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INDEX OF FIGURES

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TABLE OF CONTENTS

	<u>Page</u>
1. SUMMARY	2
2. INTRODUCTION	3
3. DISCUSSION	4
3.1 INSTRUMENTATION	4
3.2 THE INFLUENCE OF ENGINE SIZE AND FUEL FLOW RATE ON NOISE SPECTRUM	4
3.2.1 The 6.75" Standard Single Shell Engine	5
3.2.2 The 6.75" Single Shell Engine With Long Tailpipe	5
3.2.3 The 7.5" Single Shell Engine	5
3.2.4 The 7.5" Conical Engine	5
3.2.5 The 12.5" Single Shell Engine	6
3.2.6 Comparison of Noise vs. Size	6
3.3 NOISE CONTROL CONFIGURATIONS	7
3.3.1 The 6.75" Engine with Acoustic Filter	7
3.3.2 Twin 6.75" Engines in Parallel Configuration	8
3.3.3 Twin 6.75" Opposed Configuration	9
3.3.4 The 6.75" Engine with Long Tailpipe and Tabs Extending from Tailpipe	9
3.3.5 The 6.75" Engine with Long Slotted Tailpipe	10
4. CONCLUSIONS	11

NOISE SPECTRUM CHARTS:

Figure 2 -6.75" "Standard" Single Shell Engine	12
Figure 3 6.75" Single Shell Engine with Long Tailpipe	12
Figure 4 7.5" Single Shell Engine	13
Figure 6 7.5" Conical Engine	13
Figure 7 12.5" Single Shell Engine	14
Figure 8 Comparison of Noise Spectra vs. Engine Size	14
Figure 11 Comparison of 6.75" Engines	15

(continued)

INDEX OF FIGURES

(continued)

		<u>Page</u>
Figure 16	Twin 6.75" Engines - Parallel Configuration	15
Figure 20	Twin 6.75" Engines - Opposed Configuration with Untreated Duct	16
Figure 22	6.75" Single Shell with Long Tailpipe and Tabs	17
Figure 24	6.75" Single Shell with Long Tailpipe and Slotted Flare	17

PHOTOGRAPHS OF ENGINES MOUNTED ON STATIC

	TEST STAND	<u>Page</u>
Figure 1	6.75" Standard Engine	18
5	7.5" Conical Engine	18
9	Acoustic Filter Model Viewed from Tailpipe	19
10	Acoustic Filter Model	19
12	Twin 6.75" Parallel Configuration	20
13	Acoustically Treated Tailpipe Shroud	20
14	Twin Parallel Configuration in Cowl Viewed from Valve End	21
15	Twin Parallel Configuration in Cowl Viewed from Tailpipes	21
17	Twin 6.75" Opposed Configuration in Acoustically Treated Cowl, Viewed from Exhaust End	22
18	Twin 6.75" Opposed Configuration in Acoustically Treated Cowl, Viewed from Intake End	22
19	Twin Opposed Configuration - Disintegration of Acoustical Treatment	23
21	Serrated Tailpipe - Tabs	24
23	Serrated Tailpipe - Slotted Flare	24

1.0 SUMMARY

Octave Band analyses of the noise spectra of Pulse-Jet engines have been made for the following purposes:

1. Engine sizes from 5" to 12.5" in diameter have been studied to determine the influence of engine size and rate of fuel flow upon the noise spectrum, operating frequency and thrust.
2. Noise Control configurations have been tested, including twin engines in parallel configuration with an acoustically treated cowl around the tailpipes, twin engines in opposed configuration, a single engine with an integral acoustic filter, and two types of serrated tailpipe.

The present data indicates that power input (engine size and rate of fuel flow), is not the controlling factor in noise output. There is a strong indication that the high frequency portion of the noise spectrum is controlled largely by the velocity of the gases issuing from the tailpipe.

2.0 INTRODUCTION

This report describes work accomplished on item 1.5 of Exhibit A, Supplementary Agreement No. 5 of Contract AF33 (600)-5360 during the month of February, 1954.

