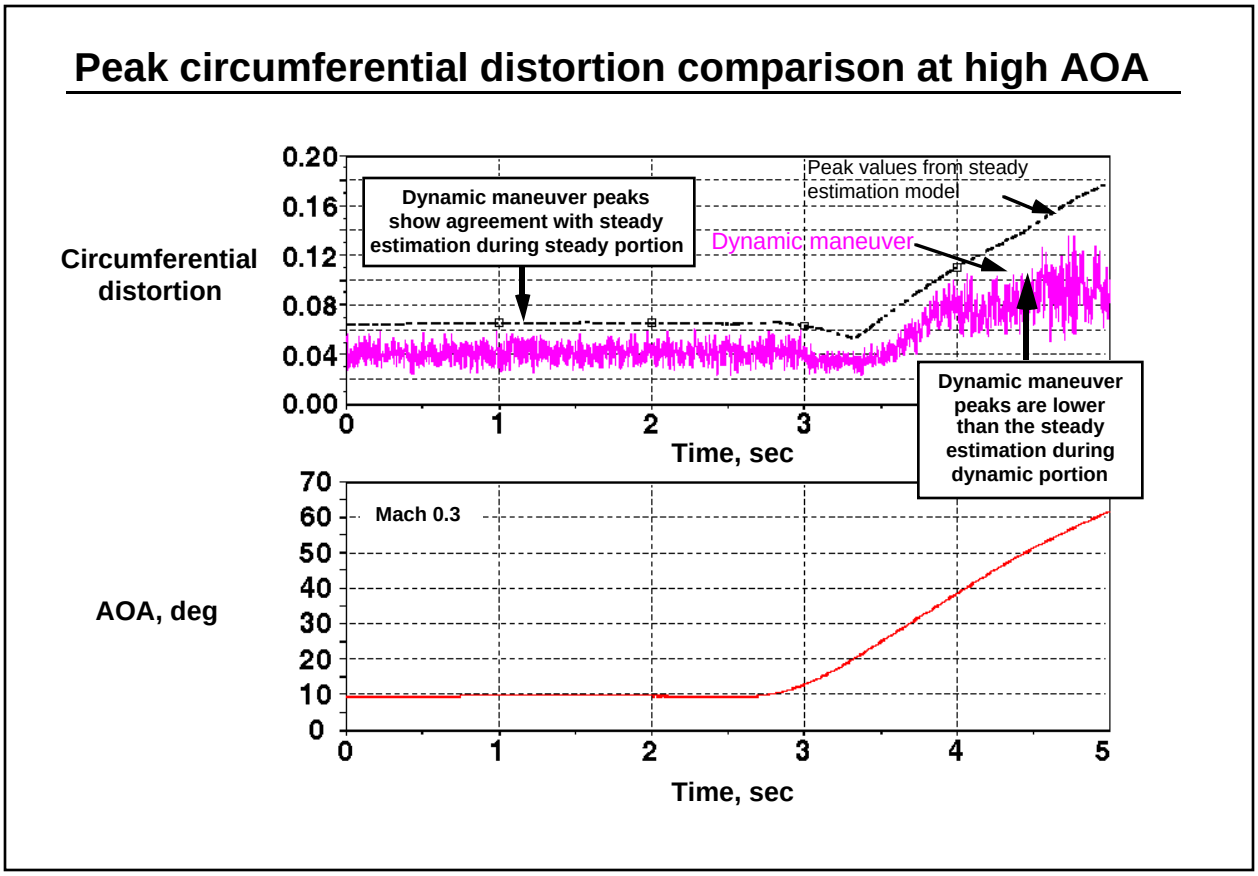
A computer program called the Dynamic Aircraft Maneuvers Program (DAMP) was written to compute inlet recovery and peak distortion descriptors based on steady aerodynamic conditions for comparison with dynamic maneuver values at equivalent conditions.



