AV-8B VTOL EXTERNAL ENVIRONMENT SURVEY - OVERVIEW

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Abstract

This paper presents an overview of the initial AV-8B (-408) VTOL External Environment Survey. The survey was funded by the Joint Strike Fighter (JSF) Program Office. Testing was conducted between 8 and 11 July, 1997 at Patuxent River, Maryland to establish an AV-8B (-408) external environment baseline. Establishment of this baseline serves as a first step towards defining safe operating areas and procedures for the JSF STOVL aircraft. This paper offers insight into the test aircraft, the test preparation, the visual cues used to position the aircraft, an overview of the external environment instrumentation, the test techniques, and the test procedures. The results presented include the measured outwash temperature, velocity and acoustic footprints, a discussion of the maximum temperatures noted on the aircraft skin, and the maximum temperatures measured on the surface of the VTOL pad. This paper also outlines plans for future JSF external environment testing.

This paper contains no information on the JSF STOVL aircraft concepts, or other JSF Contractor Proprietary data. Further information on this and related testing sponsored by JSF, as well as an electronic color copy of this paper, can be downloaded from the Joint Strike Fighter Program Office web site at http://www.jast.mil.

Background

External environment is defined as the temperature, pressure and acoustic levels present in the outwash flowfield of a STOVL aircraft. This subject, and its potential impact on basing flexibility, has been and continues to be a critical consideration during the evolution of the JSF STOVL configuration.

Currently the US Marine Corps, the Royal Navy, the Royal Air Force, Spanish Navy, and the Italian Navy have defined operational procedures and hazard areas to allow safe and productive Harrier operations in shipboard and austere site scenarios. The JSF STOVL aircraft have dramatically greater capability in STOVL operations, but at increased thrust levels. While the specific external environment characteristics of the JSF STOVL aircraft are configuratioin specific, and therefore proprietary, the increased thrust suggests a potentially more severe external environment than the Harrier for which our current operational procedures were developed. As a first step towards defining equivalent operating areas and procedures for the JSF STOVL aircraft, definition of the outwash environment of the AV-8B during vertical takeoff and landing (VTOL) operations was required. The external environment database established during this testing will also allow correlation of analytical external environment predictive methods.

Test Objectives

The primary purpose of this initial test was to quantify the external environment created by the AV-8B (-408) during jetborne operations. Specific objectives of Phase Zero included:

- Measure the outwash velocity, temperature, and acoustic noise at specific ground heights with regard to aircraft distance, heading, and height above ground level (AGL) during hover and ground high power (nogo VTO) operations.
- Evaluate the suitability of candidate high-response transducers for future tests.
- Evaluate the suitability of the test methods and procedures for future tests.
- Measure AM-2 mat temperatures during nogo VTO operations.
- Measure peak aircraft skin temperatures to determine the suitability of applique', a topcoat paint replacement technology under consideration by JSF.

Description of Test Aircraft

The test aircraft for this survey was an AV-8B Harrier II, Night Attack, BuNo 163854, Modex 85 equipped with a Rolls Royce F402-RR-408 engine, six pylons, deep strakes and an onboard MUX bus data recording system. The aircraft was assigned to the Naval Weapons Test Squadron, China Lake. Aircraft zero fuel weight was 15,014 pounds. The relative hover performance and jet pipe temperature values were plus 2.9 percent, and minus 49 degrees, respectively. The only aircraft modification was application of temperature sensitive tape to the aircraft in the quantities and locations illustrated in Figure 1. This allowed definition of the maximum temperature level encountered on the aircraft skin. Mylar type temperature tape, made by Omega, was used to eliminate any associated foreign object damage (FOD) hazard to the engine.

Scope of Tests

Tests were conducted at NAWCAD, Patuxent River, between 8 and 11 July, 1997 at the center field vertical takeoff and landing (VTOL) pad. The VTOL pad was constructed of AM-2 mat and was in excellent condition prior to testing. AM-2 is an extruded aluminum planking, available in 2 ft widths and 6 or 12 ft lengths, with a non-skid coating. It is used by the US Marine Corps for expeditionary airfields and VTOL pads. The Patuxent River VTOL pad is 132 ft by 150 ft, and is anchored around the perimeter to a concrete surface. It was inspected by representatives from the Expeditionary Airfield Support Unit from NAWCAD, Lakehurst prior to testing and during the conduct of the test.

All test points were associated with AV-8B VTOL operations. Nozzles were in the hover stop position (82 degrees - nozzles nominally vertical with the aircraft attitude of 7.5 degrees) with short lift wet (with water injection) or dry power at altitudes from zero ft AGL to 80 ft radar Altitude. As 50 ft radar altitude is a point of specific operational interest, this altitude was selected for a comprehensive definition of the environment around the aircraft. Assuming symmetry, data was collected on the starboard side of the aircraft only with the exception of two verification points on the port side. To define the impact of aircraft hover height on the external environment, data was taken at zero ft AGL (nogo VTO) and for two headings, at 30, 50 and 80 ft radar altitude. Actual testing time (data being recorded, cameras on, and flow visualization activated) was less than 1 hour. There were a total of 59 test events. For airborne test points, aircraft gross weight varied between 15,483 and 18,813 lbs and the hover weight ratio (HWR), defined as ACGW/maximum hover capability, varied between .78 and .93, respectively, for the steady hovers. Aircraft position was observed to vary by no more than ± 5 ft during all airborne points except for the pedal turn where the deviation was closer to 10 ft. Ambient winds were less than four knots. During Nogo VTOs a single Mk-83CF (nominal weight of 985 lb) inert bomb was loaded on each parent station (store stations 2,3,5, and 6) aircraft gross weight varied between 25,343 and 26,143 lbs and the HWR varied between 1.17 and 1.30, respectively. During nogo VTOs, the ambient wind varied from eight to ten knots. During the conduct of the entire test, ambient temperatures varied between 68 and 85 degrees Fahrenheit. Relative humidity varied between 47 and 88 percent. A complete set of test conditions for each test point is presented in Reference 1.

