Tiltrotor Acoustic Flight Test: Terminal Area Operations

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ABSTRACT

This paper provides a comprehensive description of an acoustic flight test of the XV-15 Tiltrotor Aircraft with Advanced Technology Blades (ATB) conducted in August and September 1991 at Crows Landing, California. The purpose of this cooperative research effort of the NASA Langley and Ames Research Centers was to obtain a preliminary, high quality database of far-field acoustics for terminal area operations of the XV-15 at a take-off gross weight of approximately 14,000 lbs for various glide slopes, airspeeds, rotor tip speeds, and nacelle tilt angles. The test also was used to assess the suitability of the Crows Landing complex for full scale far-field acoustic testing. This was the first acoustic flight test of the XV-15 aircraft equipped with ATB involving approach and level flyover operations. The test involved coordination of numerous personnel, facilities and equipment. Considerable effort was made to minimize potential extraneous noise sources unique to the region during the test. Acoustic data from the level flyovers were analyzed, then compared with data from a previous test of the XV-15 equipped with Standard Metal Blades (SMB). The data comparison revealed no conclusive acoustic advantage of the ATB over the SMB although some differences were noted in the 3000 - 4500 Hz range. The spectral density in that range from the SMB was higher than that from the ATB. Level flyovers at 250 ft altitude and a rotor speed of 677 ft/sec, the maximum Overall Sound Pressure Levels (OASPL) from both sets of blades are approximately 103 dB, although the ATB maximum OASPL impacts a larger area on the ground than the SMB.

NOMENCLATURE

ATB	Advanced Technology Blades
BPF	Blade Passage Frequency
i_n	Nacelle Tilt Angle
IPS	Instrument Positioning System
OASPL	Overall Sound Pressure Level, dB (re 0.0002 dynes/cm^2)
SMB	Standard Metal Blades
VASI	Visual Approach Slope Indicator
v_k	Airspeed (knots)
V_t	Rotor Tip Speed (ft/sec)
γ	Glide Slope

INTRODUCTION

Air traffic at major airports worldwide has become severely congested. Construction of new major airports in heavily populated areas requires surmounting significant political and economic barriers. Because the percentage of airport usage by commuter aircraft is greater than the proportional passenger load, a civil tiltrotor commuter transport offers a potential solution for relieving this air traffic congestion. A fleet of civil tiltrotor transports, operating in a National Airspace System tailored to permit vertiport access independent of airport control, would permit a significant increase in passenger movements at existing airports.

The possibility of generating unacceptably high noise levels while performing terminal area operations is of significant concern in operating the tiltrotor aircraft in highly populated areas. Terminal area operations are those operations that are performed near flight terminals, such as hover, departure, and approach. While operating in airplane mode, the tiltrotor aircraft is relatively quiet. However, while operating in tiltrotor mode or in helicopter mode, as would be required near vertiports, the noise levels are at least comparable to helicopters of similar gross weights. These noise levels will be unacceptable for future commercial rotorcraft; therefore, techniques for reducing the noise must be determined. Thus, to achieve this, the acoustic characteristics of the tiltrotor must be ascertained along with methods to predict these characteristics.

Acoustic flight testing is an essential element in obtaining the acoustic characteristics of a tiltrotor aircraft. The results from an acoustic flight test are necessary in characterizing unique tiltrotor noise mechanisms. These are also necessary to develop accurate acoustic prediction schemes.

Previous acoustic flight tests of the XV-15 tiltrotor aircraft have been limited, and conducted mostly using the original metal rotor blades. These include a brief hover test in 1981 at Moffett Field, Ca. (ref. 1), level flight conditions and approaches at Crows Landing, Ca. in 1982 and 1986 (ref. 2), and in Maypearl, Tex. in 1988. Approach data from the latter test were obtained from microphones mounted on 4-ft. stands (ref. 3). Ground board mounted microphones were used for level flyovers in the 1988 test (ref. 4). A hover test was conducted at Moffett Field, Ca., in 1990 using the Advanced Technology Blades (ATB)(ref. 5). Reference 6 reviews the state of knowledge and the needed improvement in noise methodology and measurements for tiltrotor aircraft. Reference 7 reviews the background of U.S. tiltrotor development and discusses key issues for civil tiltrotor applications with special attention to noise considerations for civil tiltrotor operations. A review of current research and technology development efforts at the Langley Research Center is also given in reference 7.

This paper will provide a comprehensive description of a 1991 terminal area operations acoustic flight test at Crows Landing Naval Auxiliary Landing Field and an assessment of the suitability of the Crows Landing complex for such testing. A preliminary comparison of level flyover acoustic data from the SMB (Maypearl 1988) and the ATB (Crows Landing 1991) will also be presented.

TEST DESCRIPTION

In August and September 1991, a terminal area operations acoustic flight test was performed at Crows Landing Naval Auxiliary Landing Field with the ATB. Crows Landing is located 100 miles southeast of San Francisco and 60 miles east of Ames Research Center, in the San Joaquin Valley. Figure 1 shows the location of the test site in the region. The test was a cooperative research effort of the NASA Langley and Ames Research Centers.

The primary purpose of the test program was to obtain a preliminary, high confidence level database of far-field acoustics for terminal area operations of the XV-15 aircraft at a nominal gross weight of 14,000 lbs. This database would augment the present databases for the XV-15 tiltrotor aircraft. This data would also be used to validate tiltrotor noise prediction codes and in planning future test programs.

A secondary purpose of this test was to determine the suitability of the Crows Landing Naval Auxiliary Landing Field for far-field full scale aircraft acoustic testing. If determined suitable, this complex is a likely candidate for future comprehensive acoustics tests by NASA. Special requirements for such a test site include low background acoustics, control of nearby airspace, personnel communications systems, accurate aircraft tracking and guidance systems and high-speed on-board data systems.

Facility Description

The Crows Landing area is flat and rural with low ambient noise levels when other aircraft are not present, making it ideal for acoustic measurements. The test was conducted in late summer, thus ensuring low humidity conditions and no precipitation.

Crows Landing offers a unique test range for acoustic and other research. The most outstanding attribute of the facility is the Instrument Positioning System (IPS), which had not previously been used for acoustic flight tests. The IPS is a guidance and tracking system under development by the Moffett Range Systems Branch at Ames Research Center. The system features a laser tracking system attached to a standard radar tracker, a mainframe computer, and an Instrument Landing System (ILS) transmitter. Once programmed for a particular flight path profile, the computer compares the actual position of the aircraft to the desired track and translates this error into an ILS signal, which is then picked up by the ILS receiver on the subject aircraft. The great advantage of this system is that it provides real-time positioning feedback to the pilot without the need for special equipment or displays; any aircraft equipped for FAA Instrument Flight Rules (IFR) operations can use IPS without extra instrumentation.

Test Aircraft

The XV-15 used in this test was equipped with the newer Advanced Technology Blades (ATB) rather than the previously used Standard Metal Blades (SMB). The ATB have a number of design features that are consistent with reduced acoustic noise. A detailed description of these blades may be found in reference 8. In summary, these all-composite blades feature thin tips with high speed airfoils to reduce tip noise. The greater solidity of the ATB over the SMB, and its twist distribution allow for adequate thrust generation at reduced tip speed which can also reduce noise. The blade thickness distribution of the ATB is non-linear compared to the SMB, which will affect loading noise characteristics.