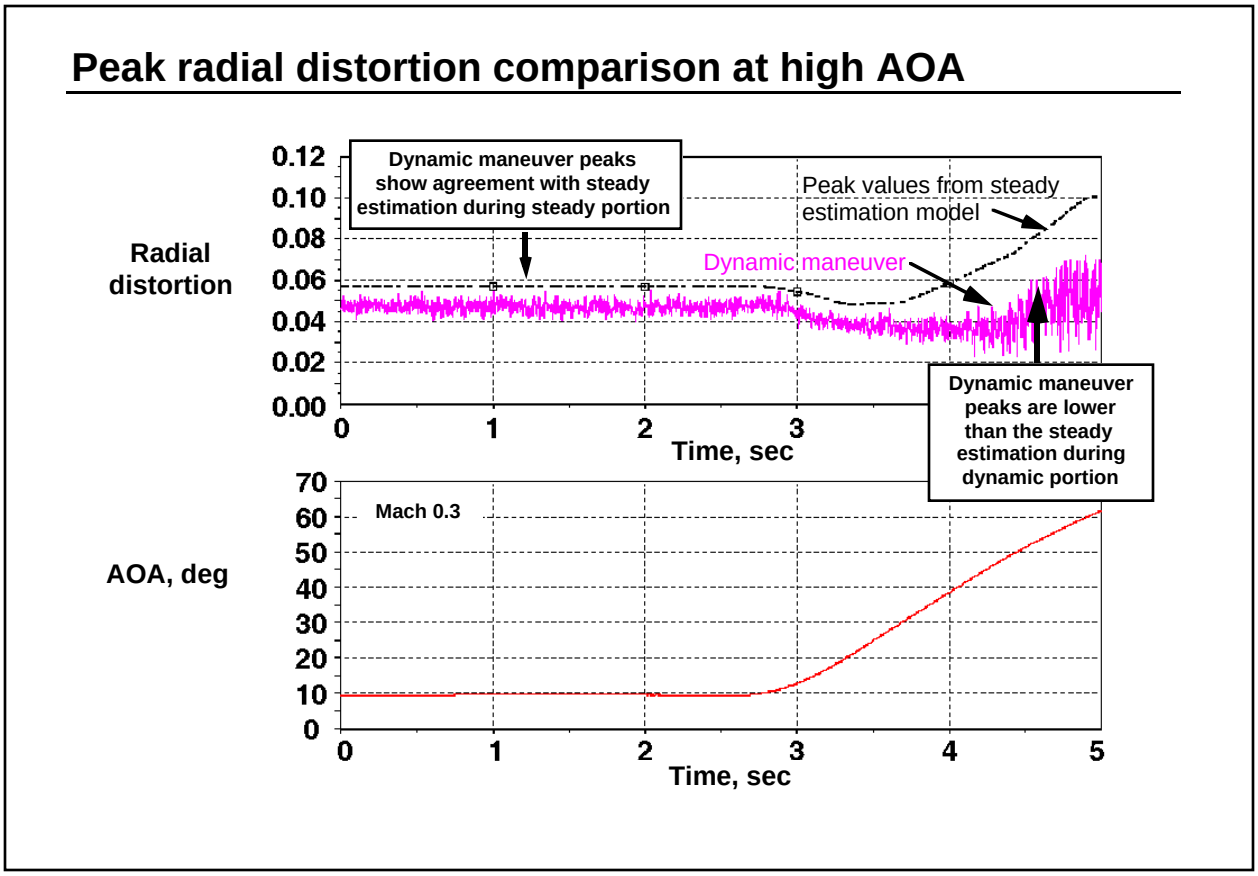
This figure shows a rapid AOA maneuver, a low-to-high AOA sweep at Mach 0.3. The initial steady portion is at 10° AOA, and is immediately followed by the dynamic portion with AOA going beyond 60°. The maximum AOA rate for this maneuver was approximately 30 deg/sec. This maneuver will be used to describe the inlet descriptor comparisons in this presentation.



