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AN ACOUSTICAL FLIGHT EVALUATION OF A ROTATING COMBUSTION ENGINE (U)

Final Report

(1 February 1970 to 1 June 1970)

June 1970

by: H. R. Corwin
R. R. DeHoroch

Prepared Under Contract N00019-70-C-0436

For

Department of the Navy
Naval Air Systems Command
Washington, D. C. 20360

By

CURTISS-WRIGHT CORPORATION
WOOD-RIDGE, NEW JERSEY 07075

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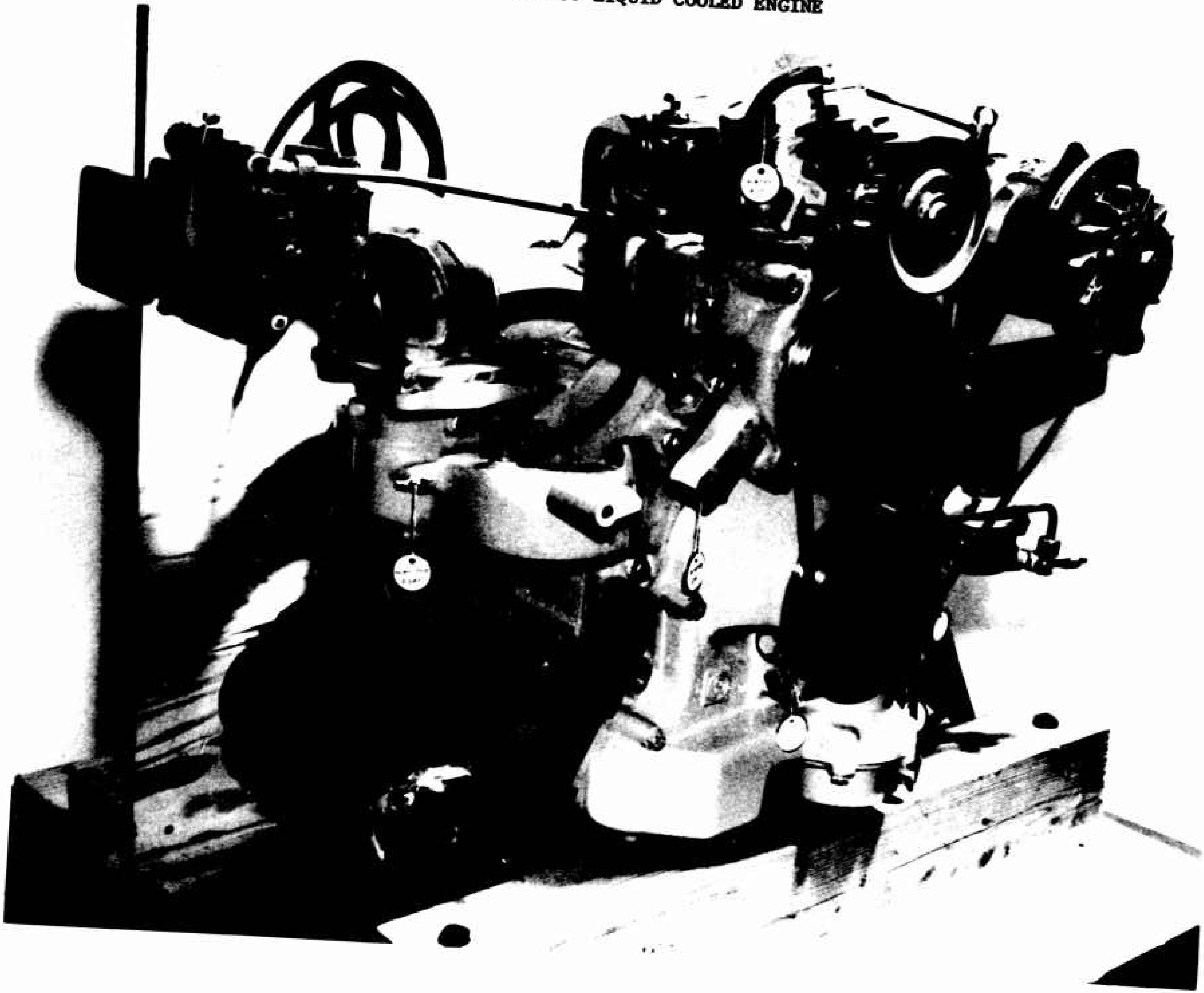
Q - STAR IN FLIGHT

RC2-60 LIQUID COOLED ENGINE



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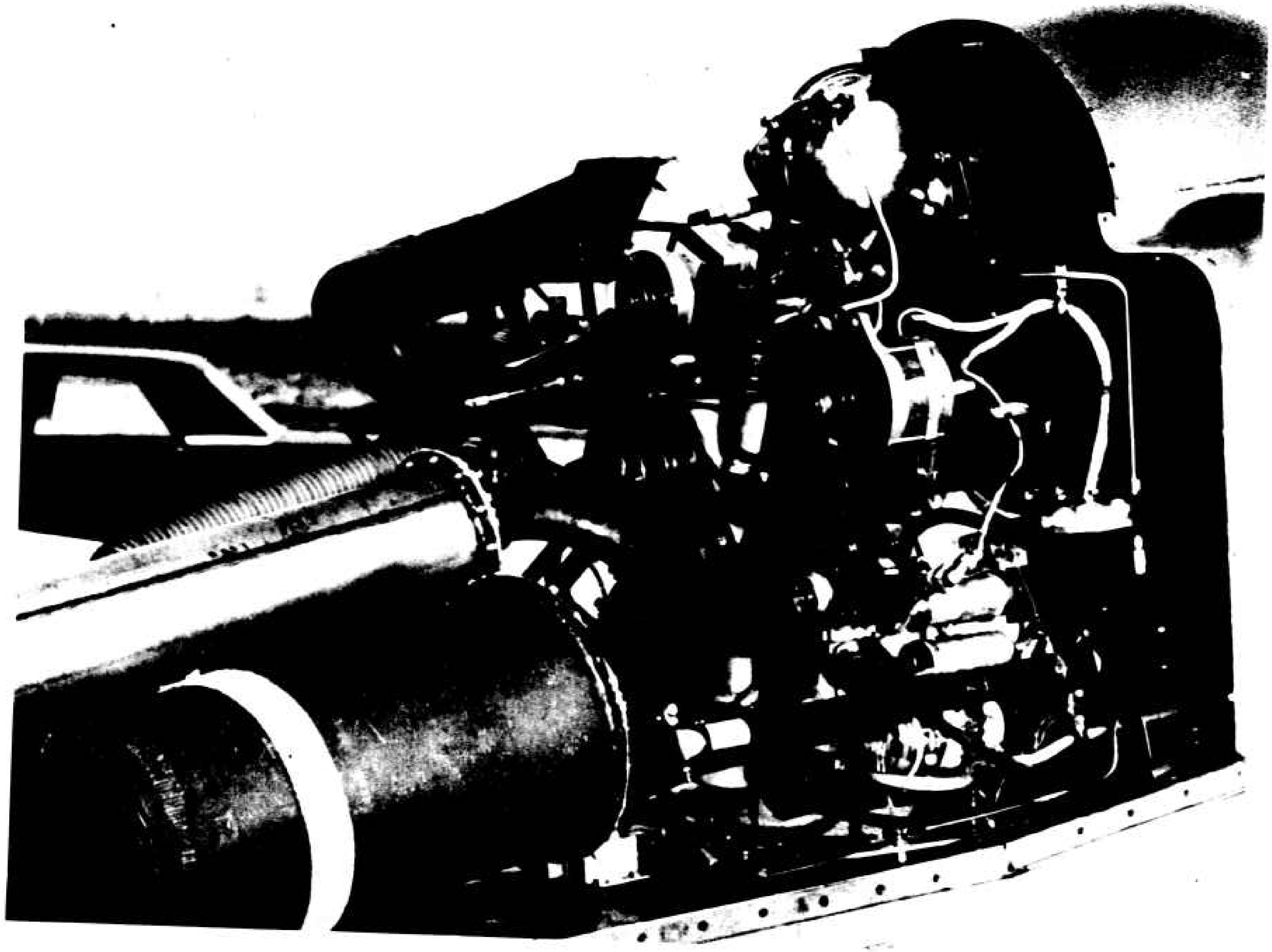
RC2-60 LIQUID COOLED ENGINE INSTALLED IN Q-STAR



I. INTRODUCTION

On September 6, 1969, through a cooperative effort of the Lockheed Missiles & Space Company, Sunnyvale, California, and the Curtiss-Wright Corporation, Wood-Ridge, New Jersey, the Lockheed-owned Q-Star research aircraft flew for the first time powered by a Curtiss-Wright developed and owned RC2-60 rotating combustion (Wankel-type) engine.

Built in early 1968 by Lockheed, the Q-Star aircraft has been used as a research test bed in support of Company-funded studies in aircraft acoustics technology. Previously powered by a 100 hp, Continental 0-200, 4-cylinder, reciprocating engine, the aircraft had been flown with 4, 6, and 3 blade propellers of various designs, with several exhaust muffler systems, and in various aerodynamic configurations (wing trailing edge extensions permit varying wing areas and various trim angles). The Q-Star aircraft is described in more detail in Appendix B.

Two aircraft designated "QT-2", built by Lockheed in 1967 and subjected to cover 800 combat mission hours during 1968, exhibit acoustic signatures which are virtually identical to the Q-Star with the 0-200 reciprocating engine. The high mission success and high survivability of these aircraft suggest that the acoustic signature is satisfactorily low for the intended missions.

Lockheed's interest in the rotating combustion engine concept originally stemmed from three salient features of the available RC2-60 version:

- A prominent noise of the QT-2 aircraft and Q-Star discernable by ground observers was "valve clatter". The rotating combustion engine has no valves and requires no valve-associated linkages or noise producing mechanisms.

- Due to the noise attenuation of the water cooling jacket, and the lack of vibration, a properly muffled RC engine should produce less noise for a given amount of power, or more to the point, provide more available power for a given noise level.

- Water cooling shows promise of easing the trade-off between cooling and quieting, since the engine installation may be more tightly cowled for noise attenuation without the vibrating problems which occur with tightly cowled air-cooled engines.

Thus, Lockheed's interest in the rotating combustion engine lay primarily in the desire to fly heavier payloads at attendant higher power settings while maintaining or enhancing acoustic signatures.

In early 1970, the initial "flight" phase of the cooperative LMSC/C-W flight program was successfully completed. Continuation of the flight program was effected under Contract N00019-70-C-0436 sponsored by the U. S. Department of the Navy, Naval Air Systems Command. The primary objective of this effort was directed toward the general suitability of the rotating combustion engine for quiet aircraft applications. Engineering and aeroacoustic investigations were conducted to identify the basic noise sources of the installation and their relative magnitude, to investigate the engine's compatibility with low speed flight in a "quiet cruise" configuration by identifying the system acoustic signature and fly-over noise levels at various airspeeds, and to study the effect of several propeller types and aircraft configurational variables on the "silent-running" effectiveness of the system. The contractual work statement included:

A. Perform engineering and acoustic flight tests to establish appropriate "quiet cruise" configurational and operational conditions for the RC2-60 engine/airframe combination. This will include assessment of aircraft low speed/low rpm capabilities and the resulting acoustic signatures plus determination of the sensitivity of the aircraft acoustic signature and noise level to selected critical operational parameters, such as engine rpm, gross weight, and propeller pitch angle. Approximately 50 hours of flight will be utilized during this period. The LMSC acoustic van will be utilized for the acquisition of noise data.

B. Analysis of test data and compilation of test results.

C. Submit final report.

II. SUMMARY

USN Contract N00019-70-C-0436 covered the period 1 February 1970 through 30 June 1970. During this period 46.3 hours of flight were logged with the RC2-60 serial number 742-6 engine installed in the Q-Star aircraft. During this time, approximately 65 take-off and landings were recorded. Total engine time including Q-Star ground run and calibration time at Curtiss-Wright was 75.0 hours. During the CWC/LSMC sponsored program (6 September 1969 to 1 February 1970), 28.5 hours of flight were completed with RC2-60 engine serial number 743-5.

Improvements in aircraft flight performance expected as a result of 85 percent increase in power available with an attendant six percent increase in empty weight were fully realized.

Considering the experimental nature of the engine installation, the achieved operational readiness rate was astonishing. No flight during the entire program was cancelled or delayed due to an engine or engine-related failure or problem.

High exhaust gas temperatures require careful selection of exhaust muffler materials and designs. It has been shown, however, that the RC engine exhaust is no more difficult to adequately quiet than conventional reciprocating engines. It is noteworthy that sound attenuating material normally used on the inside surfaces of the Q-Star cowling was not used with the RC engine installation, and there is no evidence of noise penalty due to its elimination.