The XV-15 was equipped with an extensive suite of on-board instrumentation. Transducers included strain gages, temperature sensors, accelerometers, rate sensors, and pressure transducers. Data from these transducers were forwarded to three remote multiplexer-demultiplexer units (RMDU) which provided signal conditioning, digitization, and encoding into pulse-coded modulation (PCM) format. The data stream was then recorded on an on-board tape recorder and transmitted to the ground using L-band telemetry for recording on a ground-based incident tape. A time correlation base for this system was supplied in IRIG-B format by an on-board time code generator synchronized to a GOES satellite prior to each flight.

The data were downlinked to the control station at Crows Landing and were then relayed to Ames Research Center, 60 miles to the west. At Ames, the downlinked data were monitored throughout the test by XV-15 engineers. Flight loads were monitored in real-time and compared against pre-established limits, to provide safety-of-flight.

Crew members designated “prime data” by providing a coded mark on the data tape. Prime data event numbers referenced certain segments of the data stream and associated them with the flight conditions or specific aircraft states. As such, they provided vital identification of data for inclusion in the TiltRotor ENgineering Database System (TRENDS) (ref. 9).

Acoustic Instrumentation

The acoustic instrumentation consisted of 12 analog microphone systems which were operated from one mobile data van. Each microphone system consisted of a 1/2-in. omnidirectional condenser microphone fitted with a grid cap and wind screen. This system was mounted on a planar ground-board, along with preamplifier/heater, a power supply/line driver, and an amplifier. The microphones were arranged in three linear arrays of four microphones each and located in a Government-leased field just west of runway 17-35 as shown in figure 2. The distance between adjacent microphones within each array was 200 ft, while the distance between arrays was 250 ft. The four microphones in each array provide the necessary data for Langley's ensemble-averaging technique. The three microphone arrays permit simultaneous measurement of three acoustic directivity angles, as shown in figure 3, while minimizing the number of flyovers. Further details and results of this flyover method are described in reference 10. The microphone cables were suspended a couple of feet above the ground using concrete reinforcing rods to prevent their destruction by wild animals.

Each microphone signal was recorded, along with satellite time code, on a frequency modulated, 14-track wideband-I analog tape recorder operating at 15 in/sec, thus providing a maximum frequency capability of 10,000 Hz. A pistonphone was used in the field each day before and after flight testing for sound level calibration. In addition, phase differences in the acoustic signals from the twelve microphone systems were measured, upon completion of the test, by inserting a white noise signal on all channels simultaneously.

Meteorological data were obtained before, during, and after flight testing each day using a weather balloon system located approximately 2700 feet north-west of the microphone array (fig. 2). The weather balloon system consisted of an electric winch-controlled, tethered, helium-filled balloon, an instrument/telemetry pod, a ground-based receiver/data-controller, and a ground-based support computer. Profiles of temperature, relative humidity, wind speed, and wind direction were acquired for altitudes up to 1000 feet. These weather data were acquired at a rate of 6 points per minute, displayed in real time, and recorded on magnetic disk. Figure 4 presents weather data acquired during one of the test days.

Test Configuration

The test involved coordination of personnel from several organizations. At Crows Landing, the Langley project director, Crows Landing staff, and Ames personnel manned the control room located in the NASA facility. The Ames personnel monitored the IPS and maintained constant radio contact with the test pilots. The Crows Landing staff operated the laser tracking system, computer systems, and provided support as needed. The Langley project director coordinated the flight runs with the acoustic and weather data acquisition. Langley personnel were posted at the weather balloon site and acoustics van. Navy personnel provided support to the Ames XV-15 ground crew. The Navy control tower was manned by two FAA air traffic controllers.

Communications between the various personnel involved in the test was accomplished using a variety of systems. The pilots, Crows control room and a telemetry group at Ames were linked by VHF transceivers. Langley staff - control room, acoustics van, and weather balloon site - used VHF radios programmed for two other frequencies. The Navy control tower and Crows control room communicated via telephone. After discussing the next day's test plan, the flight card was faxed from the Ames project director to the Langley project director at Crows Landing. Figure 5 shows a diagram of the communications systems that linked the various stations of the test.

Test Matrix

Flight paths used for this test were divided into two groups, level flyovers and approaches, as listed in Tables 1 and 2. Departures were not flown because of the short time available for the test. All flight paths were defined in the X-Z plane through the center of the microphone array, as shown in figure 2.

Level flyovers were flown at Z=750 ft and Z=250 ft. These conditions are identical to test conditions from a previous flight test conducted with the XV-15 with Standard Metal Blades (SMB) and therefore provided direct comparisons to assess ATB acoustic performance.

Approaches were planned for 3°, 6°, and 9° glide slopes. All approaches passed through a point 394 ft over the FAA target microphone (fig. 2). A level flight path segment was programmed into the IPS where the glide slope segment intersected Z=100 ft. A short arc was programmed into the flight path joining the glide slopes to the level segments to reduce pilot workload.

TEST EXPERIENCE

Flight operations were based out of Crows Landing. Predawn shuttle flights transported pilots and personnel from Ames Research Center. Test flight operations were conducted so that the aircraft entered the range for its first run at sunrise (approximately 5:30 a.m.). Testing started at sunrise in order to obtain data under low wind and ambient noise conditions. The allotted time for this flight test was 5 hours. Only 4.3 hours were actually used during the test because the XV-15 suffered a minor mishap resulting in a long mechanical delay.

The mishap occurred after having obtained three tiers of prioritized data. An aerodynamic fairing on one of the rotor blades slipped outboard, causing a rotor unbalance. The pilot landed safely with no further damage to the XV-15, but since this was an unplanned event, the test had to be terminated for an investigation into the causes. The time used did, however, allow for the acquisition of the highest priority data.

Noise Contaminants/Extraneous Noise Sources

To obtain the largest signal-to-noise ratio for acoustic data, the test plan designated an "acoustic quiet time" for the surrounding area. During this quiet time, ground vehicle or farm machinery operations were restricted for distances within 2 to 3 miles from the test site. Aircraft operations were restricted within 10 miles of the test site. To enforce the quiet time, personnel closest to the microphone array reported any perceived contaminants to the control room, i.e., machinery or vehicles generating high noise levels in the vicinity of the microphone array. The control room staff then addressed the problem as needed.

Agricultural flight operations were most troublesome to the test. On numerous occasions, testing was delayed when crop duster activity was detected acoustically. Timing for the aerial spraying was critical and, unfortunately, coincided with that of the flight test. Some level of coordination with these agricultural operations was achieved through negotiation. For the final day of testing, Crows Landing staff negotiated with the local farmers to schedule spraying during down time of the XV-15 aircraft and at the end of the test. These operators had contracts for their spraying far in advance of the start of this test. This stresses the need for more advanced planning and negotiations with such operators in future tests.

Nearby airports and aircraft were also potential noise contaminants, since Crows Landing is located within 75 miles of 3 major international airports: San Francisco, Oakland, and San Jose, as shown in figure 1. Aircraft flying at high altitudes were spotted during the test as well. Other possible noise contaminants noted were Interstate 5, a four-lane major highway approximately 1.3 mi west of the microphone array, and a railroad track, approximately 2 miles east.