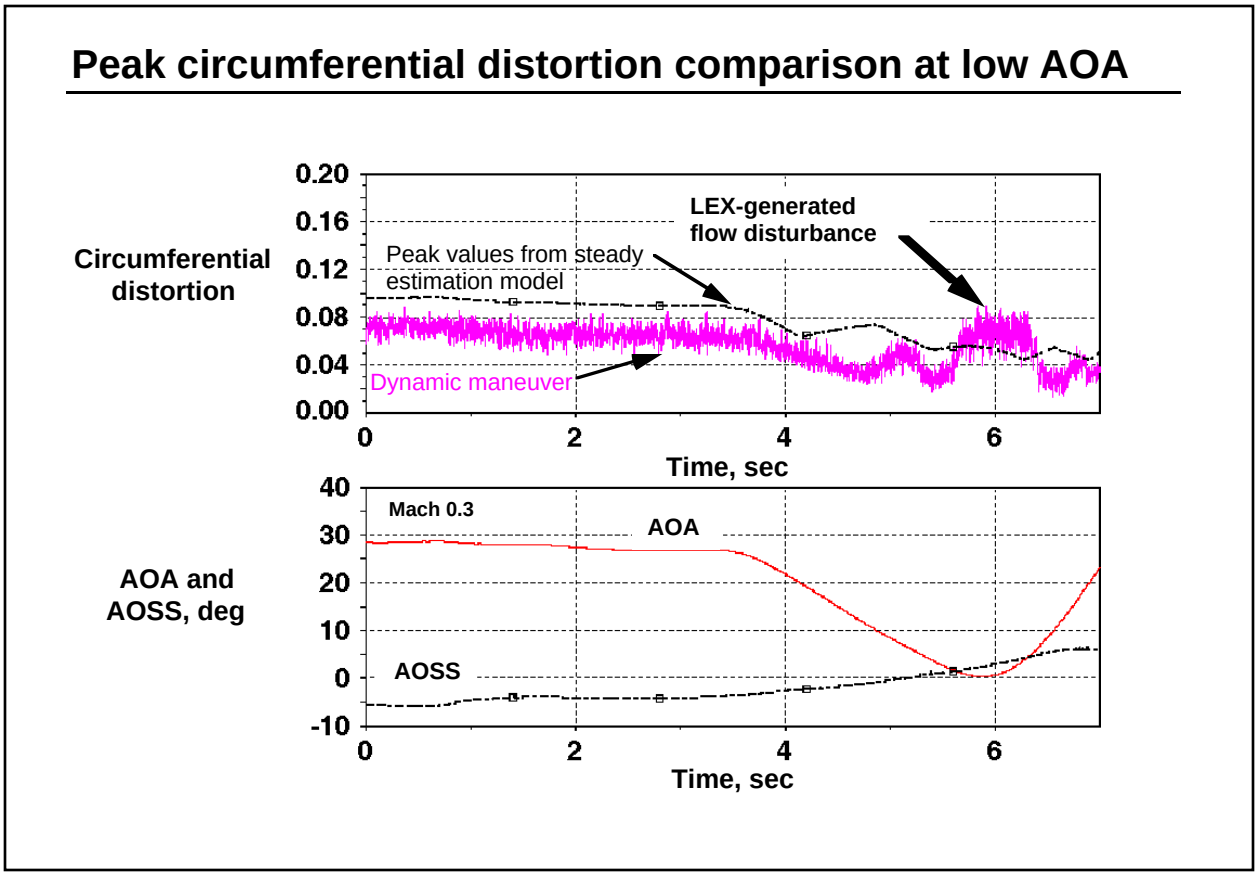
The inlet recovery characteristics during a dynamic AOA sweep are compared with the steady aerodynamic estimation. The top plot compares the recovery level for the dynamic maneuver to the estimation from the steady aerodynamic conditions. The trends show good agreement. A sudden change in the recovery at about 55° AOA does occur. It is believed to be caused by a change in the inlet flow-separation regions. The bottom plot performs a direct comparison between the recovery levels of steady estimation and the dynamic maneuver. A ±1% agreement band about the line of perfect agreement demonstrates the strong agreement between the estimated and measured recovery levels.