The qualitative nature of the program precludes numerically supported conclusions concerning the merits of the RC2-60 engine relative to other candidate quiet aircraft power plants. It has been demonstrated, however, that the engine as flown in Q-Star can readily be quieted to acceptable levels while retaining its inherent advantgages of high reliability, high maintainability, and superior power to weight ratios. Acoustic signatures of the Q-Star aircraft with the RC2-60 engine installed show that this configuration comes closer to meeting current detectability criteria than any other current candidate system.

Many interrelationships have been shown to exist between such parameters as propeller aerodynamic design features, rotational speed, pitch angles; aircraft speed and trim; and engine speed and power settings. Treating the acoustic signatures of the aircraft as a whole, as was done during this program, leads to difficulty in discussing the acoustic characteristics of the engine as an isolated noise contributer. Further, if an isolated assessment of the acoustic properties of an engine alone were possible, the data would be of questionable use to the designer of quiet airplanes, since the net acoustic signature of a point design aircraft represents the integrated contribution of engine, propeller, and airframe. It is recommended that future work continue to treat total propulsion systems including engine, propeller, and related support and accessory systems except in those areas when comparison of specific alternate engine features can be more readily isolated on a dynamometer. Several specific investigations are recommended elsewhere in this report.

III. TEST RESULTS

Acoustic signatures of the Q-Star aircraft with the Wankel engine were measured in flyover field tests. Details of the test site, test procedures, and acoustic measurement and analysis instrumentation are discussed in Appendix A. In general, these tests were performed with aircraft flying at an altitude of 125 ft. over microphones located on the ground. Both aircraft configuration and operating parameters were varied and the effects on acoustic noise signature observed. Octave band analysis was performed on all data and narrow band analysis was performed on selected samples.

Changes in acoustic noise signature were interpreted in terms of related changes in configuration or operating variables. For a selected data sample, a typical detection range for the Q-Star aircraft was estimated.

MUFFLER TESTS

Figures 1, 2, and 3 illustrate the results of acoustic measurements made to determine the effectiveness of the muffler used on the Q-Star aircraft powered with Wankel engine. Figure 1 shows baseline acoustic data taken two feet from the short tail pipe with no muffler installed. A narrow band plot of data analyzed with 15 Hz filter over a frequency range from about 50 to 5000 Hz is shown. Engine frequencies up to almost 2000 Hz show peak sound pressure levels (SPL) in excess of 100 dB. Fundamental engine frequency near 150 Hz reached SPL's of 120 dB.

Figure 2 shows results of this test repeated with muffler installed. In general, the acoustic noise level is greatly attenuated across the entire spectrum.

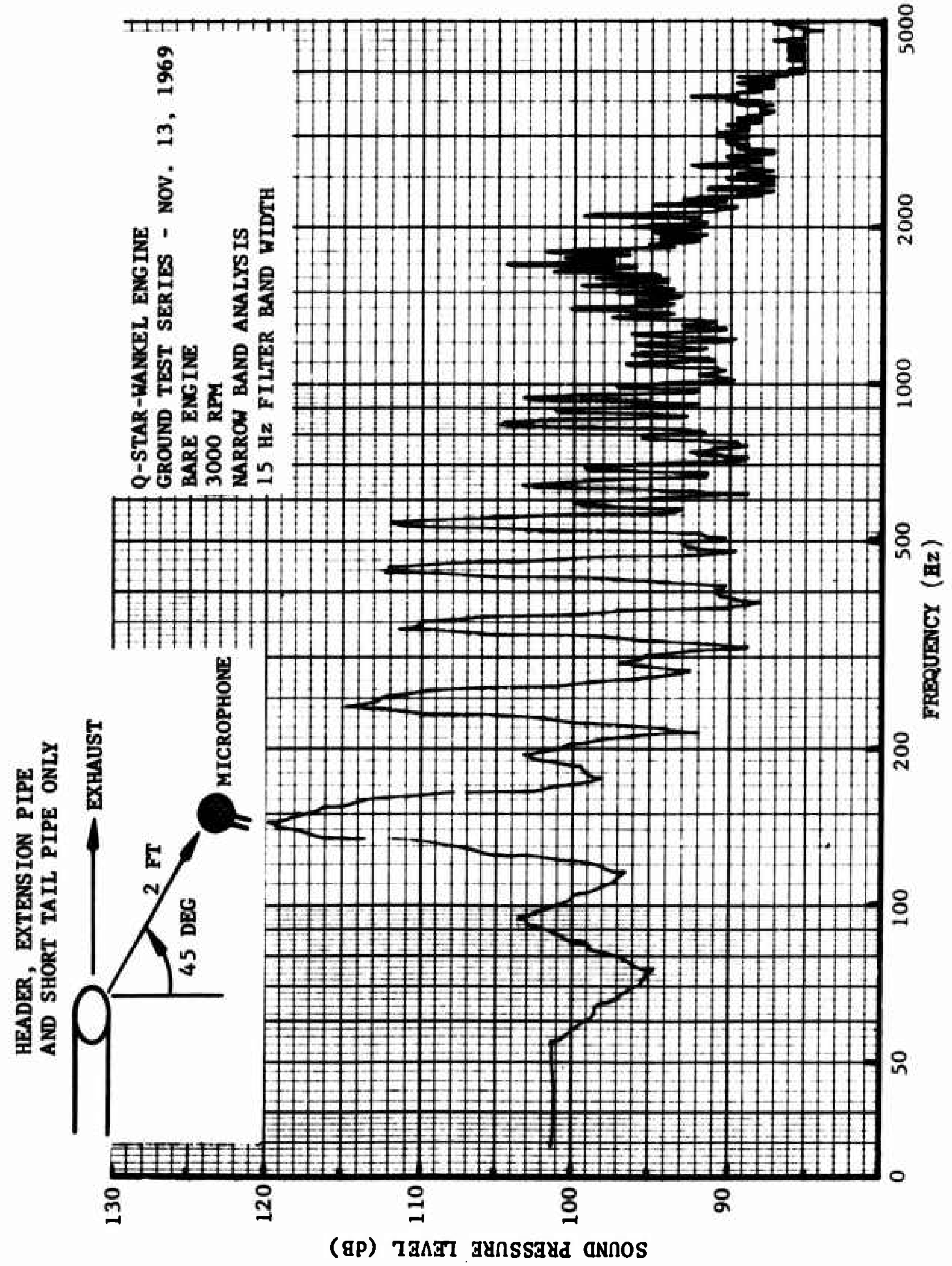


Fig. 1 Baseline Acoustic Data on Wankel Engine

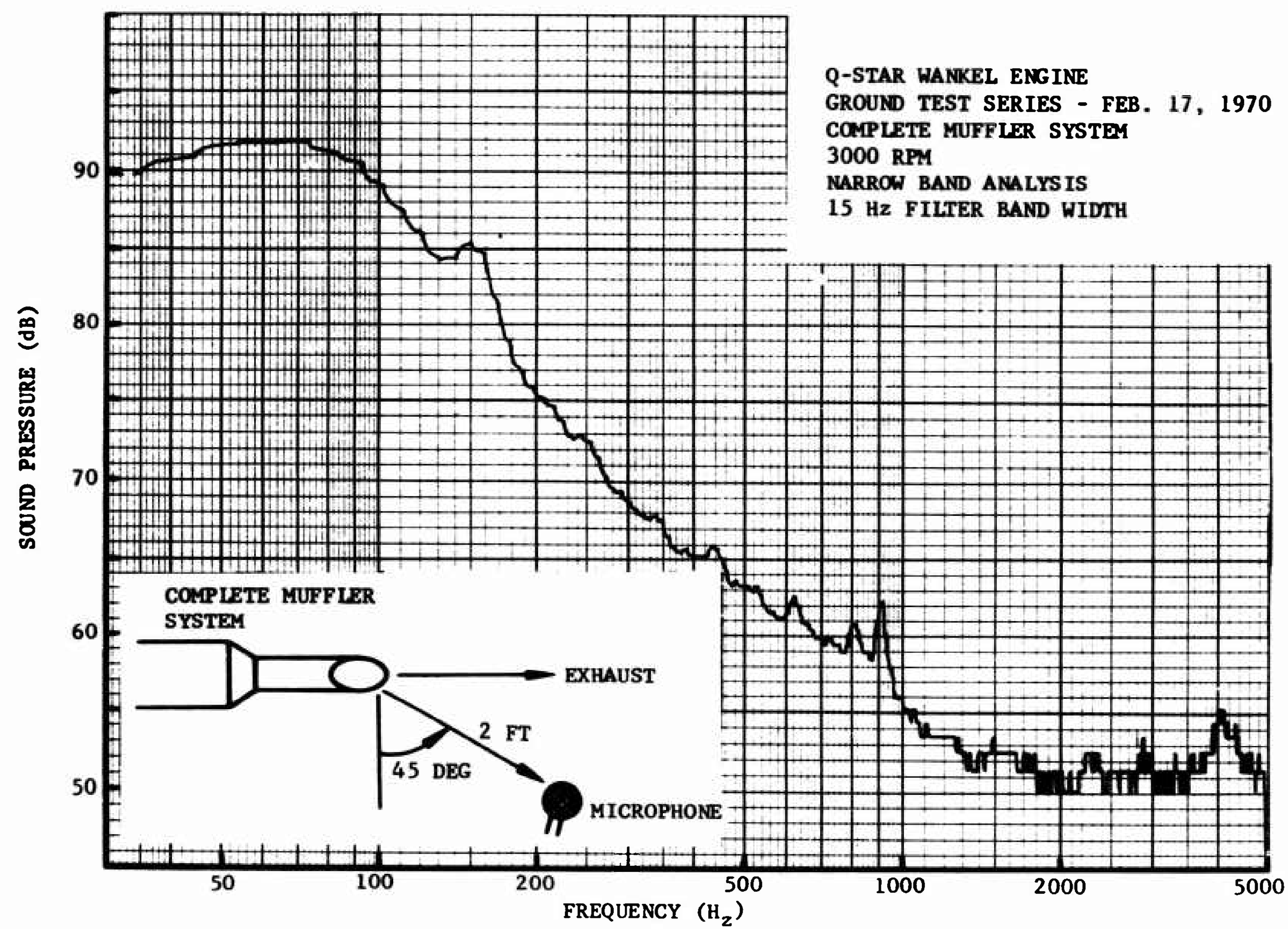


Fig. 2 Acoustic Data on Wankel Engine With Complete Muffler System

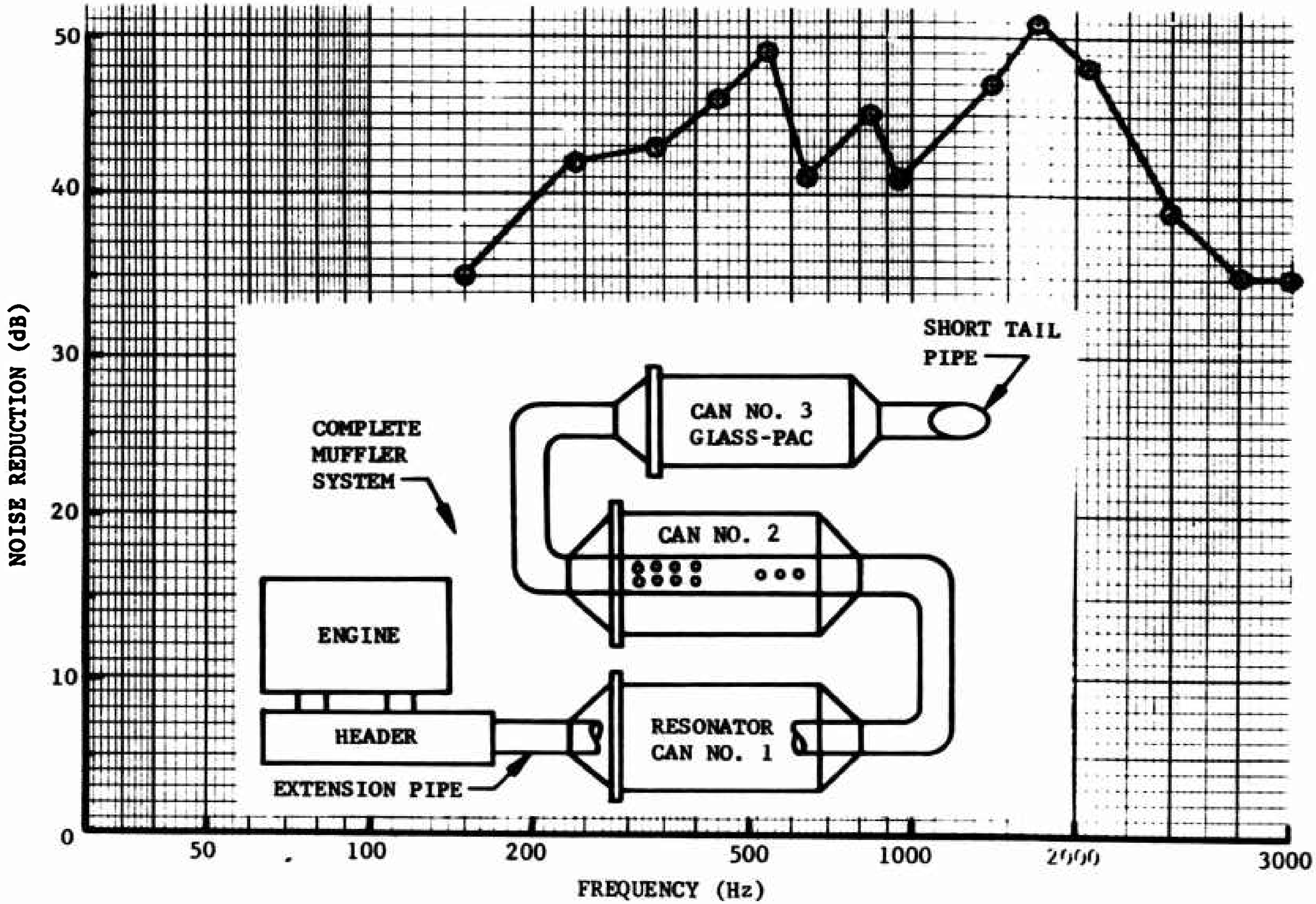


Fig. 3 Noise Reduction from Complete Muffler System

Wind noise from the propeller slip stream is thought to account for most of the noise energy below 1000 Hz. A few peaks of the muffled engine noise can be seen above this background noise level.