DATA REDUCTION AND ANALYSIS

Recorded analog acoustic data were processed using the Langley Acoustics Division Data Reduction and Analysis System (ADDRAS, ref. 11). The analog data were lowpass filtered at 10KHz and digitized at a rate of 24,000 samples per second. After converting to pressure units (dynes/cm^2), ensemble averaged power spectra were calculated from non-overlapping 2,048 element time domain arrays. A Hamming data window was applied to each array before frequency domain conversion using a fast Fourier transform algorithm. This averaging process combined data from multiple microphones having similar directivity relative to the moving aircraft. This procedure yielded spectral estimates having 40 degrees of freedom, translating to theoretical confidence limits for random signal components of +1.4 and -1.7 dB relative to the means. Confidence limits for spectral estimates associated with large amplitude deterministic components are expected to be smaller. OASPL metrics were determined by integrating on a pressure-squared basis across frequencies from 0 to 10KHz and then converting to the decibel scale. The contour plots were calculated by using bi-cubic spline interpolation to determine points between the three microphone rows.

PRELIMINARY TEST RESULTS AND DISCUSSION

Presented below are the results of the data processing described in the previous section. These include comparison of Overall Sound Pressure Level (OASPL, dB) contours of the SMB and ATB, and ATB at reduced tip speed. Time histories, frequency domain data, and frequency domain data as a function of time are presented as well.

Direct comparisons of the far-field acoustics associated with the two rotor systems of the XV-15 (SMB & ATB) are possible for level flyover. However, the limitations of the data from this and the 1988 acoustics test, performed at Maypearl, Texas (ref. 4), must be considered and are described below. The differences in how the data were acquired between these two data sets are minimal but may introduce some uncertainty when making comparisons. There were two notable differences between these tests.

One difference between the tests was analog filtering which occurred before the data was recorded. The Maypearl SMB acoustic data were high pass filtered at 16 Hz and low pass filtered at 16000 Hz. The analog data from the Crows Landing ATB test were not filtered. The difference in low pass filtering only limits subsequent upper frequency analyses and is inconsequential for the current comparisons. The high pass filtering process, however, will produce phase shifts in the recorded analog data which will result in phase changes that is different for low and high frequency components. Consequently time domain analyses of the data processed from this filtering procedure would be effected but frequency domain magnitude estimates would not.

As detailed later in this section, two different aircraft guidance systems were used for these two tests but the exact effect of these differences on the measured far-field acoustics has not yet been quantified.

Overall Sound Pressure Levels

The noise contour plots shown in figure 6 are obtained from ensemble averages of measurements along the flight path and 250 feet on either side of the flight path. The contours represent the OASPL under the aircraft during the course of an entire flyover for three flyovers: (a) SMB at 677 ft/sec tip speed, (b) ATB at 677 ft/sec tip speed, and (c) ATB at 582 ft/sec tip speed. Conditions common to all three flyovers are 160 knots airspeed, 250 ft altitude, and 0 degree nacelle tilt.

Comparison of the OASPL contours of the XV-15 aircraft with the SMB and the ATB at equal tip speed (V_t=677 ft/sec, figure 6 a&b) shows that the maximum OASPL is 103 dB for both sets of blades. This maximum level, however, covers a significantly larger area on the ground with the ATB than with the SMB. At reduced ATB tip speed, the maximum OASPL was reduced by approximately 2.5 dB. Obvious lateral asymmetry is noted for the ATB data at V_t = 677 ft/sec in figure 6(b). Longitudinally, each of the data sets show the trend of OASPLs decreasing faster with distance behind the aircraft as compared to the rate of change observed in the front of the aircraft.

Time Histories

One microphone position and time segment from each data set were selected for detailed comparison. The time segment selected represents data sampled within the rotor disk plane at 0 deg nacelle tilt during the flyover. Time domain and frequency domain data from these similarly located microphones from the different tests are presented in figure 7. The time domain data (figure 7 a and c) are single realizations of sound pressure fluctuations of a single microphone from each test. The frequency domain data (figure 7 b and d) are ensemble averaged power spectra. The conditions for these data are those presented earlier for the V_t = 677 ft/sec level flyover cases.

The general waveform amplitude and frequency content for the two rotor systems are different (figure 7 a and c). The sound pressure level at the BPF of the ATB is 6 dB greater than that of the SMB. Consequently, the pressure amplitudes for the ATB data are approximately 1.7 times larger than the SMB (peak-to-peak). The SMB time domain data shows a high frequency content that is not as dominant in amplitude as the ATB data. This difference is more clearly observed in the corresponding spectra described below.

Frequency Domain Data

The frequency domain data, figure 7 (b) and (d) show a hump of acoustic energy centered at 3500 Hz is present in the SMB data but not present in the ATB data. This difference is systematic throughout all sideline microphone locations which have been processed thus far. The ATB frequency domain data are characterized by maximum sound pressure levels at the BPF with little associated harmonic content and a general smooth decay from 78 dB at the BPF to 37 dB at 5000 Hz. The SMB frequency domain data is characterized by a maximum sound pressure of 72 dB at the BPF and a single observed harmonic. Different from the ATB data, the SMB data have several humps between 800 and 1800 Hz. The data from the ATB suggests that similar mechanisms may be operating on the ATB tiltrotor but because of the adjacent sound pressure levels this trend is not obvious. Probable sources for this noise are transmission, engine or hydraulic pump noise.

Frequency Domain Data vs. Time

Frequency domain data of the entire flyover for the same flight conditions are presented in figure 8. The figure presents time on the horizontal axis, frequency on the vertical axis, and uses color to represent the sound pressure level. Time can be associated with longitudinal directivity angles from the horizon which sweep from 15 degrees at approximately 0 seconds to 165 degrees at approximately 9.5 seconds. Each of these contour plots was generated from 18 narrowband spectra, i.e., one spectrum every half-second. The time of 4.5 seconds is associated with a longitudinal directivity of 90.0 degrees and a polar (lateral) directivity angle of 45 degrees. These contours have been graphically processed to highlight some of the subtle features present in the data.

The most obvious difference between the acoustic flyover data from the ATB and SMB is the area of increased sound pressure levels between 3000 and 4500 Hz which are present in the SMB data but not the ATB data. This area is observed to shift frequencies as a function of time as a result of the doppler effect. While prominent in these contours, the sound pressure levels associated with this character are about 30 dB below the levels associated with the BPF of the SMB. However, it is significant because it is in a frequency range that is annoying to the human ear. The hump of energy observed in the SMB frequency domain data which is centered at 3500 Hz is now understood to be a part of this doppler shifting region. The cause of this characteristic is under investigation. The presence of other low level doppler shifted noise in the range of 500 to 1500 Hz are observed in both of the data sets. This noise is evident in the SMB data for a larger period of the flyover as noted by the relative sizes of the yellow shaded areas.

With respect to acoustic exposure, the ATB data shows a higher level of acoustic energy within the 0 to 150 Hz region (red area). The higher levels in the ATB data also had a longer duration than in the SMB data.

IPS GUIDANCE SYSTEM EVALUATION

For ensemble averaging purposes, a standard Langley criteria for maximum deviation from the intended flight track is +/- 25 ft in the lateral and vertical directions. A flight track exceeding this criteria requires repeating the flight. Consequently, a guidance system which can keep the aircraft within 25 ft of the intended flight track is desirable.

This acoustic flight test was the first in which the Crows Landing IPS Guidance System was used. To determine the value of this unique guidance system in achieving accurate flight trajectories, a simple comparison of flight position data from the Crows Landing test and the Maypearl test which used a Visual Approach Slope Indicator (VASI)/Voice guidance system is presented in figure 9. These tracking data represent two 6 degree descent angle flights from each of the tests.