Test Method and Procedures

Tests were performed by operating the aircraft in a vertical takeoff and landing (VTOL) mode in the presence of instrumentation to measure the velocity, temperature, and acoustic energy of the environment surrounding the aircraft. As the rakes were fixed, the azimuth was changed by varying the aircraft heading relative to the rakes. To provide adequate data density for the construction of footprints, data was taken at 20 degree azimuth cuts around a 180 degree azimuth from the aircraft nose to tail. The test conductor was in contact with the test pilot by UHF radio and other test personnel by FM radio. A qualified landing supervisor / safety observer (LSSO) was stationed adjacent the VTOL pad to assist the pilot during airborne test points and enhance test safety. The LSSO was in contact with the pilot and test conductor by UHF radio. To ensure that test conditions were as consistent as possible, the two critical acoustic data headings, 60 and 330 degrees, were measured sequentially. Because the majority of the external environment instrumentation was more suitable for steady state testing, dwell times of 20 seconds were required for each applicable test point. Aircraft freeze data was recorded following each hover. The typical concept of operations was to conduct a sortie that included:

1) a vertical takeoff at a heading
2) dwell at that heading for 20 seconds
3) change to a second heading
4) dwell at the second heading for 20 seconds
5) change to a third heading
6) dwell at the third heading for 20 seconds
7) conduct a vertical landing at the third heading.

The sequence was selected to allow for maximum test efficiency. The total hover time for a sortie typically approached the 5 minute limit for reaction control system (RCS) requiring a timed RCS cool down period before beginning the next sortie. Depending on the aircraft performance available for the ambient conditions, two to three sorties could be conducted before taxiing to the hot pits to refuel. The dwell time for nogo VTOs was limited to 10 seconds from steady rpm to throttle down to minimize potential for aircraft heat damage. The 10 second dwells conducted during this test are twice the duration of nogos conducted normally conducted in service. The pilot cycled the heads up display (HUD) recorder and an on-board instrumentation data recording tape on and off during each test period.

Test Site Preparation

A general description of the test site is presented in Figure 2. Hover center was located on the pad to allow mounting of the 100 ft rake on the AM-2 matting. The test site was populated with four fixed rakes consisting of pressure, temperature, and acoustic sensors. The rakes were located at radial distances of 30 ft, 50 ft, 75 ft and 100 ft. The 50 and 100 ft rakes were offset by 20 degrees from the 30 and 75 ft rakes to minimize rake interference effects. The selection of the angular relationship of the rakes relative to hover center was determined based on historical wind data and the preference that ambient wind reinforce the measured outwash rather that oppose it. The temperature and velocity data processing components were located in a large, specially equipped, data van located approximately 150 ft from hover center. The data van was borrowed from the NAWCAD Propulsion Support Equipment, Evaluation and Verification (E/V) Branch for the duration of the test. A transit and measuring tape were used to locate paint stripes required for spotting the aircraft at the test headings, marks for visual cueing poles (VCP) designed to aid the pilot during aircraft positioning, and marks for the far field microphones. A circle intercepting the test heading markings was painted at the radius of the nose landing gear contact point relative to hover center to aid the plane captain during aircraft spotting. To provide for safety of ground personnel, a 50 ft hazard radius relative to hover center was marked with yellow paint.

Pilot Visual Cue System

As most of the data was taken at hover heights, it was critical to position the aircraft, as precisely as possible, to the desired location with the geometric centroid of the four lift nozzles over the hover center point. To accomplish this, a scheme utilizing visual cueing poles (VCP) was developed to provide information on aircraft position relative to hover center . The VCP system featured two sets of two poles for each desired heading. The poles were positioned such that for a given heading, when the aircraft was over hover center, the VCP pairs were coincident at 35 deg left and 60 deg right of the aircraft centerline relative to the design eye position . The angles were selected to avoid canopy bow obstruction while maintaining a minimum separation of 90 degrees. Twelve foot long sections of 2.5 inch diameter aluminum alloy conduit were painted bright orange and press fit into a T-base constructed of 4’x4’ lumber. The poles were located at radial distances of 125 and 150 ft except when conducting 80 ft hovers where six VCP locations at radial distances of 125, 150, and 175 ft were utilized. The VCP positions at 175 ft were required for the 80 ft hovers to allow for the more elevated pilot field of view. The VCP radius and height was selected assuming a nominal hover attitude of 7.5 degrees with consideration of the cockpit field of view. The VCP system, complemented with heads up display (HUD) information, provided the pilot with adequate positioning cues to locate the aircraft at hover center.

As the typical test procedure involved dwells at three different headings before landing, twelve VCPs were utilized. The VCP team stood up and laid down the appropriate poles for each heading. A VCP team coordinator optimized test sequencing and organized pole pair teams. The pole team coordinator was equipped with a scanner to monitor the test frequency and an FM radio to provide communication with the test conductor. A hover station observer (HSO), equipped with a transit, was stationed in the outside of 300 ft to observe hover station keeping.

The VCP system was not required for NoGo VTOs. For these events, the plane captain directed the pilot into position using the markings on the VTOL pad. However, the pilot did confirm the position using the VCPs.