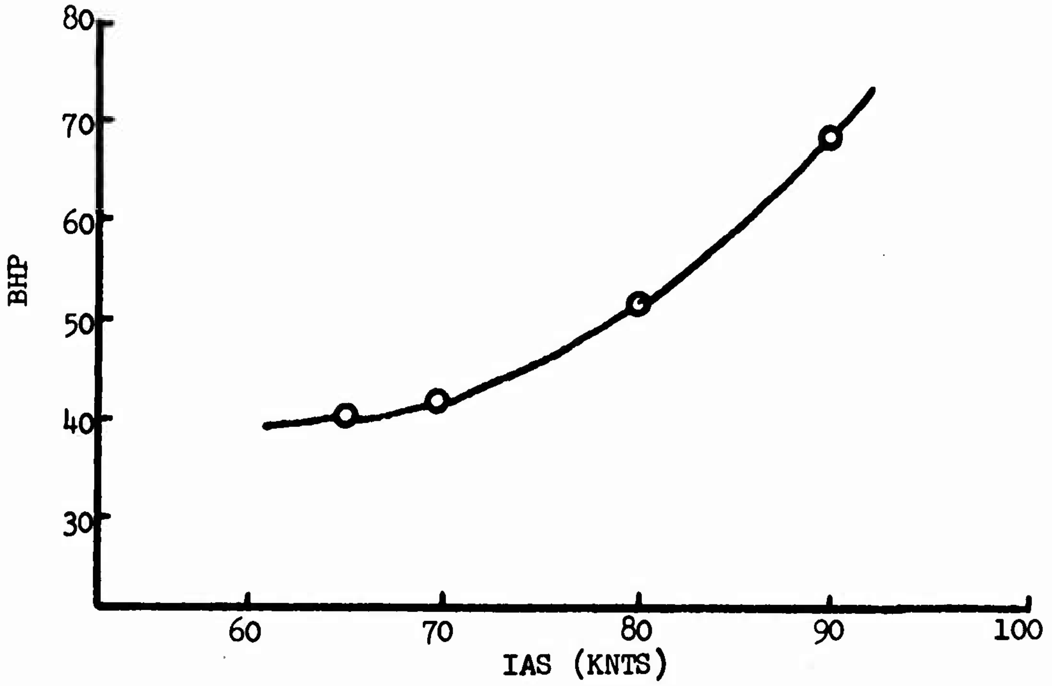
Figure 3 shows a conservative estimate of noise reduction produced by the complete muffler system installed in the aircraft. This curve is computed from sound levels indicated on plots of Figs. 1 and 2. A sketch of the complete muffler system is also shown. In the frequency range from 150 to 5000 Hz, 35 to 50 dB of noise reduction was achieved.

FLYOVER TESTS

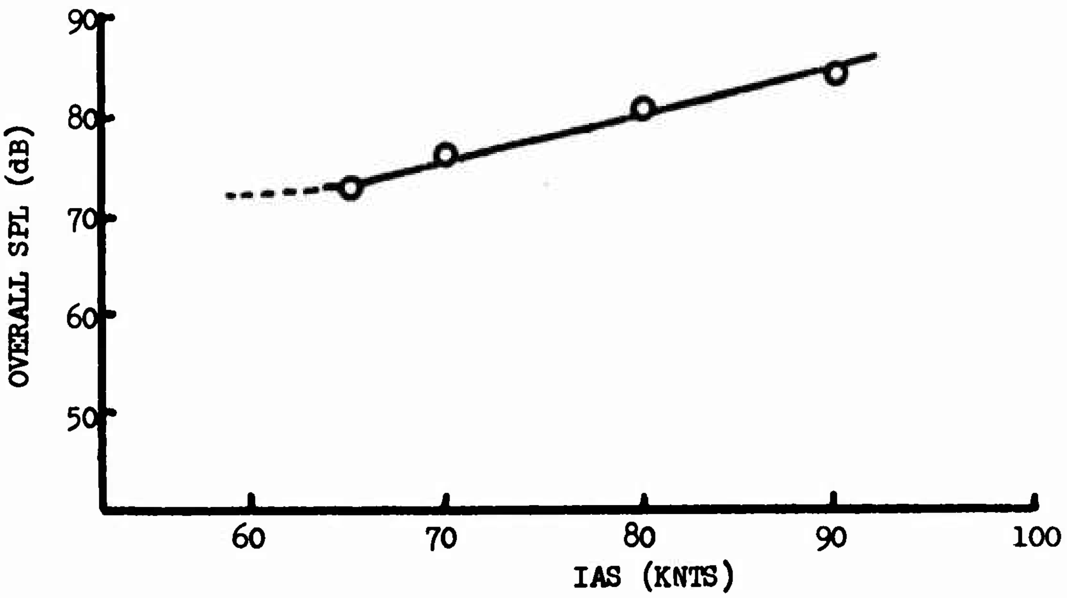
Figures 4 through 8 illustrate the results of flyover tests. Figure 4 shows performance curves for the Q-Star powered with Wankel engine and six (6) bladed propeller. Brake horsepower (BHP) and overall sound pressure level (SPL) are plotted as functions of indicated air speed (IAS). These data suggest that minimum acoustic noise signature is related to minimum power required for aircraft operation; an assumption usually made in quiet aircraft design.

OCTAVE BAND SIGNATURE ANALYSIS

Figure 5 is a comparison of the acoustic signatures of the Q-Star aircraft flying with three different propellers. In general, the six bladed propeller produced the minimum acoustic signature; however, it should be noted that the noise energy shown in the 125, 250, 500, and 1000 Hz octave band is critical with regard to aircraft detection range. Below this range the low frequency sound is usually inaudible to the human ear at normal flyover ranges. Above this range excess attenuation of higher frequencies greatly attenuates the noise. In this critical middle range of frequencies, both three-bladed propellers produced less noise than the six-bladed propeller in the 500 Hz octave band.



(a) Brake Horsepower vs. Indicated Air Speed



(b) Over-all Sound Pressure Level vs Indicated Air Speed

Fig. 4 Q-Star Aircraft Performance Curves - Wankel Engine - 6-blade Propeller

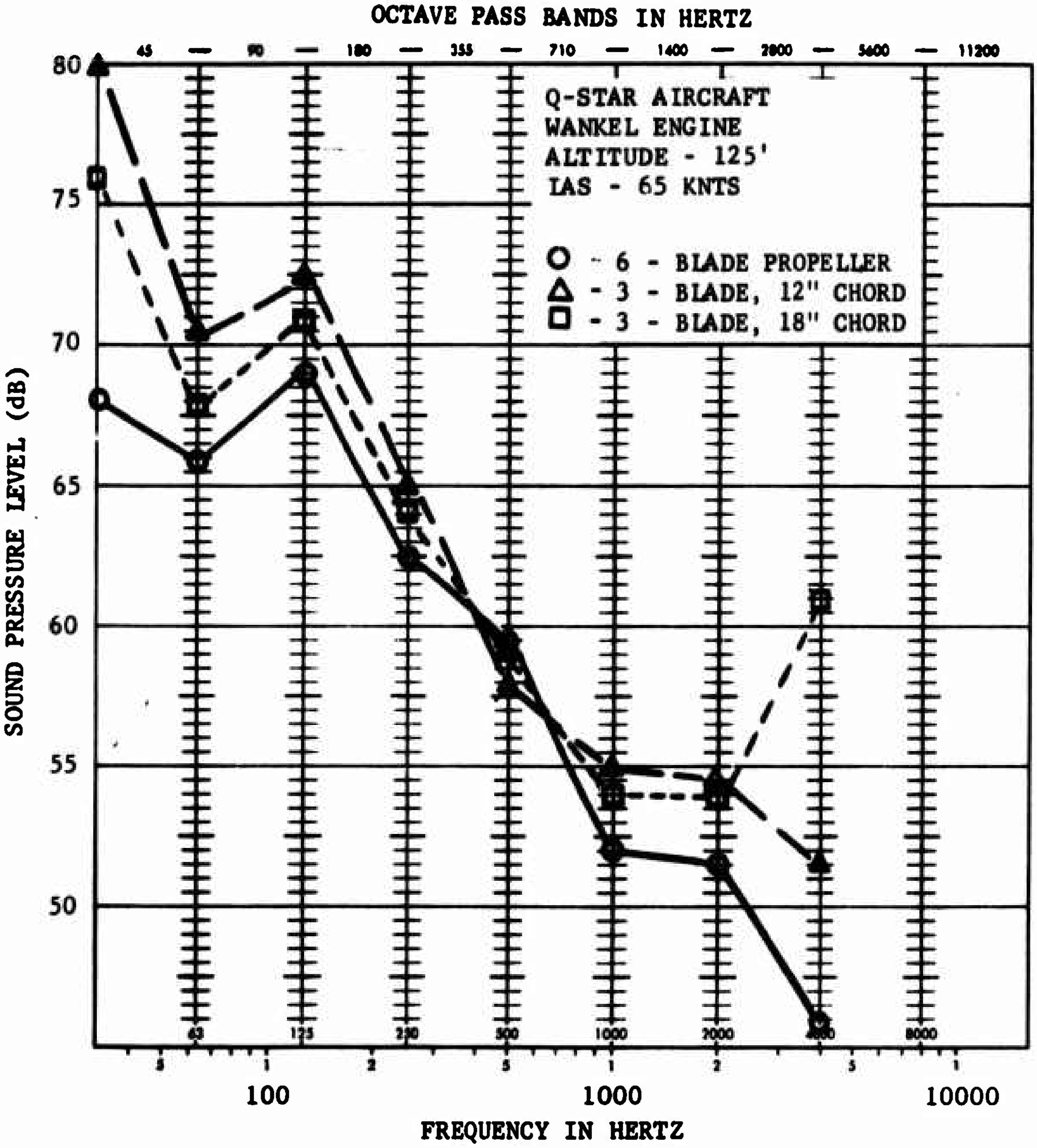


Fig. 5 Comparison of Acoustic Signatures of Q-Star Aircraft Flying with Three Different Propellers

Figure 6 shows a comparison of acoustic signatures of the Q-Star aircraft flying at three different indicated air speeds while holding rpm constant. Although the range of velocities, 56 to 65 knots, corresponds to minimum power operating range of the aircraft, and little change in overall sound pressure level is expected, a range of several dB can be seen in the 250 Hz octave band. This suggests a "best" quiet cruise velocity within rather narrow limits for minimum detectability.

Figure 7 shows a comparison of acoustic signatures of the Q-Star aircraft flying at three different RPM settings while holding IAS constant. Again, in the critical octave bands, the dB spread suggest a "best" rpm setting for quiet cruise.

Figure 8 shows comparison of acoustic signatures of Q-Star aircraft flying with and without trailing edge extensions on wings. Somewhat higher sound levels are seen in the 63 and 125 Hz octave bands before adding the extensions. These increased levels are attributed to more power required to fly the aircraft at a slightly increased angle-of-attack necessary for the aircraft without extensions.