This is the fifth report to be submitted describing the development of noise control and the use of the Pulse-Jet Analog. The report is submitted by the American Helicopter Co., Inc., describing the study program being conducted by Paul S. Veneklasen, Consultant in Acoustics.

The work was carried out and is reported by Paul S. Veneklasen and staff members G. F. Brockett and M. Herwick.

3.0 DISCUSSION

3.1 INSTRUMENTATION

All the noise studies reported herein were made with Octave Band analyzing equipment consisting of the Western Electro-Acoustic Laboratory 1000B Sound Analyzer which uses the Western Electric 640AA Condenser Microphone. In all cases the noise history of an engine run was recorded on an Ampex 350 Magnetic Tape Recorder. The recordings were made on continuous tape reels. For analysis purposes, the tape may be retained in reel form or tape loops may be cut out and played continuously. In this manner it is possible to choose an appropriate short steady period of noise out of a run which may be either too short or variable for manual analysis. It is clear that the tape recorder is used only as a storage device. Its calibration and equalization can be adjusted very accurately and with this quality machine, can be counted on for stability over long periods of time. In using tape loops for analysis purposes, considerable caution must be exercised to insure that the tape loop is played back under identical tension conditions as when recording, so as to assure faithful reproduction of frequency. Proper facilities have been added to this equipment for this purpose. The fundamental operating frequency was measured for each engine condition.

All these noise analyses were made with the engines mounted on a static test stand within the partial enclosure which is used for noise control and was described in RR-23. Figure 1 shows the 6.75" engine mounted on a test stand and is representative of the mounting of all engines used in these tests.

3.2 THE INFLUENCE OF ENGINE SIZE AND FUEL FLOW RATE ON NOISE SPECTRUM

Heretofore when it has been necessary to make calculations of expected noise from Pulse-Jet engines, we have been obliged to extrapolate data from very limited experience with various sizes of engines. It has been assumed that noise output would be proportional to rate of fuel flow, that is, to power input. The following study shows that



this assumption is far from true and demonstrates clearly certain other factors which are apparently of much greater importance in noise production by jet propulsion devices. All measurements of noise spectra here reported were made at a distance of three feet from the center line of the engines on a perpendicular midway along their length, except for the 12.5" engine.

3.2.1 The 6.75" Standard Single Shell Engine

Most of our earlier studies in connection with the noise control program have used a single shell 6.75" engine, which has a tube length of 34 inches. It is only in deference to this previous work that we refer to this as a "standard" engine. The noise output spectrum of this engine is shown in Figure 2 for several different fuel flow conditions. It will be noted that for the lowest rate of fuel flow the noise spectrum is considerably reduced, whereas for higher values of fuel flow over a considerable range there is very little change in spectrum level.

3.2.2 The 6.75" Single Shell Engine with Long Tail Pipe

This engine is identical with the standard engine except for the tailpipe which is 4.5 inches in diameter and increases the length to 44 inches. Figure 3 shows noise spectra for three different fuel flow rates. Values of thrust and operating frequency for various fuel flows are given with each figure.

3.2.3 The 7.5" Single Shell Engine

Figure 4 presents the noise spectra for this engine with appropriate rates of fuel flow. Again, the trend from a low value of noise production at low fuel flow rate to considerably higher values over a large range of higher fuel flow rates, is most evident with this engine.

3.2.4 The 7.5" Conical Engine

This engine is like the previous one except for an additional conical shell which is shown in Figure 5. Figure 6 shows the

noise spectra for this engine.