Velocity and Temperature Measurement

Thermal and velocity data, as a function of height above the ground, was collected using four fixed rakes provided by NASA Ames Research Center. Each rake was ten feet tall and populated with total pressure, 3 hole total pressure, and static pressure probes as well as thermocouples. Three angled rakes were located at 30, 50, and 75 ft from the hover center and one long rake was located at 100 ft. Directional sensors (ducks) were mounted to the angle rake base plates at three inches AGL to measure horizontal flow direction. Pressure lines were used to transfer pressure readings from the probes to the data system in the data van. Reference ambient static pressure was measured by a pressure probe that was located in a baffled box inside the data van. Additional transducers, most notably four high-response pressure transducers per rake, were added to adapt the rakes for the specific objectives of this test. A more detailed discussion of the velocity and thermal measurement systems is included in Reference 2.

Pressure Transducers and Thermocouples: Two types of pressure transducers were used. Electronic scanning pressure (ESP) modules were used to collect steady-state data and individual high-response pressure transducers were used to collect dynamic data. ESP modules were calibrated at the test site prior to each sortie. The high-reponse pressure transducers were also calibrated at the test site several times, but not prior to each sortie.

Outwash flow gas temperature was measured with 20-gauge, type J thermocouples, capable of measuring up to 900 ^{o}F. A total quantity of 32 thermocouples were utilized.

Data Systems: Three separate data systems were used to collect steady state velocity, dynamic velocity, and temperature data. Each system was sinked to inter-range instrumentation group (IRIG) time. The data systems were located in the data van. A Pressure Systems Inc. model 8400 featuring an analog input unit was used to measure all 100 channels of steady-state pressure data. High-response pressure data was collected using a personal computer based system featuring a digitizing card. High-response pressure data was sampled at 100 Hz and recorded without filtering. A TempScan/1100A unit manufactured by Iotech, Inc. was used to collect temperature data. The TempScan/100A is a compact instrument that is capable of measuring 196 thermocouple inputs at a ±0.9 ^{o}F accuracy. Temperature data was recorded on a personal computer through an RS-232/422 interface. Further detail on the data systems are presented in Reference 2.

<u>VTOL Pad Surface Temperature Measurement</u>

Since one of the test objectives was to measure the pad temperatures resulting from nogo VTO operations, a non invasive technique using a infrared (IR) imager was employed.

<u>Test Procedure</u>: The aircraft was positioned over hover center under the direction of the plane captain. Following an engine acceleration check with nozzles at 60 degrees, the aircraft power setting was stabilized at short lift wet or short lift dry for ten seconds during nogo VTOs. Immediately following the 10 second period, the aircraft was then taxied away from hover center and the infrared imager was moved into position to view the hot spot. Thermographic images were acquired at 10-20 second intervals to assess the thermal decay over approximately 8 minutes. The temperature of the hot spot at shutdown was then extrapolated from the data using a fourth order polynomial. As a step to minimize heat damage to the aircraft structure, the aircraft was not repositioned at the hover center sooner that five minutes after the previous Nogo VTO. A hand-held infrared temperature gun was used to collect pad temperature data before the camera could be positioned and for comparison to thermographic images. The temperature gun was also used to measure the main landing gear wheel temperature.

<u>Infrared Imager</u>: Thermographic images of the VTOL pad were acquired using an AGEMA Model 780 infrared imaging system. The AGEMA 780 is sensitive to infrared emissions in the 3-5 mm bandwidth. Measurements are taken in “isotherm units” (units of watts/steradian) and compared to a calibrated blackbody standard. An emmissivity setting of 0.95 was used based on spot checks of the AM-2 prior to testing and previous experience. Atmospheric transmission losses were accounted for. Further detail on emissivity and atmospheric corrections is presented in Reference 1.

To achieve the desired field of regard, the AGEMA infrared imager was mounted on the platform of a B-6 maintenance stand pulled by a pickup truck. The imager’s AGL was 22 ft. The infrared image, using a nominal 40 degree field of view, was approximately 15.5 by 16.0 ft (horizontal by vertical).

Acoustic Noise Measurements

Acoustical noise measurements were performed by a team from Armstrong Lab (AL), Bio-Acoustics Branch, Wright Patterson AFB. Noise measurements were made externally around the aircraft and in the cockpit. External Noise measurements were made during the 50 ft hover and Nogo VTO test conditions. Acoustical noise was recorded for 20 seconds for each stabilized test point. Far-field acoustical noise measurements were made for two sequential 20 second intervals during hovers. The first measurement was used to map the forward right-hand quadrant and the second to map the aft right-hand quadrant. This back-to-back sequence allowed a 180 degree angle to be measured with nearly equal fuel levels and ambient environmental conditions.

Far-Field: Far-field data was recorded by a fixed array of microphones, located as illustrated in Figure 2, covering a 90 degree sector at radii of 100 ft and 250 ft from the hover center. The microphones were located at 4 ft AGL and fed into one of two multi-channel recorders located approximately 300 ft from the aircraft. Cabling was run radially away from the aircraft and toward the recorders. Sand bags and one gallon water jugs were used to stabilize the 100 ft microphone tri-pods.

Near-Field: Near-field data was recorded at 30 and 50 ft from aircraft center. Data was recorded by microphones mounted to the 30 and 50 ft velocity rake fixtures – two microphones and a shared power supply at each rake. One microphone was 5 ft AGL and the other was approximately 8 ft AGL. Near-field data was measured at 20 degree increments around one side of the aircraft in conjunction with velocity and temperature measurements.

Cockpit: Internal noise measurements were recorded on a portable two channel tape recorder. A microphone, mounted on the external surface of the pilot's helmet was used to record ambient cockpit noise. A miniature microphone positioned under the protective earcup was used to record the noise level at the pilot's ear. The recording system interfaced with the aircraft communication system so that the pilot could verbally annotate the tape.

Ground Observer Measurements: A two channel instrumentation system was used to measure the ambient noise level at the observer's head and also under the protective earcup at the ear. The observer remained at a distance from the hover center of 50 ft or greater during testing.