The VASI/Voice system involved using a VASI calibrated to a flight track slope of 6 deg. This system delivers visual cues from the ground-based instrument to the pilot during the descent flight. The pilot of the tiltrotor also received voice communications from a test engineer monitoring the track progress from a computer display terminal connected to a laser tracking system. Practically, the VASI controlled vertical deviations and the voice communications controlled lateral deviations from the intended flight path. The IPS as described previously, in the Test Description section, uses real-time computer controlled ILS-type of information to inform the pilot of his actual position relative to his intended position.

Figure 9 presents the comparison with Y coordinate deviations on the horizontal axis and Z coordinate deviations on the vertical axis. With this type of comparison the X deviations which are associated with the aircraft's speed are not considered. If the Y and Z deviations were constant at zero for the entire flight (ideal flight track) there would appear an apparent single point located at (0,0). Because the actual flights have changing deviations during the flyover, the time series of deviations map to a fluctuating line. The two flights associated with the VASI/Voice guidance system show a systematic positive lateral bias from the intended flight track and exhibit high variability (+/- 30 ft) from their biased means. The data from flights associated with the IPS system show the deviations to be clustered near the intended flight path with small variability (less than +/- 15 ft for both vertical and lateral deviations). Although aircraft operating conditions and rotor systems were different for the flight tracks in figure 9, the suspected cause of the observed differences is due to the guidance system employed.

SUMMARY

A preliminary terminal area operations, high-quality, far-field acoustics flight test of the XV-15 aircraft with advanced technology blades was conducted in August and September 1991 at Crows Landing Naval Auxiliary Landing Field. Data were obtained for a rotor tip speed range of 582 to 771 ft/sec, nacelle tilt angles varying from 0 to 90 deg, flight speeds ranging from 50 to 190 knots, and approach angles of 3, 6 and 9 degrees.

Acoustic flight testing at Crows Landing has several definite advantages. The IPS guidance and tracking system under development at Ames Research Center provides a capability which has resulted in both more accurate and precise flight paths during the test. This system should be the method of choice when highly accurate and precise flight trajectories are needed, particularly for research purposes. The terrain is relatively flat, and weather conditions during the summer months are conducive to acoustic flight testing. The personnel at the NASA facility at Crows Landing provided strong support during the test.

Test problems at Crows Landing can easily be minimized. Typically, tests can only be scheduled nine months out of the year, since heavy fog and rain during the winter months shut operations down. Potential noise contaminants in this agricultural area have been identified and can be prevented through advance planning and negotiations. The strong support systems offered by the Crows Landing complex (personnel, communications, aircraft guidance, laser tracking and on-board instrumentation) makes this location very suitable for acoustics testing (assuming these intermittent noise sources are controlled).

The data reduced thus far do not reveal any conclusive acoustic advantage of the ATB over the SMB. Some differences have been noted. At a rotor tip speed of 677 ft/sec, the maximum OASPL for both sets of blades is approximately 103 dB, although the ATB maximum OASPL impacts a larger ground area than the SMB. A "hump" of acoustic energy in the 3000 - 4500 Hz range is present in the SMB data, but not in the ATB data. The sound level associated with this characteristic is approximately 30 dB below the fundamental blade passage frequency. More significant differences between the two blade sets may be found when the approach data is analyzed.

REFERENCES

1. Maisel, M.D.; and Harris, D.J.: Hover Tests of the XV-15 Tiltrotor Research Aircraft. AIAA Paper No. 81-2501, AIAA/SETP/SFTE/SAE/ITEA/IEEE 1st Flight Testing Conference, Las Vegas, NV, November 11-13, 1981.

2. Brieger, John T.; Maisel, Martin D.; and Gerdes, Ronald: External Noise Evaluations of the XV-15 Tiltrotor Aircraft. Proceedings of the AHS National Specialists' Meeting on Aerodynamics and Aeroacoustics, Arlington, TX, February 25-27, 1987.

3. Edwards, Bryan D.: External Noise of the XV-15 Tiltrotor Aircraft. NASA CR 187463, May 1991.

4. Golub, Robert A.; Becker, Lawrence E.; Rutledge, C. Kendall; Smith, Rita A.; and Conner, David A.: Some Far-Field Acoustics Characteristics of the XV-15 Tiltrotor Aircraft. AIAA Paper No. 90-3971, AIAA 13th Aeroacoustics Conference, Tallahassee, FL, October 22-24, 1990.

5. Conner, David A.; and Wellman, Brent: Far-Field Hover Acoustic Characteristics of the XV-15 Tiltrotor Aircraft with Advanced Technology Blades, Proceedings of the AHS/RAeS Technical Specialists Meeting on Rotorcraft Acoustics and Fluid Dynamics, Philadelphia, PA, October 15-16, 1991.

6. George, Albert R.; Smith, Charles A.; Maisel, Martin D.; and Brieger, John T.: Tilt Rotor Aircraft Aeroacoustics. Proceedings of the 45th Annual Forum and Technology Display of the American Helicopter Society, Boston, MA, May 22-24, 1989.

7. Huston, Robert J.; and Golub, Robert A.: Noise Considerations for Tiltrotor. AIAA Paper No. 89-2359, AIAA/ASME/SAE/ASEE 25th Joint Propulsion Conference, Monterey, CA, July 10-12, 1989.

8. Smith, K.E.; Alexander, H.R.; and Maisel, M.D.: Design Aspects of the XV-15 Advanced Technology Blade Program. American Helicopter Society 41st Annual Forum, Ft. Worth, TX, May 15-17, 1985.

9. Bjorkman, W.S.; and Bondi, M.J.: TRENDS: The Aeronautical Post-Test Database Management System. NASA TM-101025, January 1990.

10. Conner, David A.; Measurement Resolution of Noise Directivity Patterns from Acoustic Flight Tests. NASA TM-4134, October 1989.

11. Becker, L.W.; Rutledge, C.K.; Smith, R.A.; Grandle, R.E.; and Golub, R.E.: ADDRAS - An Integrated Systems Approach from Experimental Design to Data Analysis. Proceedings of the AHS/RAeS Technical Specialists Meeting on Rotorcraft Acoustics and Fluid Dynamics. Philadelphia, PA, October 15-16, 1991.

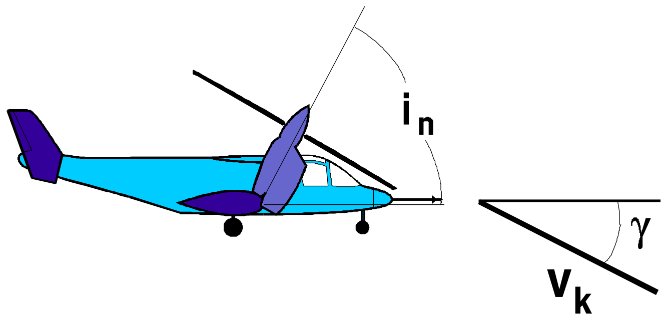


TABLE 1. Flight Parameters for Level Flyovers.

Nacelle Tilt Angle i_n, deg	Velocity, V_k, kts			
	110		160	
	ALTITUDE, ft		ALTITUDE, ft	
	250	750	250	750
0			° *	° *
60	+			

TABLE 2. Flight Parameters for Approaches.