3.2.5 The 12.5" Single Shell Engine

Figure 7 shows noise spectra for four different fuel flows. This data shows the largest variation in high frequency noise spectrum, as a function of fuel flow, which has yet been found for a Pulse-Jet engine. Note in contrast how small the variation is in the lower bands. It is also interesting to note the extreme variation in operating frequency which accompanies changes in fuel flow in this engine. This is one reason for the peculiar behavior of the noise spectra in the first two low frequency bands, because the fundamental frequency actually moves from one band into another. It would be more illuminating, although it does not at the moment seem worthwhile, to analyze these noise spectra in more detail so as to determine the levels of the prominent harmonic components which constitute the low frequency portion of a Pulse-Jet noise spectrum. It should be pointed out that this engine was measured at a distance of six feet. In view of the difficulties of starting this engine and the expectation of considerably higher levels than were actually produced, it was not considered safe to leave the microphone in its usual fixed position; therefore the microphone was kept at a safe distance until the engine was operating stably, whereupon it was moved to the 6' position. Comparison of data from Report No. 163-K-1 of Sept. 28, 1951 indicates that the spectrum may be expected to be approximately 3 db higher at the 3' position.

3.2.6. Comparison of Noise vs. Size

Noise spectra for each of the above engines for a typical medium fuel flow rate are combined in Figure 8. In this case the spectrum from the 12.5" engine is increased by 3 db for proper comparison; also the spectrum for a 9.4" engine is included, data being drawn from Report No. 163-K-1. This data very clearly indicates that there is no substance to the

thesis that noise output is proportional to power input. This finding suggests that one should search elsewhere for the controlling factor in noise production.

A possible key is amply evident in the data of this report. For example, if we compare a low value of fuel flow for a 12" engine from Figure 7 with a high value of fuel flow for a smaller 6.75" engine, for example Figure 4, we find that the smaller engine produces a much greater high frequency noise spectrum. Since the rate of flow of exhaust gases is probably about the same but occurs over a much larger section area in the case of the larger engine, it must be that the actual exhaust velocity is smaller for the larger engine. (It is a shame that we do not have a quantitative measurement of exhaust velocity to confirm these deductions.) It is therefore suggested by the data of this report that exhaust velocity is perhaps the most controlling factor in the production of high frequency noise (which controls the nuisance effects of noise and its influence on communication).

3.3 NOISE CONTROL CONFIGURATIONS

3.3.1 The 6.75" Engine with Acoustic Filter

One of the attempts in the study of noise control possibilities is represented in Figures 9 and 10, which show a simple acoustic filter built on the tailpipe of a 6.75" engine. This filter consists simply of an extra cylindrical shell around the tailpipe. The cavity so formed is connected with the tailpipe through perforations. The performance of this device is indicated in Figure 11, where its spectra is compared with more typical 6.75" engines.

The greatly reduced thrust produced by this engine is indicative of lower average exhaust velocity since the effect of an acoustic filter is to convert a pulsating flow of gas into a steady flow. Unfortunately, this method of noise reduction is hardly tolerable, which emphasizes the point that we are obliged to find methods of noise control which will not

destroy the thrust-producing mechanism of the Pulse-Jet engine. The above result confirms some of our earlier approach. It appears that a proper method must retain the pulsating output flow from the tailpipe and surround this outflow, for noise reduction, at a sufficient distance to avoid rearward reaction forces on the enclosing shroud.

In this same figure the comparison between two different tailpipe lengths is also most apparent. It is interesting to note in this comparison that the engine with the greater thrust produces the lower noise level. The possible explanation which will bear further study is as follows: the longer engine which encloses a larger mass of gases in the tailpipe probably produces its thrust by accelerating a larger mass of gas to a lower value of exhaust velocity.

3.3.2 Twin 6.75" Engines in Parallel Configuration

The following data continues tests of this configuration, to which considerable study has already been devoted. Figure 12 shows this configuration mounted on a test stand. The present tests were intended to study the effectiveness of a shroud having an acoustically absorbent lining, which is shown in Figure 13. Figures 14 and 15 show the enshrouded engine configuration mounted on the test stand. The lining of the shroud consists of Refrasil wool (High temperature Fiberglas) which is held in place by a layer of Refrasil cloth and a perforated Inconel-X screen. It was not expected that this particular sample would be the last word in durability, not to mention performance. However, the Refrasil liner did stay in place long enough to permit the recording of noise samples. The results are shown in Figure 16, which shows the spectrum for the twin engines without shroud, for comparison with the spectrum produced by the engines in the treated shroud. The present tests confirm earlier experience with an untreated shroud, namely that the