The circumferential distortion levels during a dynamic AOA sweep are compared with the peak estimation from steady aerodynamic conditions. The top plot shows the actual distortion levels while the bottom plot shows the AOA trace from 10° to 62° AOA. The distortion levels show the expected increase in the level and activity of distortion as higher AOA is reached. The peaks in the circumferential distortion levels for the transient portions of the dynamic maneuver are less than those of the steady aerodynamic estimation model. This was true for all excursions into the high AOA region of 30° to 62°.



The radial distortion levels during a dynamic AOA sweep are compared to the peak estimation from steady aerodynamic conditions. Again, the top plot shows the actual distortion levels while the bottom plot shows the AOA trace from 10° to 62° AOA. The peak radial distortion levels for the transient portions of the dynamic maneuver are less than those of the steady aerodynamic estimation model. This was true for all excursions into the high AOA region of 30° to 62°. The steady estimation peak levels of radial distortion tended to be approximately 0.01 to 0.03 higher than the peak levels obtained during dynamic maneuvers.



This figure shows the circumferential distortion levels during a dynamic AOA sweep into the low AOA region of 0° to 4°. As before, the top plot shows the distortion levels while the bottom plot shows the AOA trace from 30° to 0° to 25° AOA. The dynamic maneuver was also performed starting from –5° AOSS. The circumferential distortion levels of the dynamic maneuver exceeded the steady aerodynamic estimation at 0° to 2° AOA. It was clear that the discrete steady-aerodynamic conditions did not provide a sufficiently detailed description of the inlet behavior during this maneuver. The ingestion of a LEX-generated flow disturbance is believed to be a factor contributing to the elevated levels. This result was noted in a number of low AOA sweeps at Mach 0.3 and 0.4. The greatest difference seen for the entire database was 0.05.

Results

- **Inlet recovery comparison**
  - **Dynamic maneuver values were typically within ±1% of those at steady aerodynamic conditions**
  - **Discrete changes in recovery trend at high AOA noted during dynamic maneuvers, possibly associated with changing inlet separation regions**

For inlet recovery comparisons:

1. Within the AOA/AOSS model boundary conditions, the majority of inlet recovery levels for the dynamic AOA maneuvers are within ±0.01 of the steady aerodynamic model estimations.

2. The dynamic maneuver data exhibit discrete changes in the recovery trends in the vicinity of 50° to 60° AOA at Mach 0.3 and 40° AOA at Mach 0.4, during low to high AOA sweeps. At these conditions, the steady aerodynamic model overpredicts the inlet recovery level. The inlet recovery change is associated with an increase in dynamic activity and changes in the circumferential distortion trend. These changes require further investigation. The associated behavior of the inlet lip and throat pressures will be examined.

Results (continued)

- **Peak circumferential distortion comparison**
  - **At high AOA (30° to 62°), dynamic maneuver levels were less than or equal to steady aerodynamic estimations**
  - **At low AOA (–6° to 4°), dynamic maneuver levels exceeded the steady aerodynamic estimations by as much as 0.05 (or 5%)**
  - **LEX-generated flow disturbance is a possible factor at low AOA**

For peak circumferential distortion comparisons:

1. At high AOA conditions (30° to 62°), the peak circumferential distortion levels for the transient portions of any dynamic maneuver are less than or equal to those of the steady aerodynamic estimation model. The trends in the peak distortion levels are consistent between the dynamic maneuvers and the steady aerodynamic estimation model.

2. At low AOA (–6° to 4°), during high-to-low AOA maneuvers, the dynamic-maneuver peak circumferential distortion levels exceeded those of the steady aerodynamic estimation model, especially at Mach 0.4. It was clear that the discrete steady-aerodynamic conditions did not provide a sufficiently detailed description of the inlet behavior during these maneuvers. A LEX-generated flow disturbance is thought to be a factor.

3. The maximum peak value of the circumferential distortion during dynamic AOA maneuvers relative to the steady aerodynamic estimation model was 0.05 at less than 4° AOA.