Nacelle Tilt Angle i_n, deg	Velocity, V_k, kts											
	70			80			90			100		
	γ,deg			γ,deg			γ,deg			γ,deg		
	3	6	9	3	6	9	3	6	9	3	6	9
70	+	+		+			+			+		
80	+	+ ¤										
85	+	+										
90	+	+	+									

<u>Rotor Tip Speed (ft/sec)</u>

° 582
* 677
+ 692
¤ 771

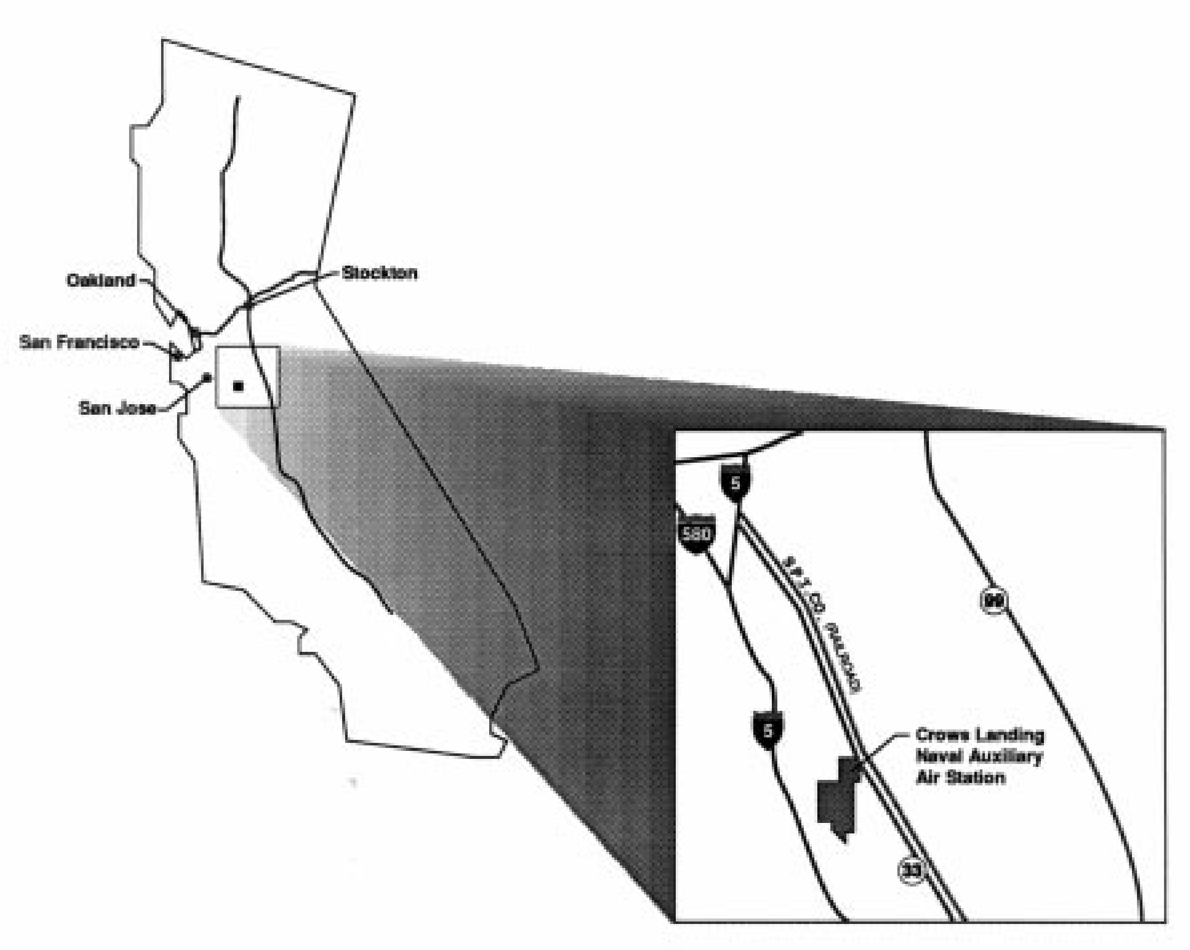


Figure 1. N.A.L.F., Crows Landing Regional & Vicinity Map

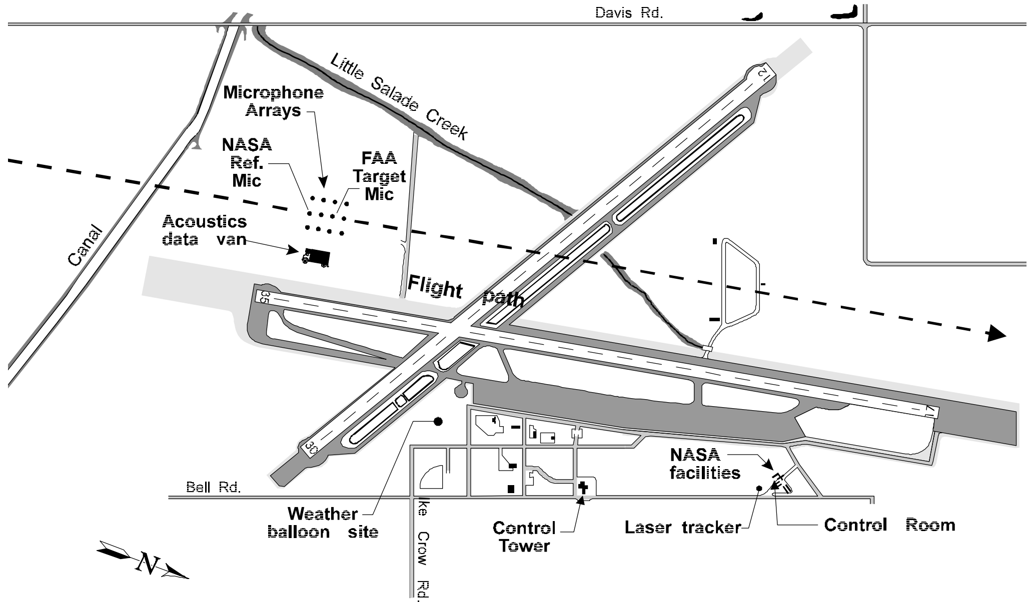
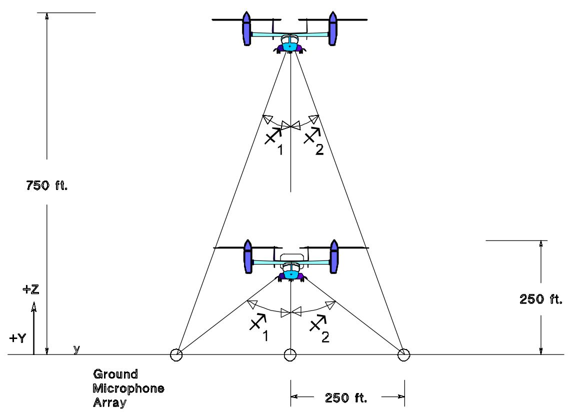


Figure 2. XV-15 / ATB far field acoustics test set-up at Crows Landing, CA.



DIRECTIVITY ANGLES

$\chi = \chi_1 = \chi_2$

FLIGHT CONDITION	LEVEL		DESCENT
ALTITUDE, ft	250	750	VAR.
χ	18°	45°	22° - 78°

Figure 3. Acoustic directivity angles during flyover and descent.