NARROW BAND ANALYSIS

Figures 9 through 11 are examples of narrow band spectral analyses that were performed on selected data samples. Figure 9 shows the analysis of a typical flyover using a 1.5 Hz filter over a range up to 500 Hz. The period over which the analysis is performed is 1.0 sec at the peak scund pressure level during the flyover. Figure 10 shows the results of utilizing a broader 6.0 Hz filter over a range up to 2000 Hz. The time period of analysis is 0.25 sec taken from within the time period of the previous plot. Figure 11 shows the results of utilizing a 15 Hz filter over a range up to 5000 Hz. The analysis time period is 0.10 sec selected from within the period of the previous plot.

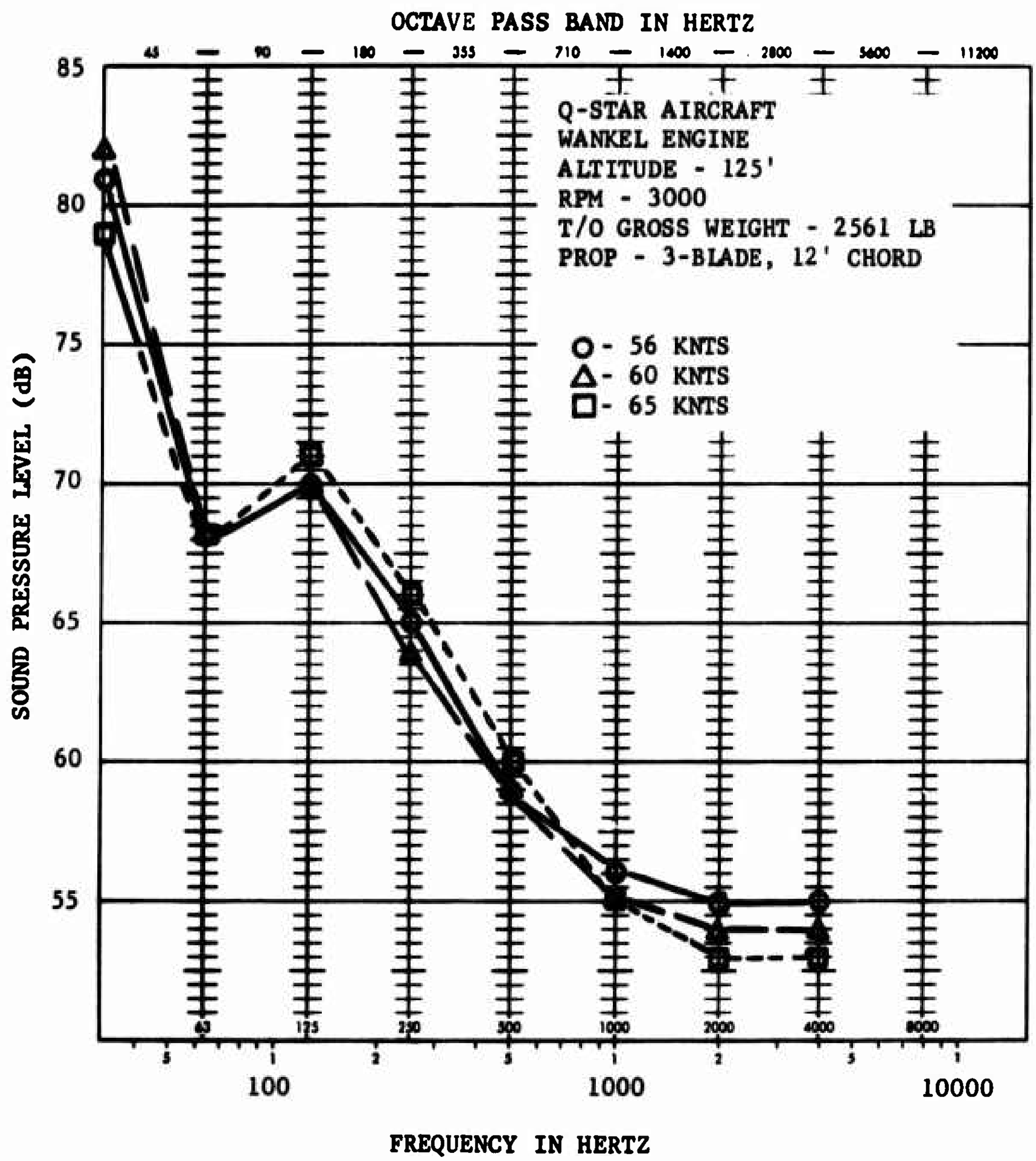


Fig. 6 Acoustic Signatures of Q-Star Aircraft Flying at Three Different Indicated Air Speeds with Constant RPM

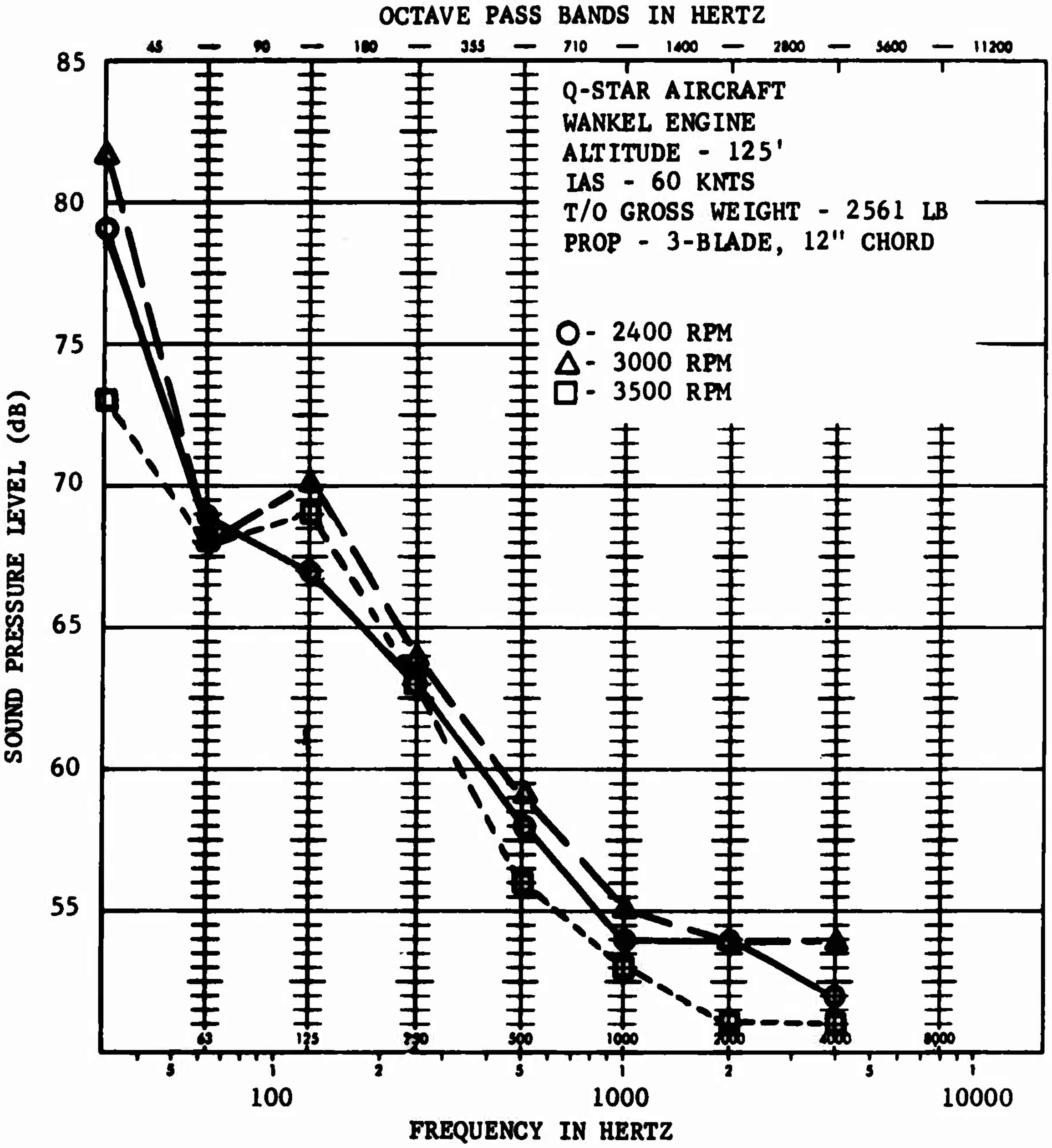


Fig. 7 Acoustic Signatures of Q-Star Aircraft Flying at Three Different RPM with Constant IAS

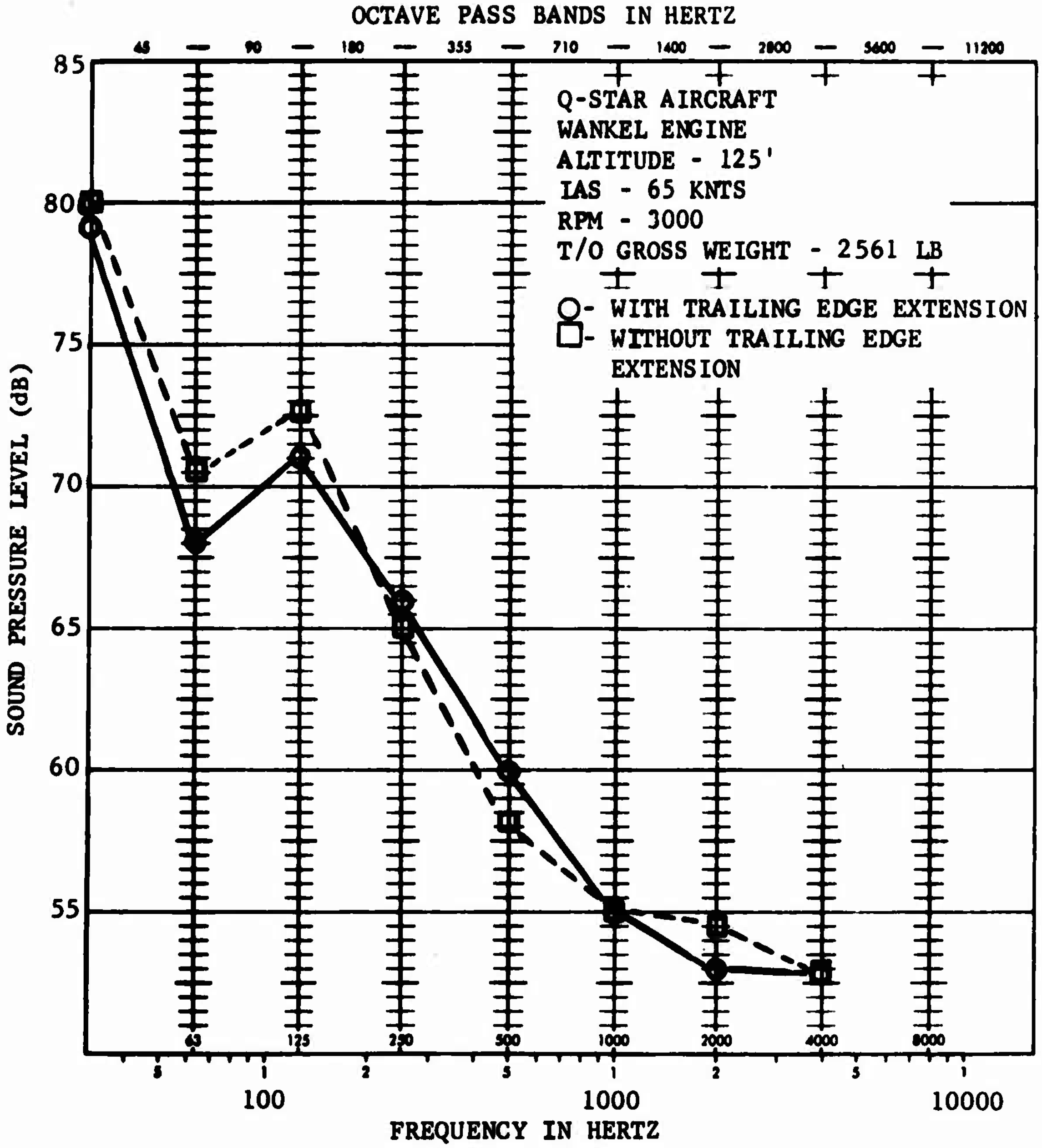


Fig. 8 Acoustic Signatures of Q-Star Aircraft Flying With and Without Trailing Edge Wing Extensions