benefit furnished by the pairing of engines in the reduction of low frequency noise is to a large extent forfeited by the use of a shroud. However, the present tests also indicate a useful reduction in high frequency spectrum, which has not been hitherto achieved. It is not at present known why the use of a shroud restores the low frequency noise. Perhaps the length of the shroud has been unfortunately chosen so that the resonant frequencies characterized by this length are excited by the engine. Since temperature conditions within this shroud are hardly predictable, it is difficult to choose an appropriate length except on an empirical basis. However, if future work succeeds in achieving a combination of the low frequency noise reduction resulting from pairing, together with the high frequency reduction produced by a small treated shroud, we shall have achieved useful progress in noise control.

3.3.3 Twin 6.75" Opposed Configuration

Figures 17 and 18 show the mounting on the test stand of the twin opposed configuration which has been tested previously. The present tests were intended to measure the performance of this configuration, using an acoustical liner for the common shroud, which diverts gases from the tailpipes. Figure 19 shows the result, which was simply to strew the lining material over the neighborhood. The material did not stay in place long enough to measure its effectiveness. It had been planned to test this material, using small metal deflectors, to protect the material from direct impingement, but these were not installed with the intention of determining the durability of the material. As a result the only noise records which are of value are shown in Figure 20, which is for the engine with common cowl but without liner.

3.3.4 The 6.75" Engine with Long Tailpipe and Tabs Extending from Tailpipe

Rectangular extensions were welded to the tailpipe, as shown in Figure 21. This experiment was an attempt to test the method proposed by the British, of serrating the tailpipe of a Jet engine. We do not know what theoretical

background may exist for such a proposal.
Figure 22 shows that the results were negative.

3.3.5 The 6.75" Engine with Long Slotted
Tailpipe

This experiment was a slightly different attempt to test the British theory. Hacksaw Slots were cut into the trailing edge of the tailpipe for about the length of the flared section, as shown in Figure 23. Figure 24 again indicates insignificant results.

4.0 CONCLUSIONS

- A. Noise spectra have been measured for engines ranging in size from 5" diameter to 12.5" diameter. It is found that size alone is not the controlling factor in noise output.
- B. Each engine has been studied for the influence of rate of fuel flow on noise output. It is found that for very low rates of fuel flow, the high frequency portion of the spectrum is comparatively reduced.
- C. Operating frequency has also been studied as a function of rate of fuel flow. It is found that in general the fundamental frequency decreases as the fuel flow is increased.
- D. The influence of tube geometry is indicated by the fact that, for a given rate of fuel flow and chamber diameter, the high frequency noise is decreased and the thrust is increased if a longer tailpipe with larger diameter is used.
- E. There is a strong indication that a primary factor in determining high frequency noise spectrum is the exit velocity of the gases.
- F. Continuing the development of twin engines in parallel configuration, it is found that an acoustically treated cowl surrounding the tailpipes produces a useful amount of high frequency noise reduction. Unfortunately, the advantage of low frequency noise cancellation is largely lost in the present configuration. The effect on thrust is not indicated because the cowl was hand-held.
- G. The noise reduction for the twin engine opposed configuration with an acoustically-lined tailpipe duct could not be evaluated because the lining material was blown out immediately upon starting.
- H. A built-in acoustical filter reduced the high frequency noise with severe loss of thrust.
- I. Two types of serrated edges at the tailpipe exhaust proved ineffective.