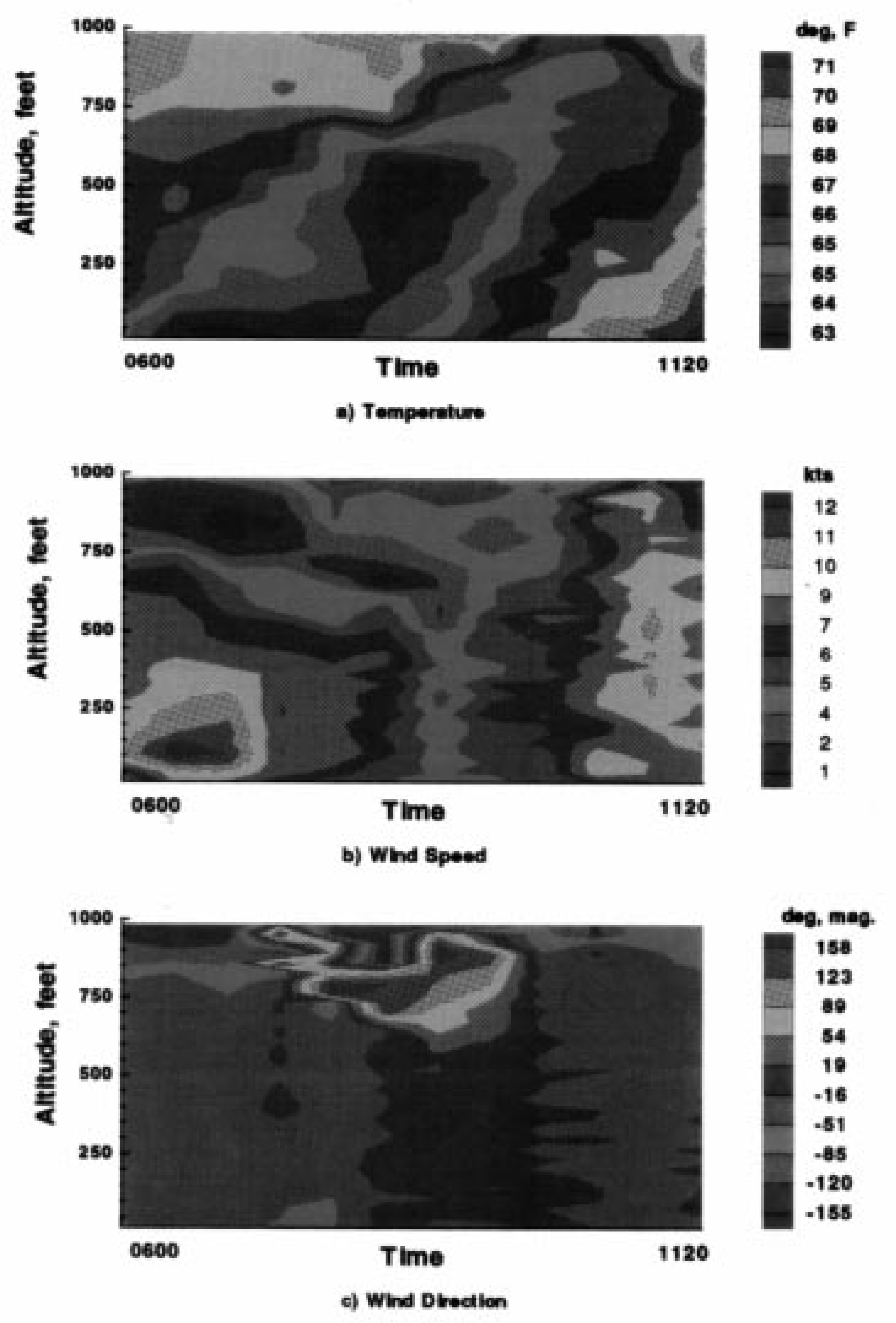


Figure 4. Weather profile at Crows Landing, CA, 9/06/91.

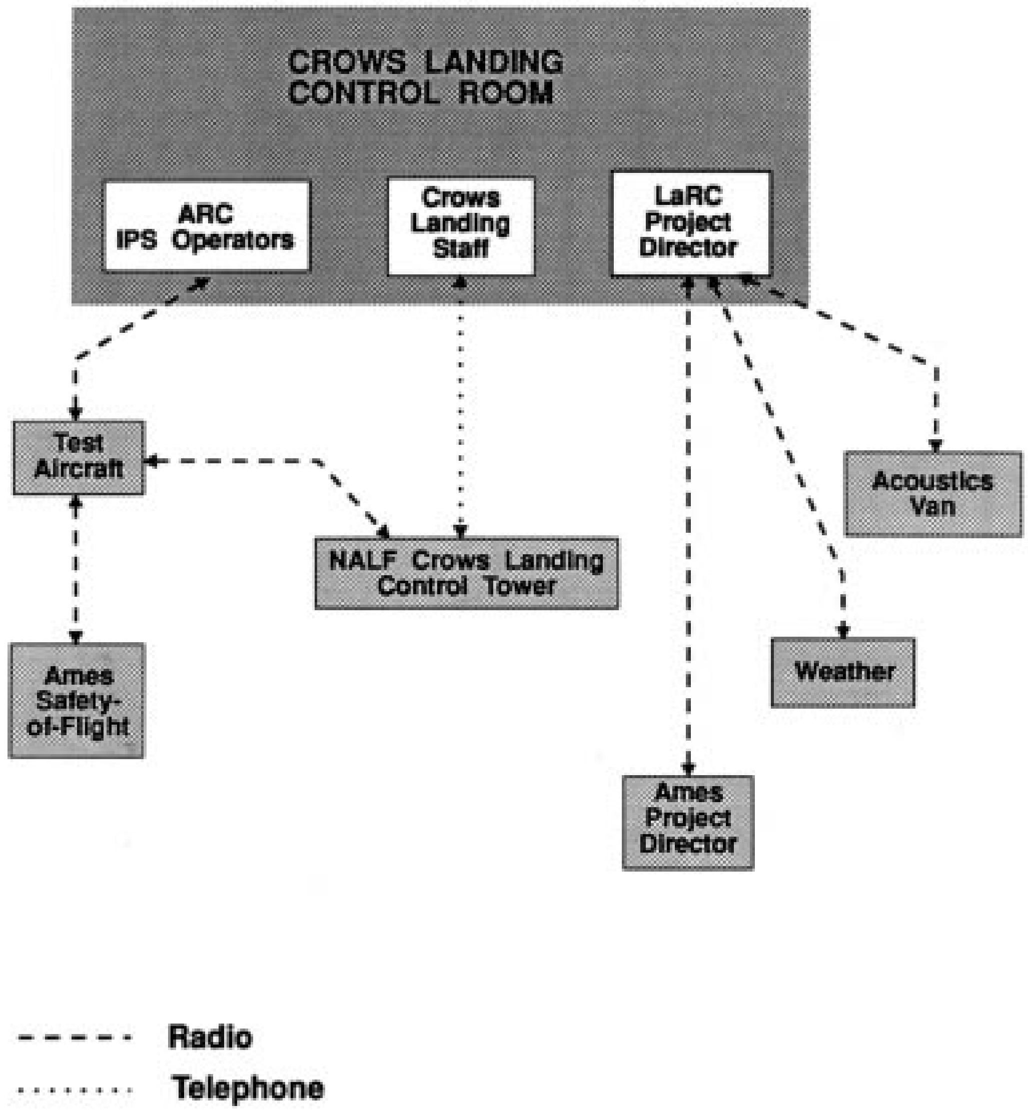


Figure 5. Communications diagram for test personnel.