Flow Visualization

Two types of flow visualization techniques were employed. The first used an infrared camera located at approximately 300 ft of radial distance. The second used smoke grenades (MK-13 - orange aircrew emergency locators) in conjuction with a video recorder. The smoke grenades were attached, using safety wire and aluminum tape, to both ends of a ten foot piece of 3/4' metal conduit. A Radiance 1 Portable Infrared

Camera System was used to visualize flow field characteristics. The camera was a fully integrated, self contained, high performance infrared camera system based on staring focal plane array technology. This system used a 256x256 Indium Antimonide (InSb) array sensitive over the 3 to 5 micron waveband. The camera was cooled with a mechanical micro-cooler not requiring liquid nitrogen. Data and IRIG time was stored on VHS video tape. The camera was powered by a 110 V AC power generator.

Observers

Qualitative observers fitted with cranials, goggles, double hearing protection, coveralls, and safety shoes were permitted to experience the outwash field as close as 50 ft from the hover center during aircraft maneuvers. Observations on flowfield characteristics were also provided by VCP team members.

Results

Steady-State Velocity and Temperature

The outwash velocities and temperatures were successfully quantified for steady hovers and during Nogo VTOs. Velocity and temperature peak (maximum steady state value measured at a given rake location) data footprints for 50 ft hovers are presented in Figure 3. Aircraft gross weight and HWR are provided for each data point. Interpolation to allow generation of contours was conducted using a weighting process known as kriging. For a 50 ft radar altimeter height, the measured peak velocity and temperature at the published 50 ft hazard radius was 61knots at 60 deg off the nose and 129 deg F at 80 deg off the nose, respectively. Both of these peaks were measured low to the ground at the nine inch AGL sensor locations; However, it is important to note that the profile of velocity and temperature as a function of height AGL varies sharply as a function of azimuth. Towards the wingtip, the ground sheet is relatively thin. At the nose and tail, the sheet is much thicker. A comprehensive discussion of the measured data as a function of height AGL is presented in Reference 2. Less comprehensive data was collected for hover heights of 30 and 80 ft of radar altitude. Peak velocity and temperature data are provided in Tables 1 and 2 for comparison. 50 ft hover data at 310 degrees will be presented in a future NAWCAD report. It should be noted that the aircraft gross weight was 16,123 (HWR 0.80), 15,483 lbs (HWR 0.79), and 16,803 lb (HWR 0.83) for the comparable 30, 50 ft, and 80 ft hovers, respectively. A comprehensive data set, including comparable data from the high-response data system, is presented in Reference 1. Comparisons with other Harrier outwash measured data and analytical predictions are underway. A discussion on the normalization of the outwash data relative to the aircraft hover weight is presented in Reference 3.

Unsteady Velocity and Temperature

To allow validation of both independent pressure measuring systems, the peak and mean velocity data from the high-response data system were plotted against the results from the steady-state system for comparison. The mean high-response data generally compared well with the steady-state data. The high-response velocity data from the dynamic maneuvers is questionable because static pressure local to the dynamic sensors was not recorded. There was also lag in the temperature data system affecting the computation of velocity. The velocity footprints presented in this paper, as well as those presented in Reference 1, were derived from steady-state data. Raw temperatures and pressures, as well as velocity time histories for selected dynamic maneuvers, are presented in Reference 1. Data was filtered, post-test, at 0, 0.5, and 5 Hz with 5 Hz being optimum for isolating meaningful data.

Acoustic Noise

Comprehensive external and cockpit internal noise data, overall and spectral, is presented and analyzed in Reference 4. The external noise can be characterized as broadband with no pure tone content within the audible frequency band. An A-weighted acoustic noise level carpet plot for a 50 ft hover condition is presented as Figure 4. For all high power test conditions, the noise level exceeded the threshold for double hearing protection, 104 dB(A), at the 250 ft microphone locations. Overall A-weighted levels at the pilot's ear during ground idle and hover conditions were 50 and 54 dB(A), respectively. These are benign levels from both a hearing hazard or communications perspective.

VTOL Pad

VTOL Pad Surface Temperatures: Following the first, third, and fifth nogo VTO, the infrared imager was positioned over the hot spot in a time of 2:15, 1:15, and 1:07, respectively, from the time of throttle down. Peak AM-2 Mat temperatures extrapolated from thermographic images ranged between 426 and 578 degrees Fahrenheit. A complete thermographic data report is presented in Reference 1.

VTOL Pad Surface Erosion: There were several events of AM-2 non-skid erosion observed following the nogo VTO testing. The Expeditionary Airfield personnel on-site indicated that the relatively small areas of erosion would not result in the pad being downed, as the failure criteria is 30% of the non-skid coating being eroded from a panel. Erosion of non-skid coating from AM-2 has not been a problem in service; However, the length of time at full power for the test nogos was twice that of worst case exposure during standard operations. The panels retained the non-skid coating in the area above the AM-2 webs, indicating that the non-skid was retained in areas that were able to more efficiently conduct heat away from the surface. A more comprehensive discussion of the observed erosion is presented in Reference 5.

Aircraft Skin Temperatures

Peak skin temperatures exceeded 400 degrees Fahrenheit in the areas indicated in Figure 1. Results indicate that current applique's are unsuitable for some surface areas of the Harrier and possibly the STOVL variant of JSF. Further evaluation of the suitability of applique' on STOVL aircraft is being considered for the next phase of Harrier testing. Specifically, applique' coupons may be applied to high temperature areas.

Lessons Learned

Visual Cue Pole System: The VCP system was satisfactory based on HSO personnel observations. However, the pilot commented that the concept could be improved by arranging the poles symmetrically relative to the test heading (sacrificing angular separation). Positioning the poles at +/- 35 degrees relative to the pilot design eye position will be considered for future tests. Symmetric pole orientation should enhance gross acquisition of the target heading. The pilot confirmed that the VCP height and radii were satisfactory. He noted that the 125 ft poles were out of his field of view during 80 ft hovers as expected.