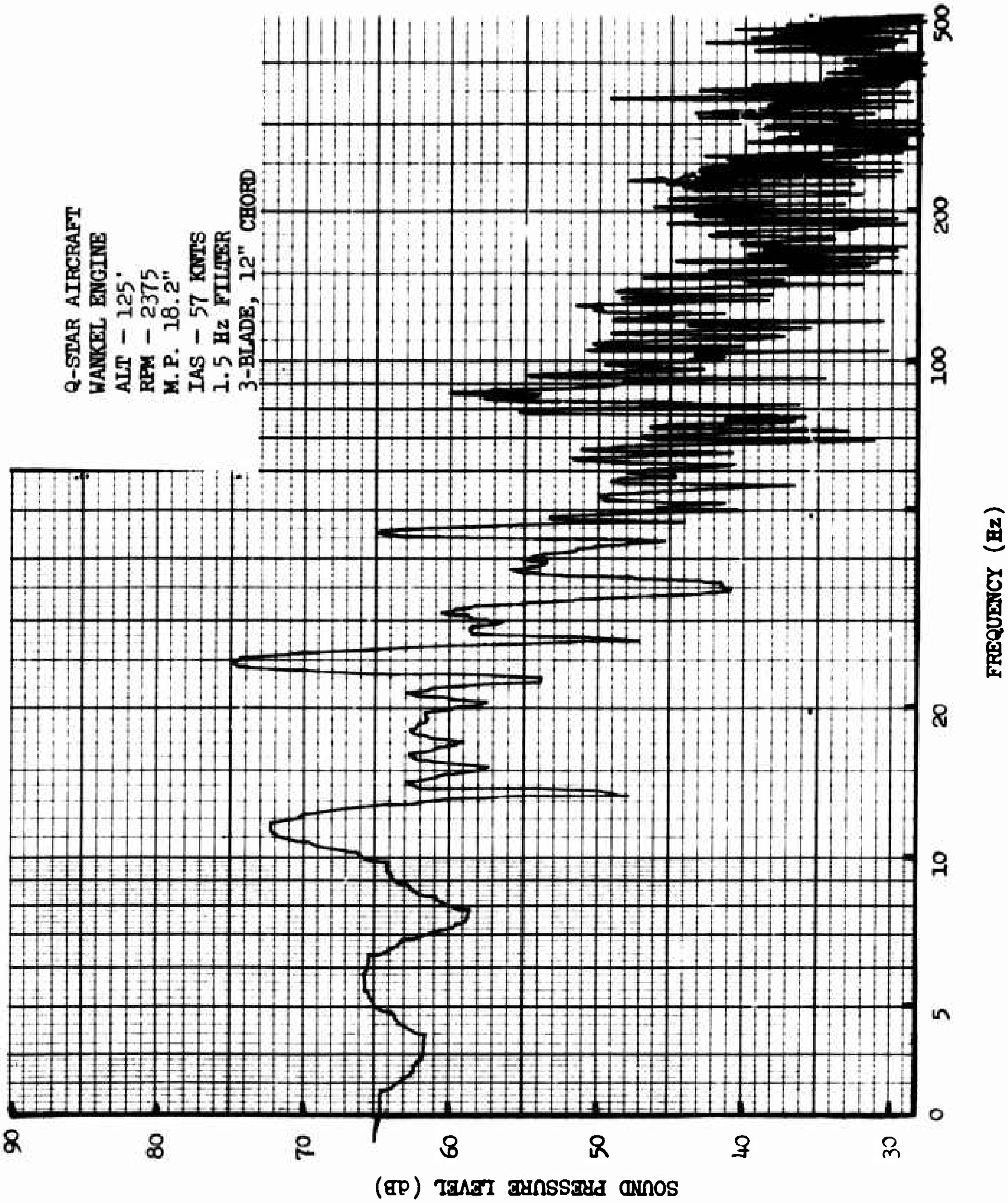


Fig. 9 Narrow Band Analysis of Q-Star Acoustic Signature 500 Hz Range

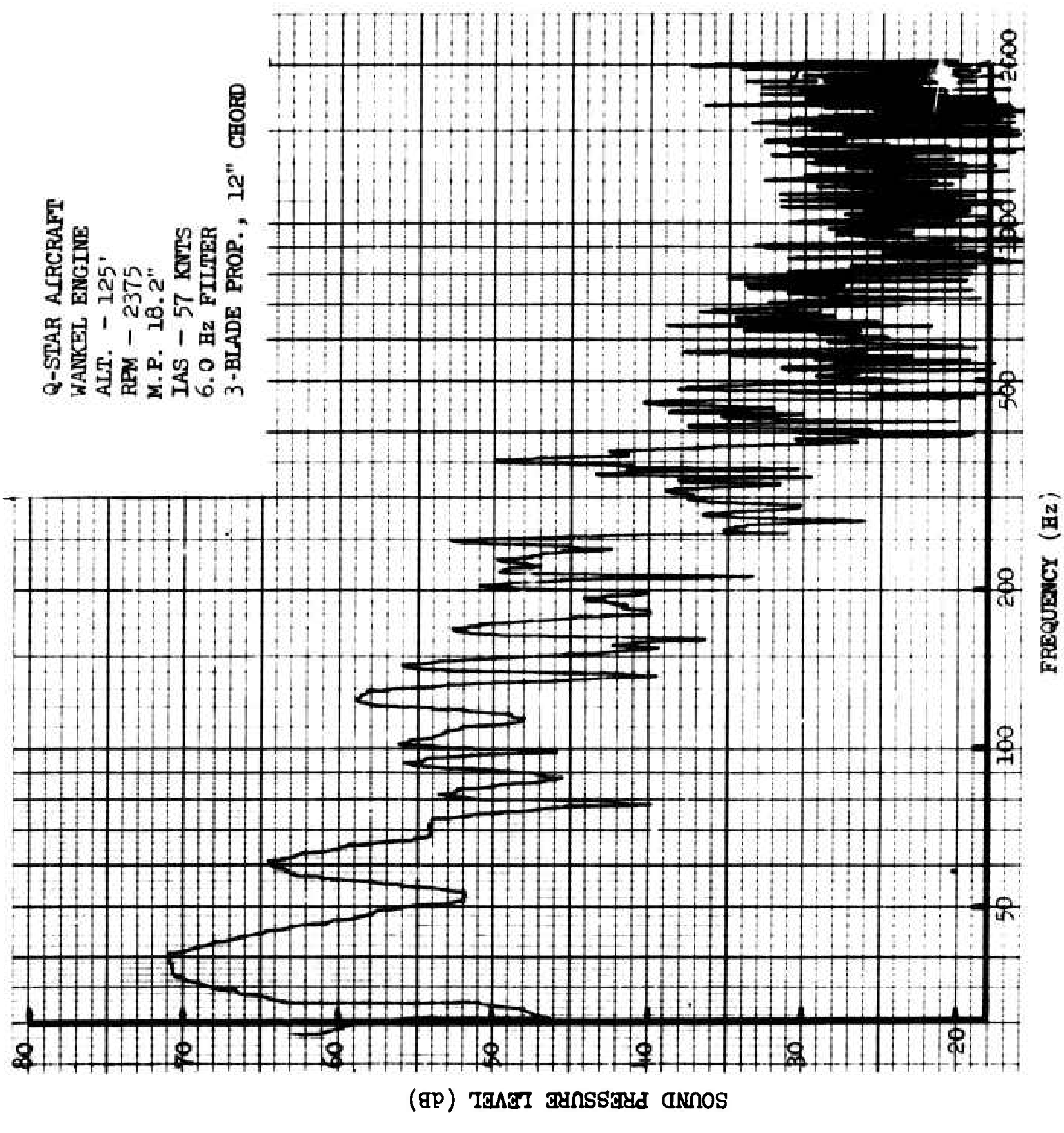


Fig. 10 Narrow Band Analysis of Q-Star Acoustic Signature, 2000 Hz Range

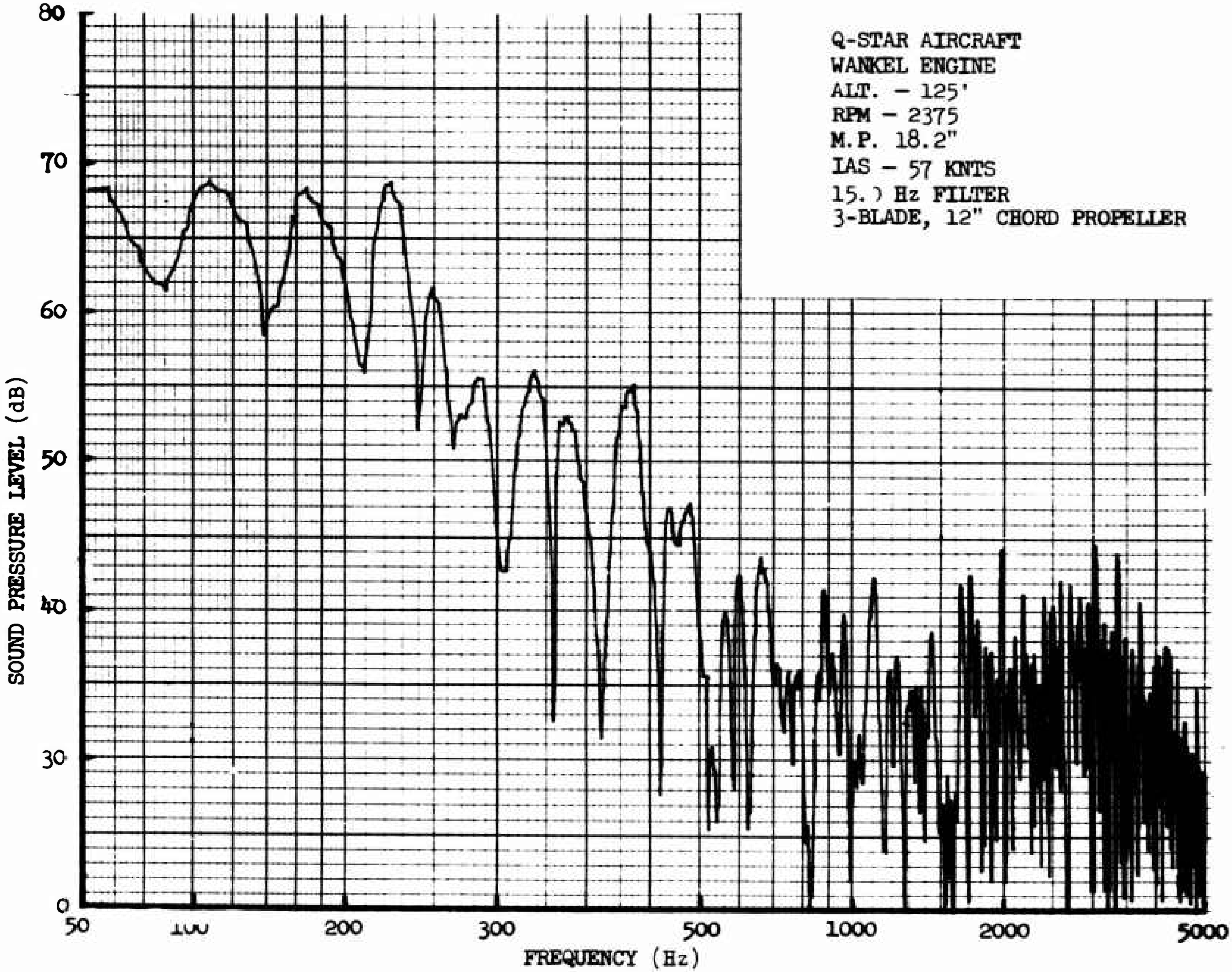


Fig. 11 Narrow Band Analysis of Q-Star Acoustic Signature 5000 Hz Range

DETECTION RANGE

Figure 12 shows the spectrum level of the acoustic signature of the Q-Star aircraft computed from narrow band analyses of data taken from 125-ft flyover. Superimposed on this plot is an "acoustic goal" for a proposed quiet airplane. This goal represents the maximum spectrum level for an aircraft flyover at 125 ft if the aircraft is to be undetected at a slant range of 2000 ft. An arbitrary background noise level is assumed. For comparison purposes, a military Cessna T41 aircraft will exhibit typical detection ranges on the order of 8000 ft or more when operating under conditions similar to those experienced by Q-Star during the flyovers noted.

These data show that the Q-Star aircraft with Wankel engine and three-bladed propeller almost meet this criterion. Suppressing the acoustic peaks between 200 and 500 Hz (suspected to be propeller noise) will provide a quiet aircraft that will be undetected, in most cases, at a range of 2000 ft.

ACOUSTIC GOAL FOR QUIET AIRCRAFT

The acoustic goal for a quiet aircraft is to remain undetected while flying at a given altitude by observers listening on the ground. Predicting this altitude or slant range at which the aircraft cannot be heard is complicated by several variable factors. The factors include variation in aircraft signature under normal operating conditions, variations in propagation of acoustic energy in changing atmospheric conditions, and variations in ability of the observer to aurally detect and recognize sounds of the aircraft.