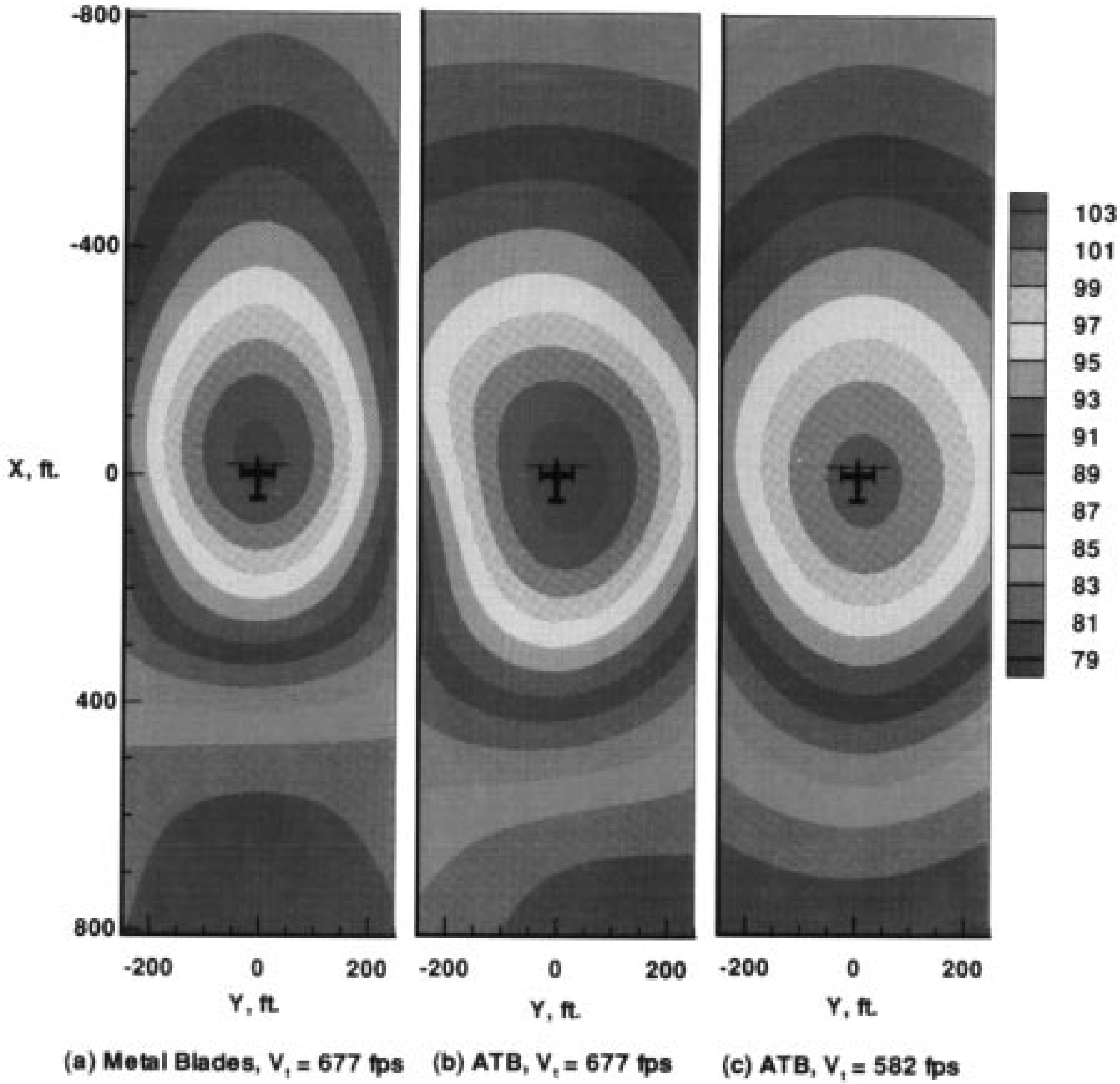


Figure 6. Level flyover OASPL contours for XV-15 tiltrotor aircraft operating in airplane mode; 160 knots velocity, 250-ft altitude.

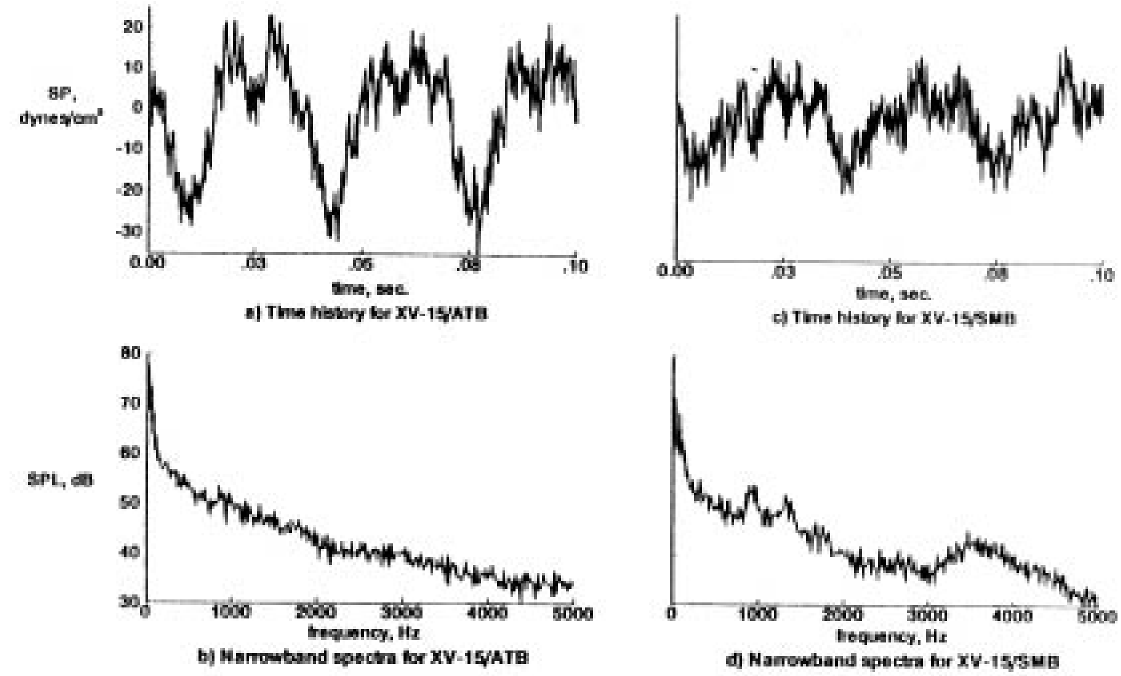


Figure 7. Comparison of ATB and SMB airplane mode acoustic data from microphone located in rotor tip path plane 250 ft. to the left of centerline; 250 ft altitude, 160 kts velocity, 677 ft/sec rotor tip speed, 13,000 lbs gross weight.