Hover Station Observer: The HSO concept for accessing hover station keeping was satisfactory for the purposes of this test. However, for future tests the concept will be enhanced by using video recording cameras that feature a vertical reference line and IRIG time. This solution is preferred over a laser tracker approach because of the costs and complexities associated with laser systems and temporary reflector installations on test aircraft.

Nogo VTOs: The main gear tires failed following the sixth nogo VTO. Following each nogo, the plane captain visually inspected the tires during the cool down period. The plane captain expressed concern on the condition of the tires following the fourth nogo. The tires were considered to be too weakened to continue testing following the sixth nogo (sidewalls had lost stiffness). Following a cool down period, an attempt to taxi the aircraft back to the hangar to replace the tires was made. Shortly after entering the taxiway the tires were considered too deflated to allow safe taxi. The tire failure was apparently caused by a combination of the high temperatures softening the sidewalls and the high sideloads caused by a tight turning radius at a high gross weight. The softening of the tire carcass allowed the tire bead to deform resulting in a loss of pressure. Monitoring of the tire temperature with the handheld infrared gun indicated that the hub temperatures did not approach the 345 F temperature typically associated with fuse plug melting. It is speculated that the cumulative effects of hot nozzle flow against the tire sidewall led to the failures. Similar failures should be anticipated and prepared for, as they were for this test, if repeated nogo VTOs are to be performed.

There was evidence of ground sheet rollup before reaching the 100 ft rake during nogo VTO testing with 10-12 knots of ambient wind. This suggests that future tests should be limited to a wind component opposing the outwash below five knots .

Observers

Outwash flow field observation were made by dedicated observers who approached as close as 50 ft away from hover center as well as those individuals at 100 to 200 ft from hover center. Upon review of test video, one would conclude initially that the observers at 50 ft would be most uncomfortable with the poor footing and instability associated with the unsteady outwash. However, one observer, who experienced the outwash in the area of a wingtip, indicated that the high temperature was predominant. Observers outside of 100 ft noted longer than expected delays in the arrival of the ground sheet. It was noted that during vertical takeoffs the ground sheet arrived typically in about 3-4 seconds at 125 ft radial distance. There were some differences as a function of aircraft azimuth, but in most cases the sheet arrived in less than 5 seconds. There was one instance, at an azimuth 45 degrees off the nose, that the sheet took 12 seconds to arrive at 125 ft. When the sheet did arrive at that radial distance, it was noted that the velocity felt constant with height above the ground.

Instrumentation

Flow Visualization: The MK-13 locator flares (smoke grenades) used to provide flow visualization were unsatisfactory because smoke generation was too brief. However, limited smoke flow visualization was captured on video. In the future, longer duration smoke cans should be used. The infrared camera system worked satisfactory for flow field visualization for the aft nozzles. The combustion byproducts proved to be an acceptable seeding material. The infrared system did not pick up front nozzle efflux. The system was not useful for quantitative measurement of ground sheet characteristics. While the directional ducks did not provide the desired recorded directional data because they were not properly calibrated, they served as a useful visual indication of the flow dynamics in terms of angularity and frequency.

Sensors and Data Systems: The flow sensors and data systems were satisfactory with the following exceptions or recommended enhancements:

- thermocouple data acquisition system components failed when not in a environmentally controlled environment
- thermocouple system lag is a concern for future dynamic testing
- greater angular resolution of the ambient wind system is desirable
- upfront data filtering for data spike management is recommended
- low cost high-response sensors exhibited undesirable drift

Future Tests

An advanced outwash measurement system (OMS) has been designed and is currently under fabrication by the JSF STOVL Test Team. The OMS will be a remotely controlled, cart-mounted rake system. The OMS will feature components suitable to collect oscillatory temperature and pressure data under extreme STOVL outwash flow conditions including those predicted for the JSF STOVL variants. The OMS is being designed to obtain accurate data throughout the wall jet profiles typically found in STOVL aircraft outwash during both steady and dynamic maneuvers. The focus will be on high-response data, as the long residence maneuvers required by a steady-state data system are not acceptable for the X-32B/X-35B flight test programs. The OMS will be used for a second

AV-8B -408 test in the fall of 1998. This test will repeat a set of conditions previously tested to prove the viability of the OMS. In addition, the scope of the database will be expanded to include the short takeoff environment and other conditions of interest. Following assessment of the next set of test data, and further refinement of test procedures from the next test phase, the cart system will be improved as required for JSF demonstrator testing. Pending JSF Program Office approval, the OMS will be utilized during X-32B and X-35B lift system testing at Pratt & Whitney followed by X-32B and X-35B aircraft testing

Acknowledgments

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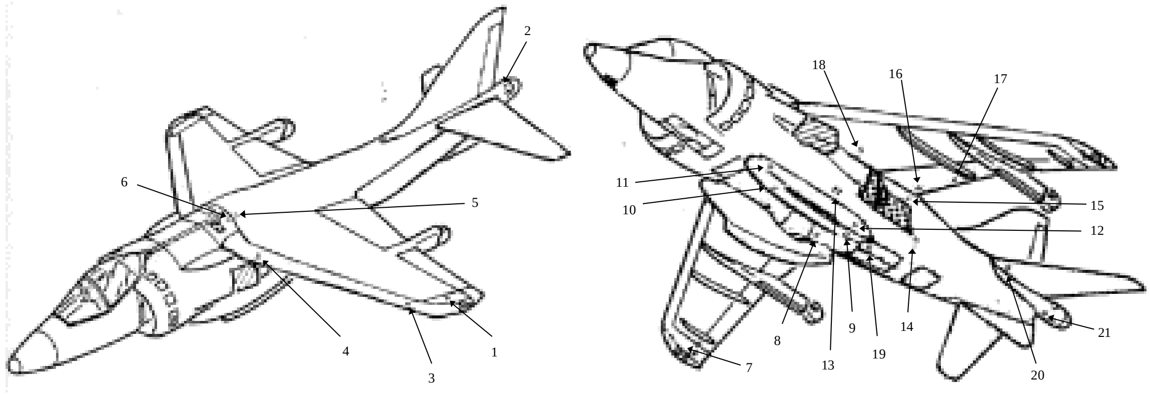