For a given aircraft operating with set parameters such as propeller pitch and rpm, velocity, and trim conditions, the acoustic signature remains fairly constant. But variations of one or two dB in sound pressure level in critical frequency regions can cause significant changes in detection range. Such variations in signature can occur in production aircraft because of manufacturing tolerances. Static tests of propellers show such changes in cross wind conditions for instance. Finally, minor mechanical problems or damage

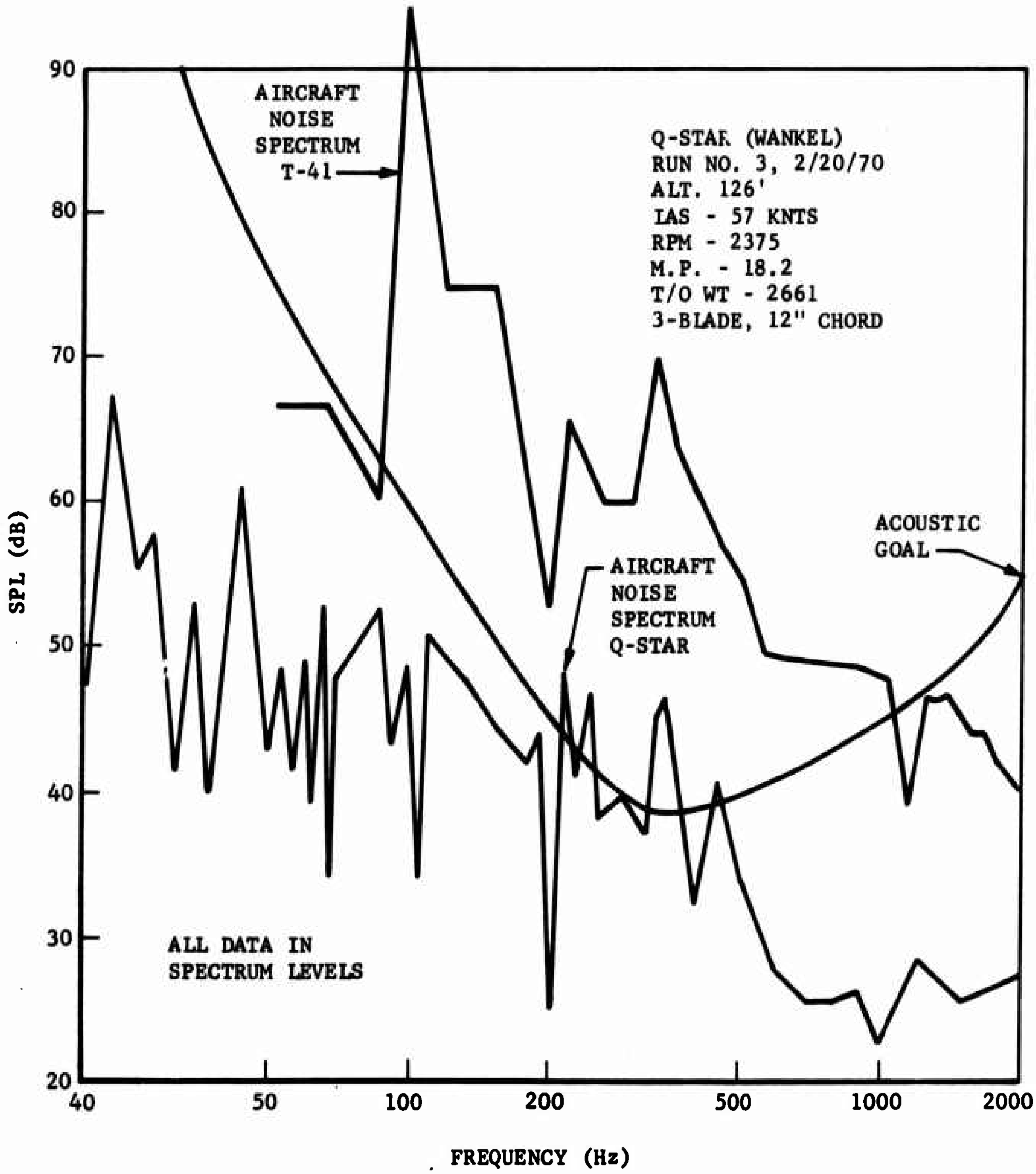


Fig. 12 Detectability

to the quiet aircraft may increase drag and result in increased power required that may produce one or two dB variation in sound levels.

Sound energy propagating in the atmosphere suffers reflection, refraction, and attenuation due to a variety of causes which are usually unpredictable for field operation. Ten dB and greater viarations in sound levels can be noted in the aircraft noise signature in aircraft flyovers above 1000 ft. Statistical analysis must be applied to this time varying signal for purposes of estimating detection range.

The ability of the ground observer to detect the sound of the quiet aircraft is dependent upon both the threshold of hearing for the individual and to local ambient background noise. Both factors can contribute many dB of variation in detection level of the acoustic signature. The observer also has the problem of recognizing the sound as aircraft noise.

In summary, it is difficult to set a realistic acoustic goal for a quiet aircraft that will guarantee that it will fly undetected at a useful altitude. However, assuming a standard day (or night) with no temperature inversions and a minimum background noise level, an estimate of the acoustic signature measured at 125 ft that will assure a detection range of 2000 ft has been made and appears elsewhere in this report. Under extreme conditions an aircraft with this signature identified as the "acoustic goal" might go undetected at 1000 ft, but under other conditions might be detected and identified at 3000 ft.

IV. CONCLUSIONS

The following conclusions are drawn from the acoustical tests conducted on this program:

(1) Quiet cruise velocity for the Q-Star configuration is between 56 and 65 knots. More work is required to identify "best" velocity for the aircraft with each type of propeller from the standpoint of detectability.

(2) Lower rpm settings near 2400 rpm seem to offer advantages in acoustic signature.

(3) Wing extensions which minimize the flight angle of attack and power required for "quiet cruise" improve acoustic signature.

(4) This Q-Star configuration will have a detection range of approximately 2000 ft when operating over an area with very low background noise environment.

(5) More work is required to assess the performance of the three propellers available.

(6) The rotary combustion engine concept lends itself well to quiet aircraft applications. Muffling of the exhaust noise is amenable to conventional treatment with tuned resonators and absorbers. Design and fabrication of muffler systems required care due to the higher than normal gas temperatures produced by the engine. The vibrationless characteristic of the engine and the absence of reciprocating parts such as valve mechanisms provide demonstrable advantages for quiet aircraft applications.

A significant "second order" advantage of the rotary combustion concept is the relatively high power to weight ratio. Aircraft noise is a function of horsepower required at mission cruise velocities; which is, in turn, a function of aircraft gross weight. Significant weight savings such as provided by the rotary combustion concept relate to reduction in quiet aircraft noise production.

V. RECOMMENDATIONS

Further experimental work with Q-Star fitted with the RC-2-60 rotary combustion engine can contribute materially to the data bank needed to support future quiet aircraft design tradeoffs and decisions. Three areas suggest themselves:

(1) The recently completed feasibility program, while producing some quantitative data in the area of acoustics, was largely qualitative in the area of flight performance. A short but intensive flight program could provide useful quantitative data on:

- Flight performance reduced to standard conditions

  Takeoff distance and rate of climb
  Cruise speed, top speed, stall speed
  Gross weight/velocity/noise tradeoffs

- Engine performance

  Specific fuel consumption
  Exhaust gas analysis
  Muffler back pressures
  Cooling characteristics
  (size radiator and provide buried installation)

(2) Critical to the noise produced in aircraft flight is propeller noise. Three propellers of different characteristics exist for application to Q-Star. A continued program of propeller development could provide useful data for designers of rotary combustion engine installations in quiet aircraft applications.

(3) Prediction of human detectability of aircraft required treatment of both technological and psychological factors. Analytical work to date on aircraft noise has been done on data measured mechanically and expressed in terms of pressure lines at specified frequencies. Background noise levels, also measured mechanically and expressed as pressures, have often been used in conjunction with statistical data of the well known Fletcher Munson type in attempts to predict human detectability.

Although the Fletcher Munson approach, namely, the measurement of hearing thresholds of a large number of human subjects to sound pressure levels at discrete frequencies attempts to bridge the gap, it does not take into account the psychological factors involved in the areas of human motivation, or a prior knowledge and signature recognition.

Relationships between aircraft noise signatures (measured mechanically and expressed in terms of pressure) and human detectability under "real world" conditions, are not well understood.

Nearly all detectability tests are conducted by using observers who know that they are to listen for an airplane, who know ahead of time the general nature of the aircraft sound signature, who have no other mental or physical choice than to listen for the airplane, who generally know the rough time and direction of aircraft arrival, and who are "success motivated", i.e., from the paid observer point of view, it is better to hear the airplane than not to hear the airplane. Such exercises do little to improve understanding of the relationships between aircraft pressure signatures and human detectability.

Q-Star, a commercially available quiet aircraft, is the ideal vehicle around which to plan and implement an experimental verification of the required analytical studies in this important field.

Appendix A
ACOUSTIC TEST PROCEDURES

Over the several years of acoustic engineering and testing of quiet aircraft, LMSC has developed effective acoustic test procedures for determination of aircraft noise signatures. These procedures are discussed below.

TEST LOCATION

The low level of the acoustic signature of the quiet aircraft demands that an acoustic test program be conducted at a site possessing extremely low background noise levels. Usually, the time during the day of tests is dictated by the attainment of an acceptable signal-to-background noise level. The test program described herein was conducted at the Crows Landing Naval Air Station, Crows Landing, California. The acoustic measuring station was located in an available grassy area between the existing runways and taxiways at the airport. The LMSC Mobile Acoustic Test Support Van, including the necessary acoustic instrumentation and test support equipment, was the only structure in the immediate area but was located approximately 400 ft from the acoustic measuring station. The layout of the test site is shown in Fig. A-1.

INSTRUMENTATION

All instrumentation utilized in this test program for purposes of the acquisition and analysis of acoustic performance data was in a state of current calibration.

Acoustic Instrumentation. The acoustic data acquisition system is capable of recording multiple channels containing both acoustic and supporting data which were reduced and analyzed subsequent to the test series. The equipments, with appropriate model numbers, shown in Table A-1, and illustrated in Fig. A-2, comprise the data acquisition and octave band data reduction system to be employed during this test series. Other support equipment, such as aircraft radios, installed on the Mobile Acoustic Test Van were also used as deemed appropriate to support the test program. A block diagram of the complete system is provided in Fig. A-3.