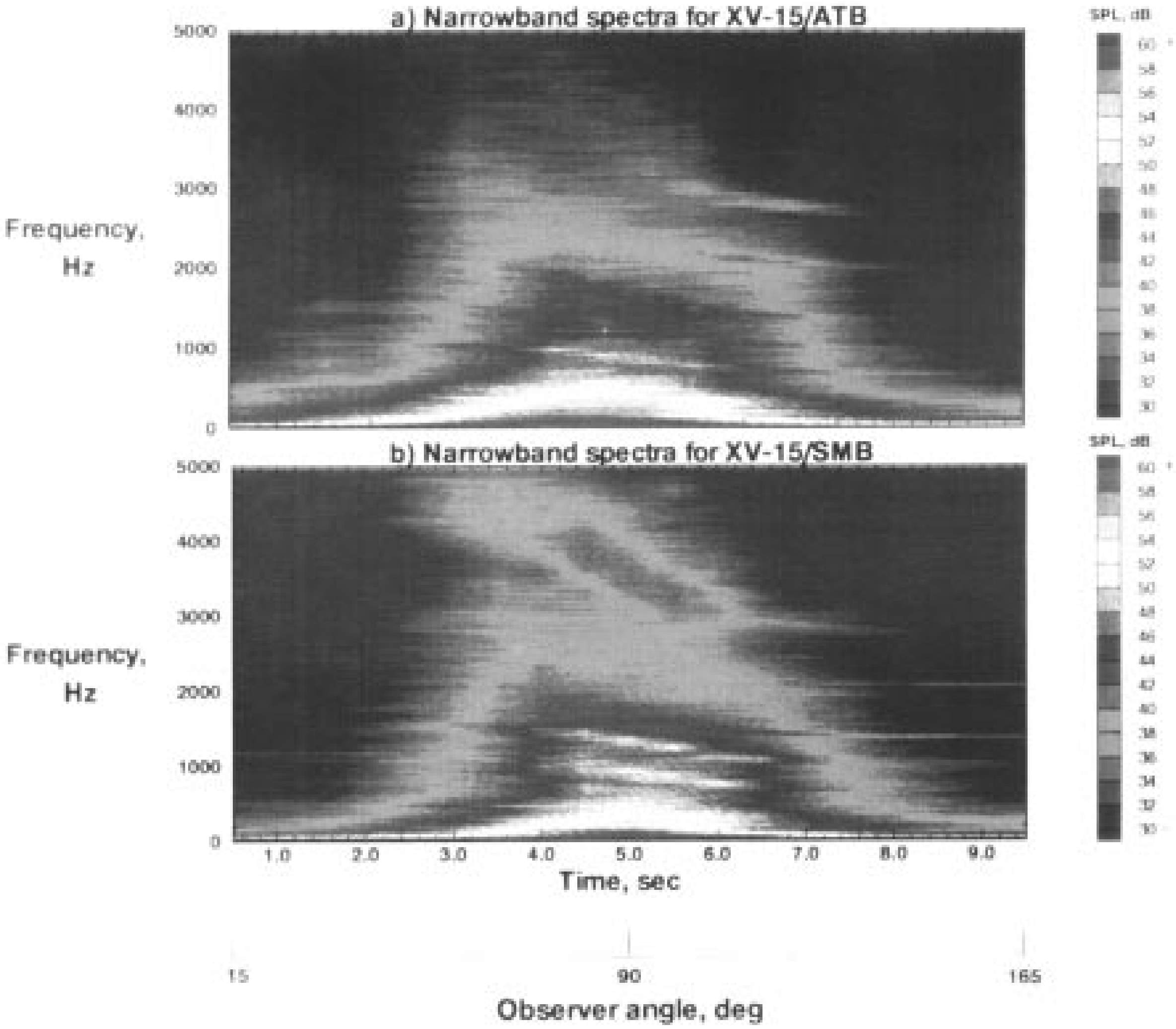


Figure 8. Comparison of ATB and SMB narrowband spectra representing entire flyovers; microphone location 250 ft to the right of centerline, 250 ft altitude, 160 kts velocity, 677 ft / sec rotor tip speed, 13,000 lbs gross weight, 0° nacelle tilt.

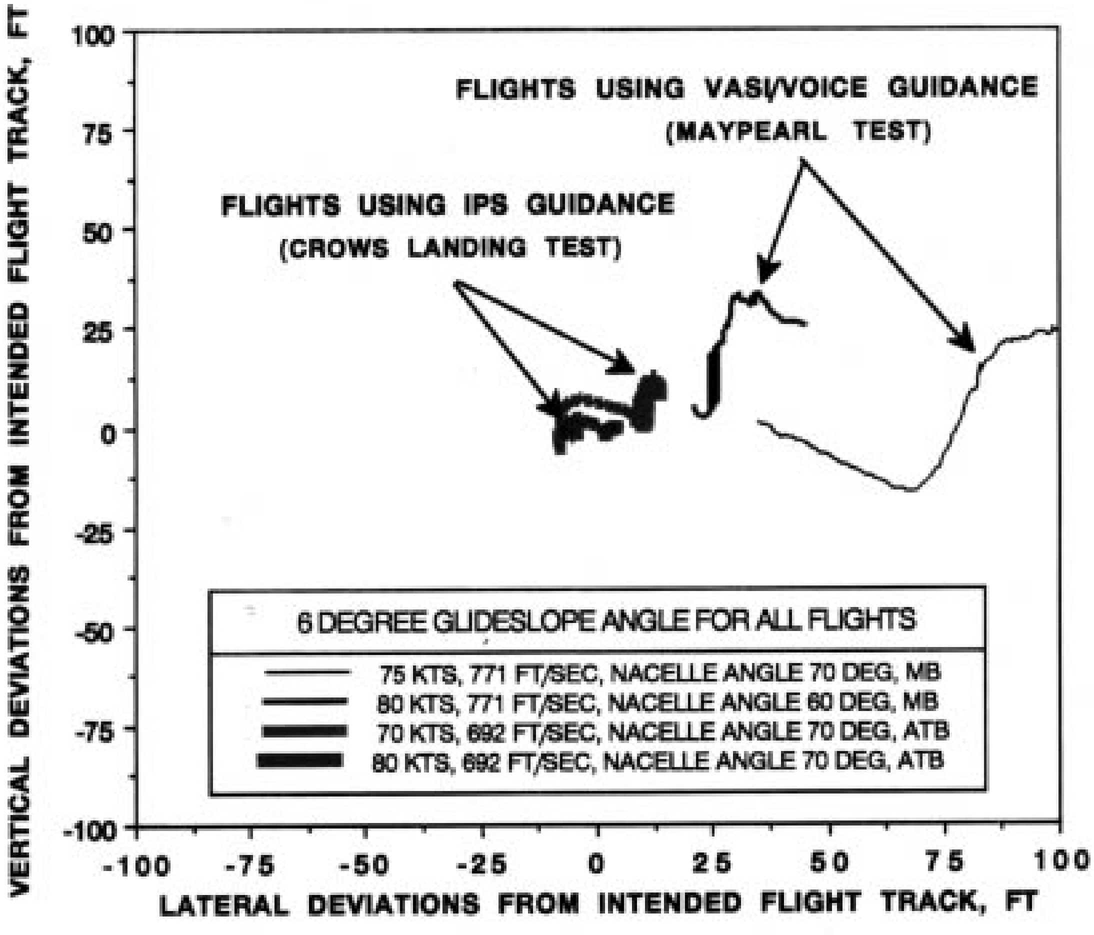


Figure 9. Flight track deviations from two guidance systems.