6.75" SINGLE SHELL ENGINE SINGLE SHELL REGION

	Thrust lb.	Fuel Flow GPH	Rev. GPM
1.	21.0	100	141
2.	32.0	120	141
3.	36.4	140	141
4.	37.5	160	140
5.	37.0	180	140
6.	36.7	200	140

Microphone Position
3' - 90°

OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .0002 DYNE CM⁻²

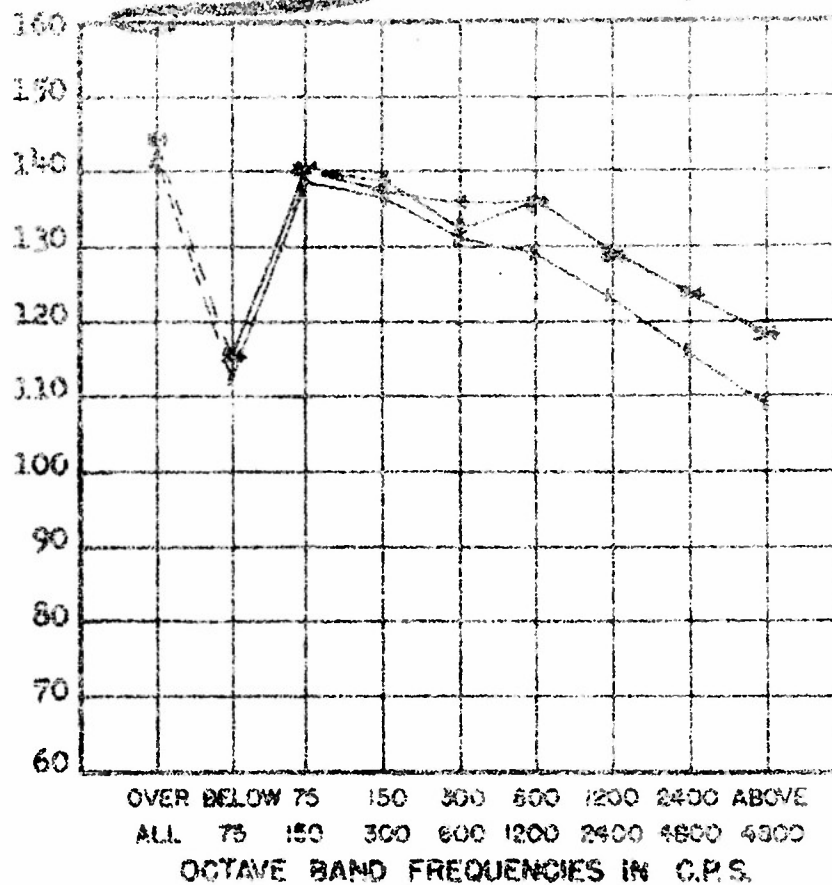


Figure 1

6.75" SINGLE SHELL ENGINE WITH LONG TAILPIPE

	Thrust lb.	Fuel Flow GPH	Rev. GPM
1.	28.0	110	118
2.	45.9	150	112
3.	53.0	190	112