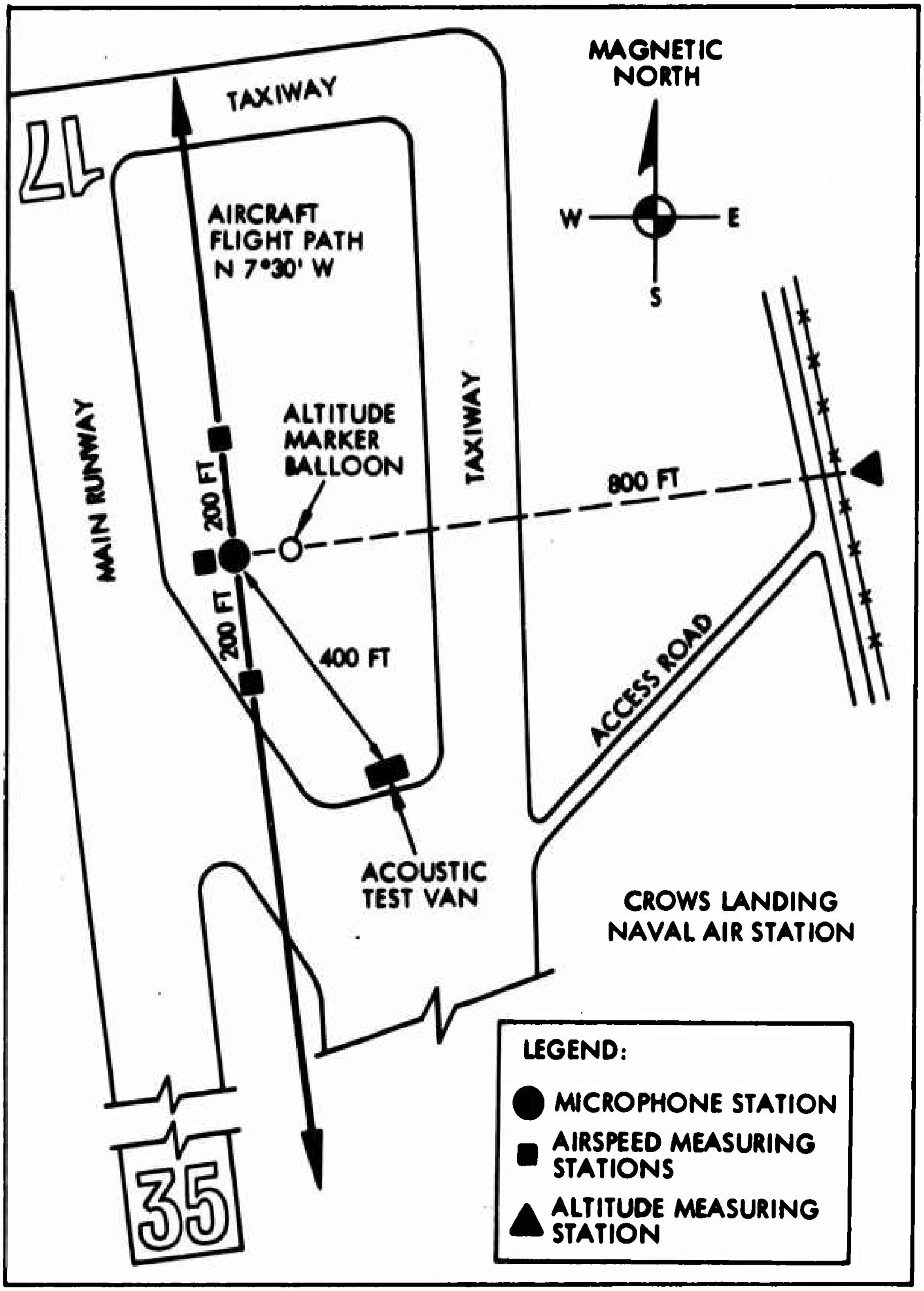


Fig. A-1 Layout of the Test Site at Crows Landing Naval Air Station

Table A-1

ACOUSTIC INSTRUMENTATION

Equipment	Manufacturer	Model No.
Microphone	B&K Instruments	4132
Preamplifier	B&K Instruments	2619
Amplifier	B&K Instruments	2211/S4MM
Pistonphone Calibrator	B&K Instruments	4220
Frequency Response Calibrator	Hewlett Packard	3550B
Time Code Generator	Electronic Engineering Co.	EECO 858A
Windscreens	B&K Instruments	UA 0082
Octave Band Analyzer	B&K Instruments	2112
Graphic Level Recorder	B&K Instruments	2305
Tape Recorder	Ampex	FR 1300
Visicorder	Minneapolis-Honeywell	906A

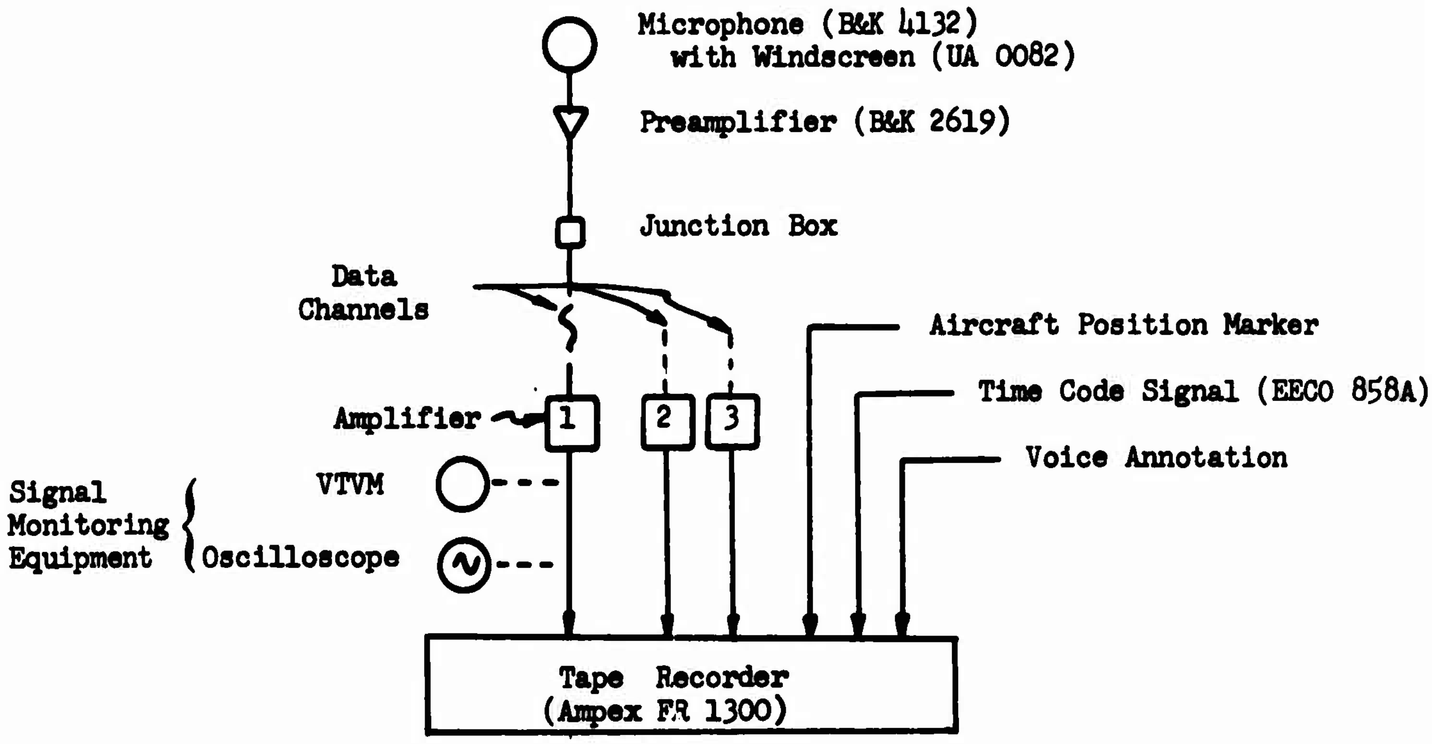


Fig. A-2 Typical Instrumentation Set-Up

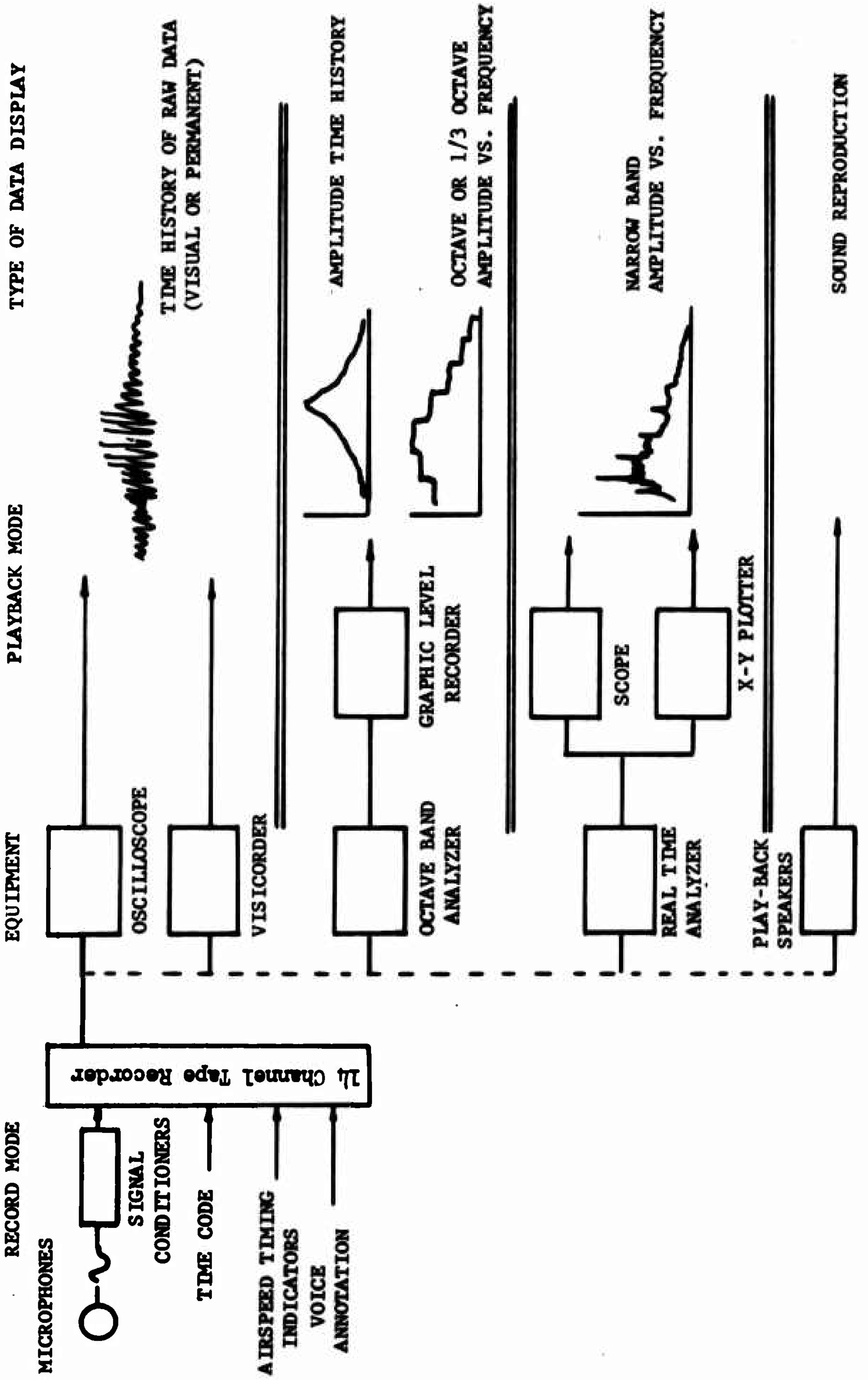
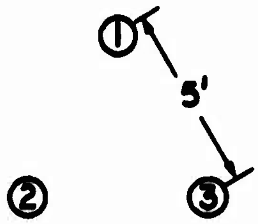


Fig. A-3 Block Diagram of Acoustic Data Acquisition and Reduction System

Acoustic Measuring Station Layout. Acoustic data were acquired using three microphone systems. Each microphone was positioned five feet above the ground and spaced five feet apart to form a triangular pattern as depicted below:



The microphone diaphragms were positioned to minimize the frequency response correction due to the angle of incidence between the acoustic wave fronts and the microphone's diaphragm. For the B&K Model 4132 microphones, the diaphragm was oriented in the vertical plane which included the aircraft flight path. A fourth microphone, positioned seventy-five (75) feet to the side was also used in most tests. The acoustic measuring station was established as depicted on Fig. A-4 with respect to the aircraft flight path and the location of the other instrumentation.

ACOUSTIC DATA ACQUISITION SYSTEM CALIBRATION

System Frequency Response Determination. Prior to the initiation of the flight test activities but following the layout of the test course and the set-up of the acoustic measuring station, the acoustic data acquisition systems were calibrated to determine the in-the-field system frequency response and amplitude linearity. The microphones were removed and an insert voltage calibration conducted across the audio frequency spectrum on each microphone system using the Hewlett Packard Model 3550B Calibrator. This provided a complete check of each system less microphone; the microphones are calibrated at the LMSC Measurement Standards Laboratory and each is provided with a current frequency response curve.

System Electrical Noise Survey. The electrical noise associated with each of the microphone systems was determined prior to the start of the test flight program. System electrical noise was recorded on the designated data channels of the magnetic tape recorder by replacing the microphone with a dummy load device.