Temp Tape Number	Location On Aircraft	7/8/97	7/9/97	7/10/97	7/11/97	Highest Temp (deg F)
1	upper, port wingtip inboard of RCS outlet	> 400	> 400	> 400	> 400	> 400
2	top surface of aft tail bullet fairing	410	410	410	410	410
3	port wing leading edge outboard	160	160	160	160	160
4	port wing leading edge inboard	180	180	180	180	180
5	top center wing skin aft of APU exhaust	120	NR	NR	150	150
6	APU access panel just aft of APU exhaust	< 330	NR	NR	< 330	< 330
7	lower, starboard wingtip skin inboard of RCS outlet	270	310	310	310	310
8	lower fuselage skin between strakes	< 330	< 330	< 330	< 330	< 330
9	aft inboard skin of port strake	< 250	250	Missing	Missing	250
10	forward inboard skin of port strake	< 170	170	200	200	200
11	forward outboard skin of port strake	< 170	< 170	< 170	< 170	< 170
12	aft outboard skin of port strake	< 250	< 250	250	Missing	250
13	lower center fuselage skin between nozzles	130	130	170	170	170
14	port fuselage skin just aft and below blast deflector	< 250	< 250	< 250	< 250	< 250
15	port fuselage skin between blast deflector and flap	< 250	< 250	< 250	< 250	< 250
16	lower inboard skin of port flap skin	310	330	330	330	330
17	lower outboard corner of port flap skin	120	130	180	180	180
18	lower port inboard wing skin between nozzles	< 170	< 170	170	170	170
19	main landing gear door forward edge port side	200	> 270	Missing	Missing	> 270
20	inboard forward corner of port stabilator	< 170	< 170	< 170	< 170	< 170
21	lower skin just forward of pitch RCS outlet in tail bullet	> 400	Missing	Missing	Missing	> 400
	Notes: "NR" indicates that temperature was not recorded					
	"Missing" indicates that the temperature tape came off the aircraft during flight					
	< or > symbols indicate that temperatures were lower or higher than applied temp tape range					

Note: Five 8-point irreversible temperature tape ranges were utilized. The temperature resolution of the tapes ranged from 5 degrees F for the lower temperature ranges to 10 or 15 degrees F for the higher range.

Figure 1
Measured External Skin Temperature Data (Maximum in Degrees Fahrenheit)