Results (continued)

- **Peak radial distortion comparison**
  - **At high AOA (30° to 62°), the dynamic maneuver levels were less than the steady aerodynamic estimations**
  - **At low AOA (–6° to 4°), the dynamic maneuver levels slightly exceeded the steady aerodynamic estimations by less than 0.01 (or 1%)**

For peak radial distortion comparisons:

1. At high AOA conditions (30° to 62°), the peak radial distortion levels for the transient portion of any dynamic maneuvers are less than those of the steady aerodynamic estimation model. The peak radial distortion of the steady aerodynamic model was estimated to be 0.01–0.03 higher than the dynamic maneuvers.

2. At low AOA conditions (–6° to 4°), during high-to-low AOA maneuvers, the dynamic-maneuver peak radial distortion levels slightly exceeded those of the steady aerodynamic estimation model by less than 0.01 at Mach 0.4 (not shown in presentation).

Concluding remarks

- **No evidence of peak inlet distortion levels being elevated by dynamic maneuver conditions at high AOA (30° to 62°) compared with steady aerodynamic estimations**
- **During sweeps to high AOA, dynamic maneuver distortion levels rarely rose to steady aerodynamic peak estimations**
- **Dynamic maneuvers effective at identifying conditions where discrete changes in inlet behavior occur**
  - **Propagation of separated flow region**
  - **Possible LEX-generated flow disturbance**

Concluding remarks:

1. There was no evidence that peak inlet distortion levels were being elevated by dynamic maneuver conditions when compared to those at steady aerodynamic estimations at equivalent vehicle attitudes for high AOA conditions (30° to 62°).

2. During attitude changes to high AOA, the circumferential and radial distortion values rarely rose to values obtained during maneuvers with steady aerodynamic conditions.

3. Dynamic aircraft maneuvers were effective at characterizing elevated circumferential distortion levels where a LEX-generated flow disturbance may have occurred. Such disturbances could not be verified by other means.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
June 1997

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
F/A-18A Inlet Flow Characteristics During Maneuvers with Rapidly Changing Angle of Attack

5. FUNDING NUMBERS
WU 505-68-30

6. AUTHOR(S)
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and Kevin R. Walsh

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Analytical Services & Materials, Inc.
Edwards, California

General Electric Aircraft Engines
Cincinnati, Ohio

8. PERFORMING ORGANIZATION REPORT NUMBER
H-2146

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
NASA Dryden Flight Research Facility
P.O. Box 273
Edwards, California 93523-0273

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM-104327
NASA Contract NAS 3-26617

11. SUPPLEMENTARY NOTES
Oral presentation presented at the NASA High Angle-of-Attack Technology Conference, Inlet Aerodynamics and Propulsion Session, NASA Langley Research Center, September 17–19, 1996, Hampton, Virginia.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified—Unlimited
Subject Category 07

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

The performance and distortion levels of the right inlet of the F/A-18A High Alpha Research Vehicle were assessed during maneuvers with rapidly changing angle-of-attack at the NASA Dryden Flight Research Center, Edwards, California. The distortion levels were compared with those produced by current inlet-engine compatibility evaluation techniques. The objective of these analyses was to determine whether the results obtained for steady aerodynamic conditions were adequate to describe the inlet-generated distortion levels that occur during rapid aircraft maneuvers. The test data were obtained during 46 dynamic maneuvers at Mach numbers of 0.3 and 0.4. Levels of inlet recovery, peak dynamic circumferential distortion, and peak dynamic radial distortion of dynamic maneuvers for a General Electric F404-GE-400 turbofan engine were compared with estimations based on steady aerodynamic conditions. The comparisons were performed at equivalent angle-of-attack, angle-of-sideslip, and Mach number. Results showed no evidence of peak inlet distortion levels being elevated by dynamic maneuver conditions at high angle-of-attack compared with steady aerodynamic estimations. During sweeps into high angle-of-attack, the peak distortion levels of the dynamic maneuvers rarely rose to steady aerodynamic estimations. The dynamic maneuvers were shown to be effective at identifying conditions when discrete changes in inlet behavior occur.

14. SUBJECT TERMS
Comparison to steady aerodynamic conditions, F/A-18A aircraft, High angle of attack, Inlet distortion, Rapid angle-of-attack maneuvers

15. NUMBER OF PAGES
22

16. PRICE CODE
AO3

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT
Unlimited