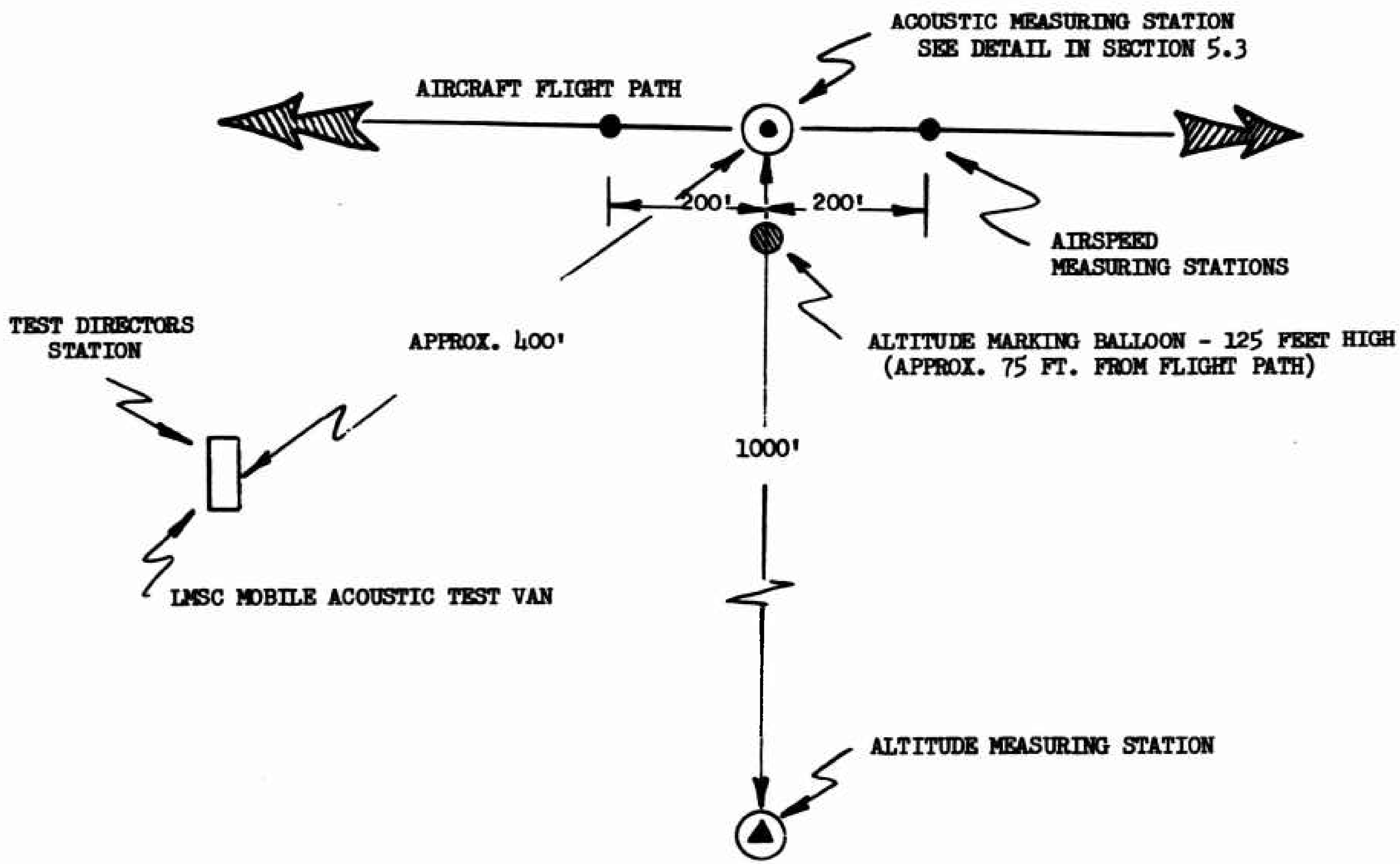


Fig. A-4 Test Course Layout

System End-to-End Calibration. A complete system end-to-end calibration was performed at the beginning and end of the test flight series. In addition, when testing was interrupted for a period exceeding one hour, for any reason, the calibration procedure was repeated before resumption of testing. Calibration signals were also recorded at the end of a tape reel and on the beginning of the next reel, when the test series requires the use of more than one reel of magnetic recording tape.

The system end-to-end calibration was performed with the Pistonphone Calibrator Type 4220, which generates a calibrated tone at 250 Hz at a sound pressure level of 124 dB relative to 20 N/M^2 (sea level). A correction factor, associated with any difference between the ambient atmospheric pressure and the standard atmosphere, will be applied if necessary.

This calibration was performed by removing the microphone windscreens (Type UA 0082), sliding the Pistonphone Calibrator over the microphones (in turn), and, for approximately 60 seconds, tape recording onto the designated data channels the tones thus generated. While the calibrator is in position on each microphone, the microphone amplifier for each channel (2211/S4MM) was adjusted. This was accomplished by monitoring the amplifier output voltage on an oscilloscope and adjusting the "k" factor for an 8.9 voltage output.

Acoustic Data Reduction. Acoustic data reduction consisted of time history plots of the attained sound pressure levels, in dB (ref: 20 N/M^2), for each octave-band (31.5, 63, 125, 250, 500, 1000, 2000, and 4000 Hz bands). The B&K Instruments Model 2112 Octave-Band Analyzer, in conjunction with the Model 2305 Graphic Level Recorder, was used for the data reduction. The graphic Level Recorder was operated with the following readout parameters:

Pen Writing Speed - 200 mm/sec
Paper Speed - 10 mm/sec

These plots were reviewed and a representative value for the peak sound pressure level achieved was defined and tabulated. The representative peak level reached was selected from each octave-band irrespective of the aircraft location relative to the microphones.

OTHER FLIGHT TEST INSTRUMENTATION

Aircraft Altitude Assessment. The aircraft altitude (height above the ground) at the time of passage over the microphones was determined optically with a surveyor's transit positioned 800 feet from and perpendicular to the aircraft's ground track. The altitude determination was used as a "GO/NO-GO" gauge of the flyover's acceptability; in this manner, aircraft altitude will be controlled to within ±5 feet of the nominal 125-foot value.

The transit was positioned and the required triangulation accomplished prior to the start of test. The elevation angle for the transit optics was established in accordance with standard engineering procedures.

Aircraft Flight Speed Instrumentation. The aircraft flight speed, at the time of passage over the microphones, was monitored on board the aircraft during the pilot's visual observation of the airspeed indicator (Indicated Airspeed - IAS) and transmitted via radio link to the ground-based Test Director's station for transfer to the Test Data Sheet.

The aircraft flight speed was also measured from the ground using a photoelectric detector reacting to the aircraft's overhead passage. These optical detectors were positioned 200 ft on each side of the microphone station along the flight path and generated an electronic trigger to be recorded on one channel of the magnetic tape. These markers were used in conjunction with the recorded time code to determine the aircraft equivalent airspeed.

Environmental Monitoring Equipment. Ambient air temperature and relative humdity were measured using a laboratory grade sling psychrometer during the course of the flight test program.

Atmospheric pressure was measured during the course of the test series using a Wallace and Tiernan absolute pressure gauges.

Wind velocity and direction was monitored at the Test Director's station during each aircraft pass over the acoustic measuring station. Wind velocity was measured with a hand-held, pitch-ball aneometer.

Appendix B

Q-STAR AIRCRAFT DESCRIPTION

This appendix presents program and product data on the Lockheed Missiles & Space Company aircraft N5713S, known as "Q-Star".

AIRCRAFT DESCRIPTION (See Fig. B-1)

Airframe

Configuration: Schweizer SGS 2-32

Modification: Pylon added for propeller drive shaft front bearing mounting

Canopy opening provisions changed as shown

Power plant accommodation added as shown

Landing gear (main and tail wheel) added as shown

Approximately seven square feet fin area added.

Structure: Schweizer SG 2-32

Modification: Structural mods to accommodate above noted configuration mods.

Wing and fuselage modified to provide limit load factor of 3.8 at max. gross weight of 3100 pounds.

Integral (wet wing) fuel tanks to accommodate 40 gallons usable.

AIRCRAFT MISSION

Provide flying research laboratory to support studies in the field of quiet flight.

Propulsion system test bed
Aerodynamic configuration test bed
Mission equipment test bed
Applications and missions demonstrator

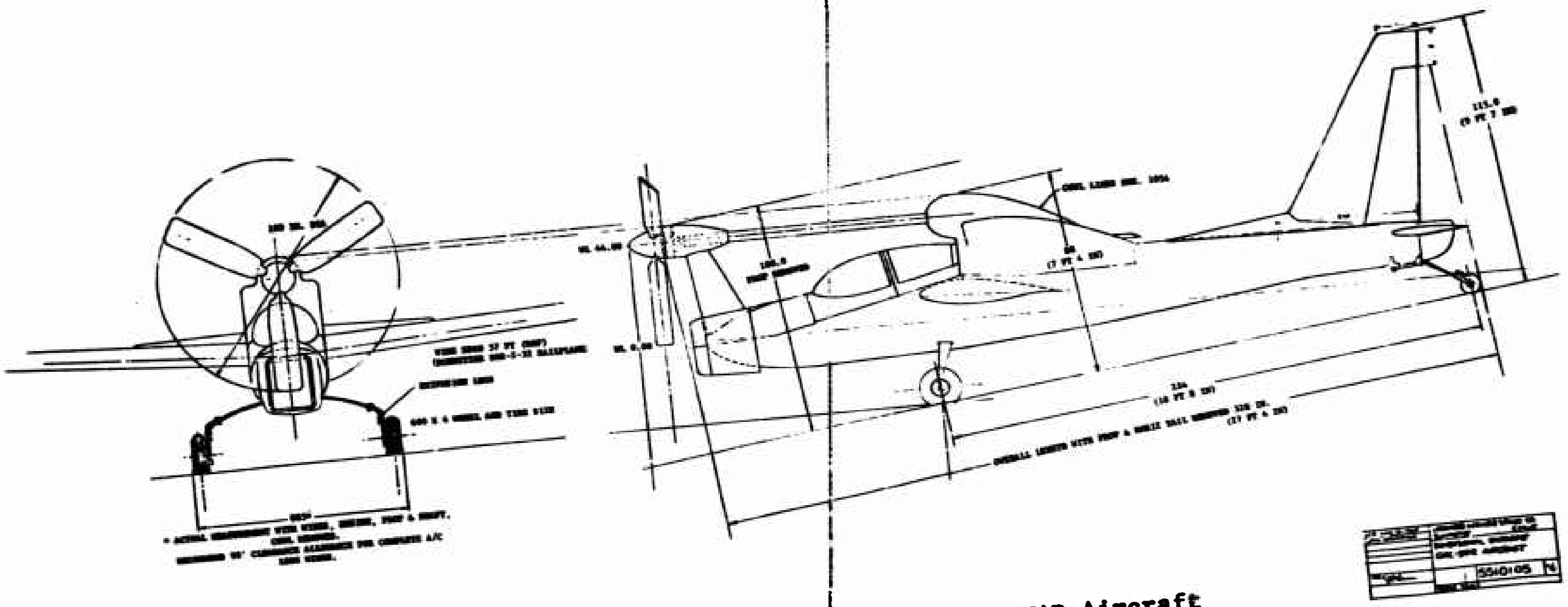


Fig. B-1 Dimensional Envelope QRC-STAR Aircraft

AIRCRAFT PERFORMANCE

Q-Star has flown with various propellers and engines, and at various gross weights. The research oriented mission of the aircraft has not supported a detailed analysis of performance figures reduced to standard atmospheric conditions and compiled in usual format. The following figures list best estimates of the aircraft performance with two different engines and three different propellers.

Characteristic	Performance	
Engine	Reciprocating Continental 0.200	Rotating Combustion Curtiss-Wright RC2-60
Rated Horsepower	100	185
Weight, empty (lb)	2020	2166
Max gross wt flown	2450 (typ)	2975
Takeoff distance over 50' obstacle (ft)		
6 blade F.P. prop 2441 lb GW	2145	-
3 blade C.S. prop 2619 lb GW	-	1223
6 blade F.P. prop 2547 lb GW		1564
Max Rate of climb (FPM @ sea level)		
6 blade F.P. prop (est 2490 lb GW)	545	-
6 blade F.P. prop (2640 lb GW)	-	600
3 blade C.S. prop (est 2725 lb GW)	-	800 (pilot est.)
Max Level Flight Speed (KTS IAS)		
6 blade prop 2640 lb GW	105 (pilot est.)	120
3 blade prop 2638 lb GW	-	132

AIRCRAFT PROGRAM

First flight

Fahlin 4 blade fixed pitch X1150-2 propeller

Continental 0-200 4 cylinder reciprocating engine — 3 June 1968

Flight hours to April 16, 1969	128.9
First flight	
Fahlin 6-blade fixed pitch propeller	
Curtiss-Wright RC-2-60 rotating combustion engine	6 September 1969
Flight hours to March 26, 1970	205.0

RC ENGINE PROGRAM

Engine Serial 743-5		hr:min
Test stand time at Curtiss-Wright		23:45
Ground run time in Q-Star		40:33
Flight time in Q-Star		28:37
	Total time	92.55
Engine Serial 742-6		
Test stand time at Curtiss-Wright		16:50
Ground run time in Q-Star		11:49
Flight time in Q-Star		46:20
	Total time to 15 May 1970	74:59

It should be noted that the radiator configuration selected is approximately twice the size required, based on aircraft airflow studies and engine heat rejection analysis. For first flights of the Wankel concept engine, the ultraconservative approach was thought justified, especially since the original plan included an ultimate burial of the radiator in the fuselage after verification of heat rejection and airflow performance.

Unclassified
Security Classification

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13. ABSTRACT

Forty-six hours of flight were completed wherein the acoustical characteristics of the Curtiss-Wright Corporation RC2-60 liquid-cooled Rotating Combustion Engine were evaluated (U).

The Lockheed Corporation "Q-Star" prototype quiet aircraft was utilized as the test vehicle (U).

It has been demonstrated that the acoustic signature of the Q-Star aircraft with the RC2-60 engine installed comes closer to meeting current detectability criteria than any other current candidate propulsion system (U).

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Noise						
Engine Noise						
Aircraft Engine Noise						
Rotating Combustion Engine Noise						
Propulsion System Noise						
Quiet Rotating Combustion Engine						
Rotating Combustion Engine for Low Noise Level Aircraft						
Low Noise Level Aircraft						

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