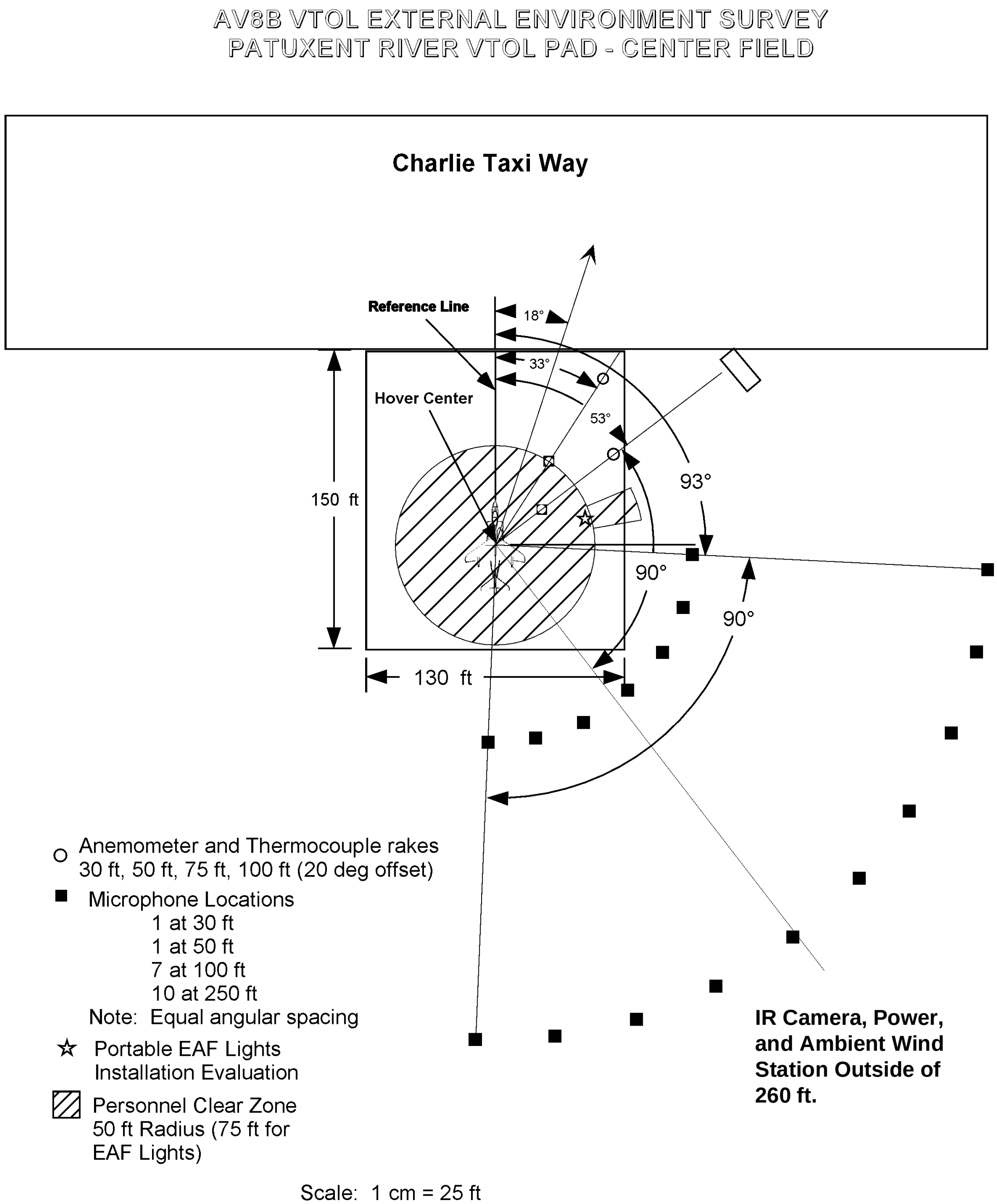
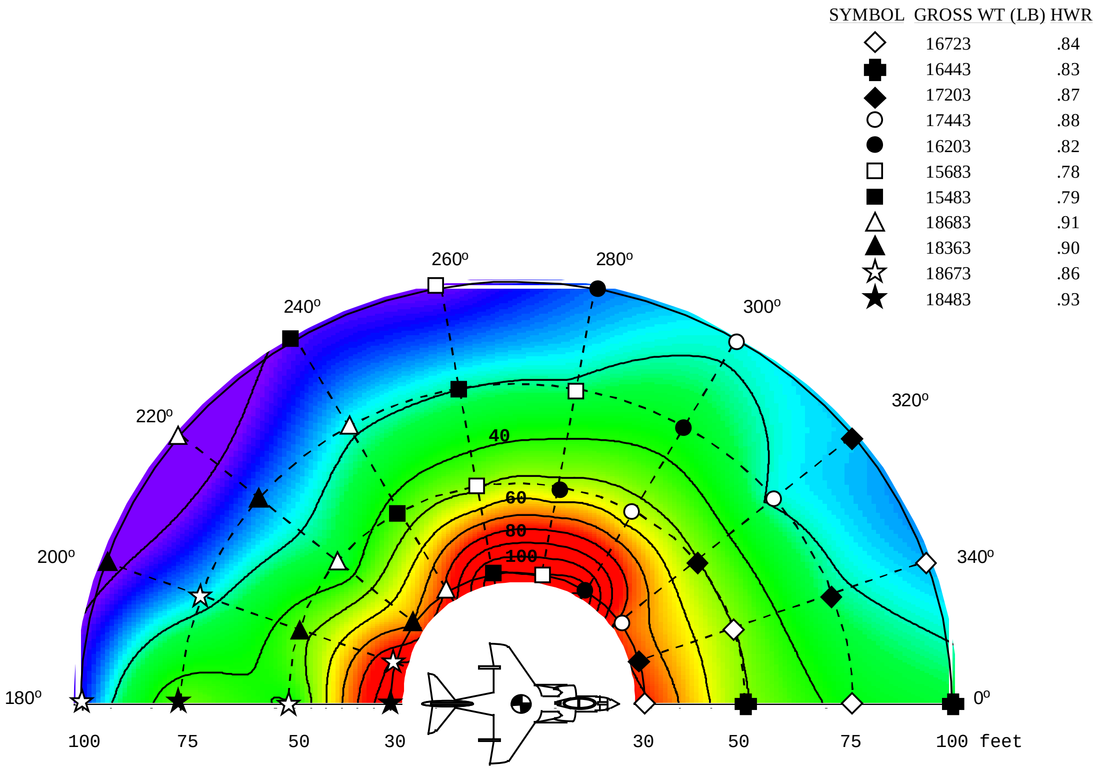
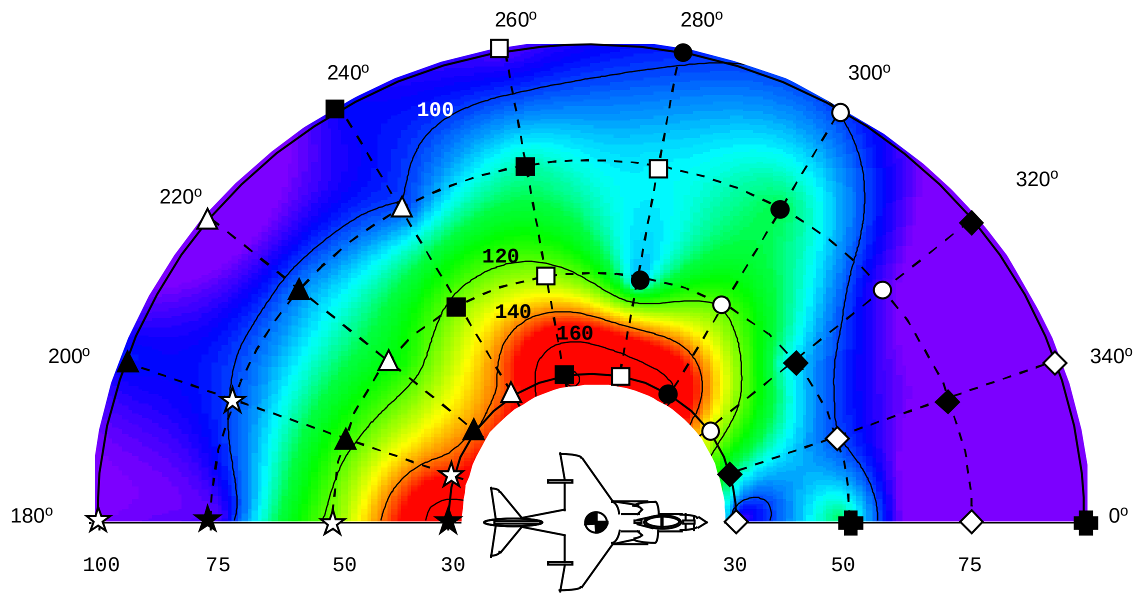


Figure 2. General Test Site Arrangement

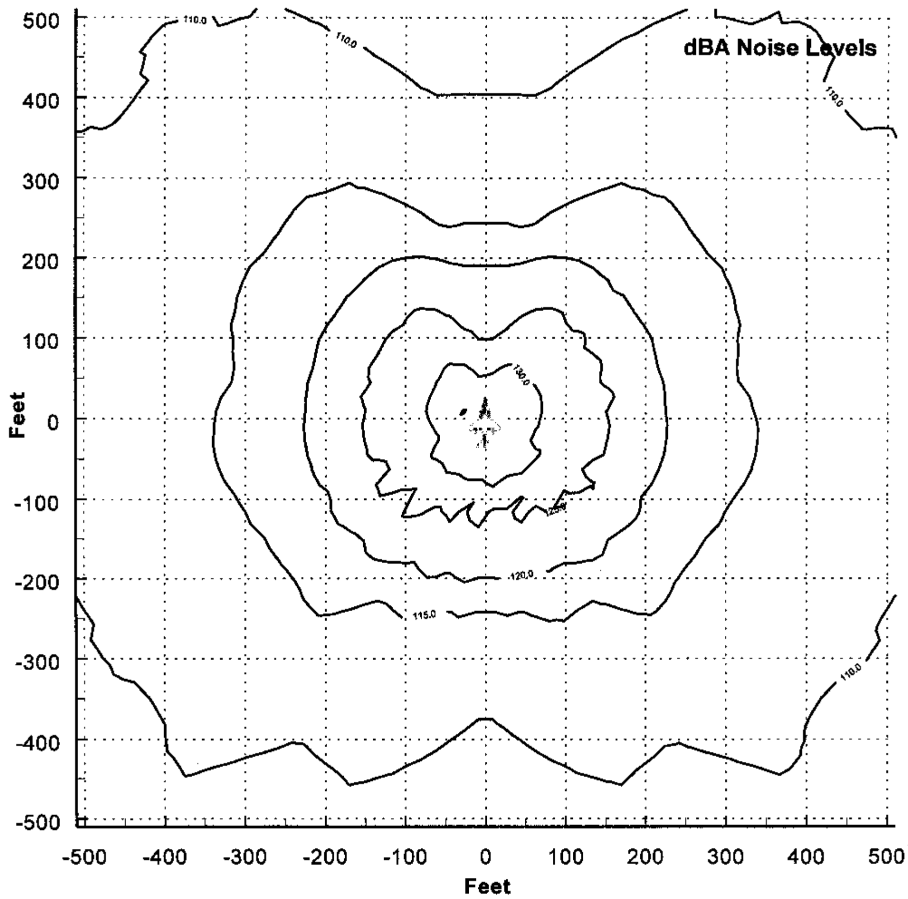


AV-8B MAXIUM VELOCITY (KNOTS) CONTOURS DURING 50 FT-AGL HOVERS



AV-8B MAXIMUM TEMPERATURE (ºF) CONTOURS DURING 50 FT-AGL HOVER

Figure 3. Maximum Velocity and Temperature Contours



Appendix A

Figure 4. Acoustic Contours During 50 ft Hover

Table 1. Peak Temperatures for 30, 50, and 80 ft Stable Hovers

	Horiz.Dist. from Aircraft (ft)														
		30				50				75				100	
Azmuth (deg)	30 ft Hov	50 ftHov	80 ft Hov		30ft Hov	50ft Hov	80ft Hov		30ft Hov	50ftHov	80ft Hov		30ft Hov	50ft Hov	80ft Hov
0 (nose)		97.1				108.3				83.6				94.4	
340		109.3				89				94.3				82	
330					91.5		96.28						87.8		87.37
320	103.9	116.6	124.27			106			92.6	97.3	96.34			92.3	
310	105.24		114.44						91.7		94.8				
300		167.2			122.12	121.2	110.7			109.2			103.72	99.9	92.38
280		171.5				128.5				104.5				99	
260		183.6				126.6				107				96.3	
240		145.3				126.6				100.3				96.3	
220		138.5				114.7				102.3				91.2	
200		143.1				119.1				100.8				98.9	
180 (tail)		167.5				124.6				96.4				95.6	

Note:Temperatures in Deg F

Table 2. Peak Velocities for 30, 50, and 80 ft Stable Hovers

	Horiz.Dist. from Aircraft (ft)														
		30				50				75				100	
Azmuth (deg)	30 ft Hov	50 ftHov	80 ft Hov		30ft Hov	50ft Hov	80ft Hov		30ft Hov	50ftHov	80ft Hov		30ft Hov	50ft Hov	80ft Hov
0 (nose)		82.11				53.23				38.55				34.60	
340		78.10				54.48				32.41				27.79	
330					25.2		45.45						10.78		21.91
320	65.65	78.10	82.18			56.25			27.77	30.65	36.39			28.35	
310	60.45		79.98						21.84		35.89				
300		122.60			51.21	60.99	49.95			36.67			25.19	29.26	21.17
280		112.21				57.36				31.47				25.28	
260		115.62				52.05				30.70				20.48	
240		82.75				47.74				29.95				21.81	
220		70.36				36.24				26.87				15.43	
200		91.69				49.38				28.23				18.62	
180 (tail)		94.93				39.56				48.25				21.07	

Note: Wind Velocities are in Kts