Microphone Position
3' - 90°

OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .0002 DYNE CM⁻²

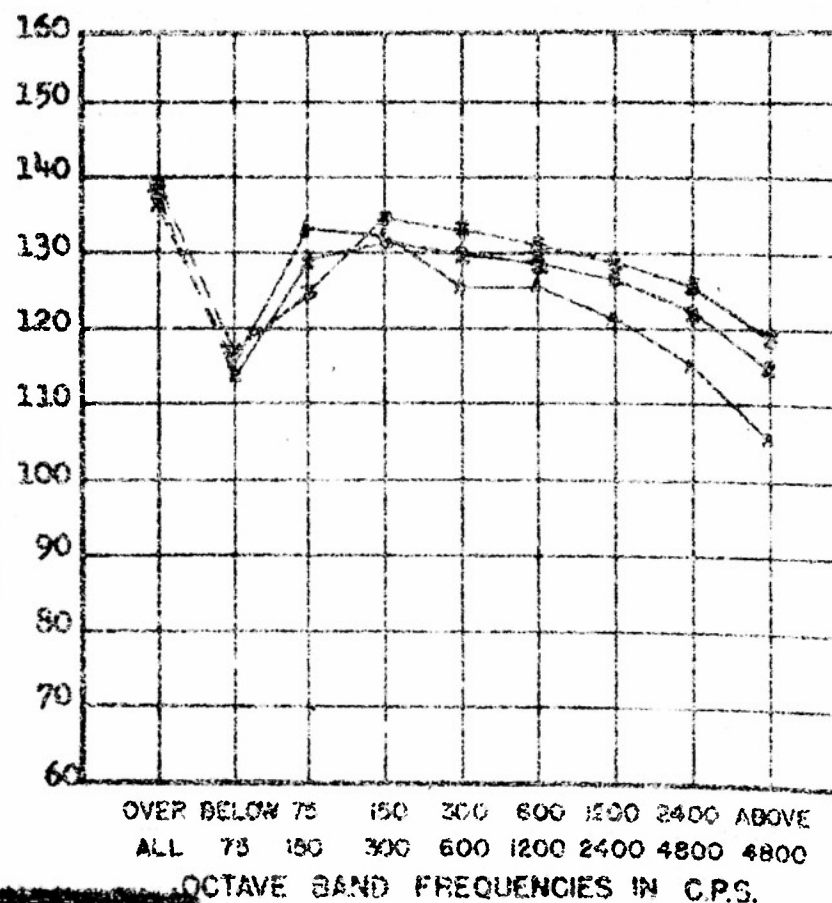


FIGURE 4

7.5" SINGLE SPARK ENGINE

	Throttle In.	Fuel Flow GPH	Power HP
1.	8.5	90	151
2.	45.5	150	185
3.	52.0	190	188

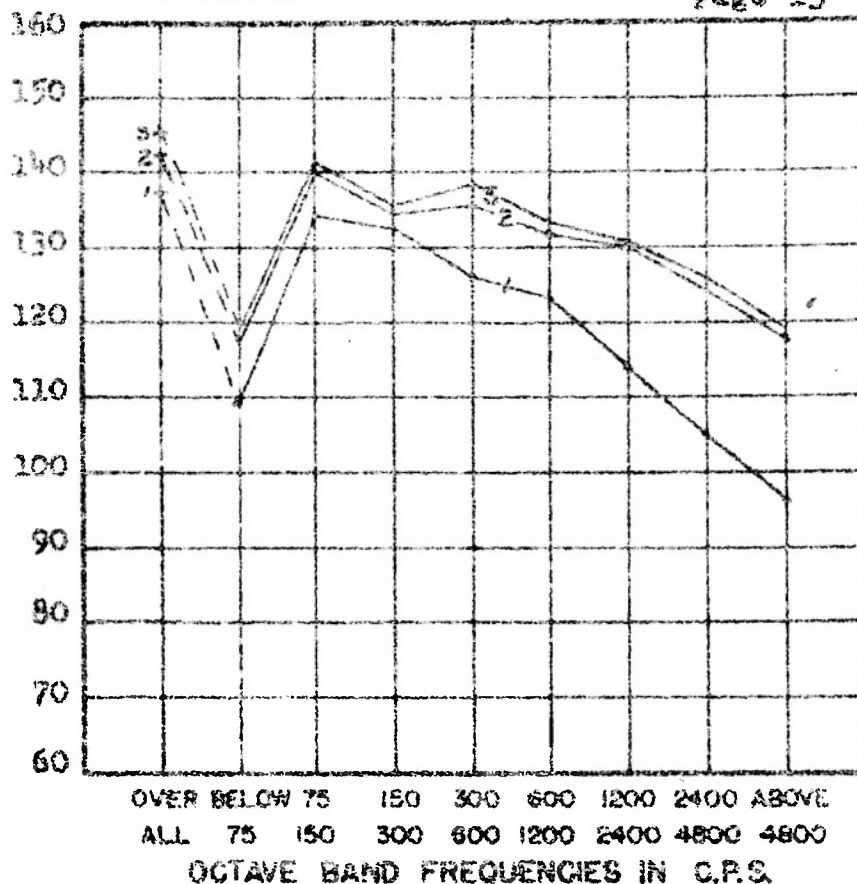
Microphone Position
3' - 90°OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .002 DYNE CM⁻²

FIGURE 6

7.5" CONICAL ENGINE

	Throttle In.	Fuel Flow GPH	Power HP
1.	8.3	90	150
2.	37.3	150	131
3.	44.5	220	132

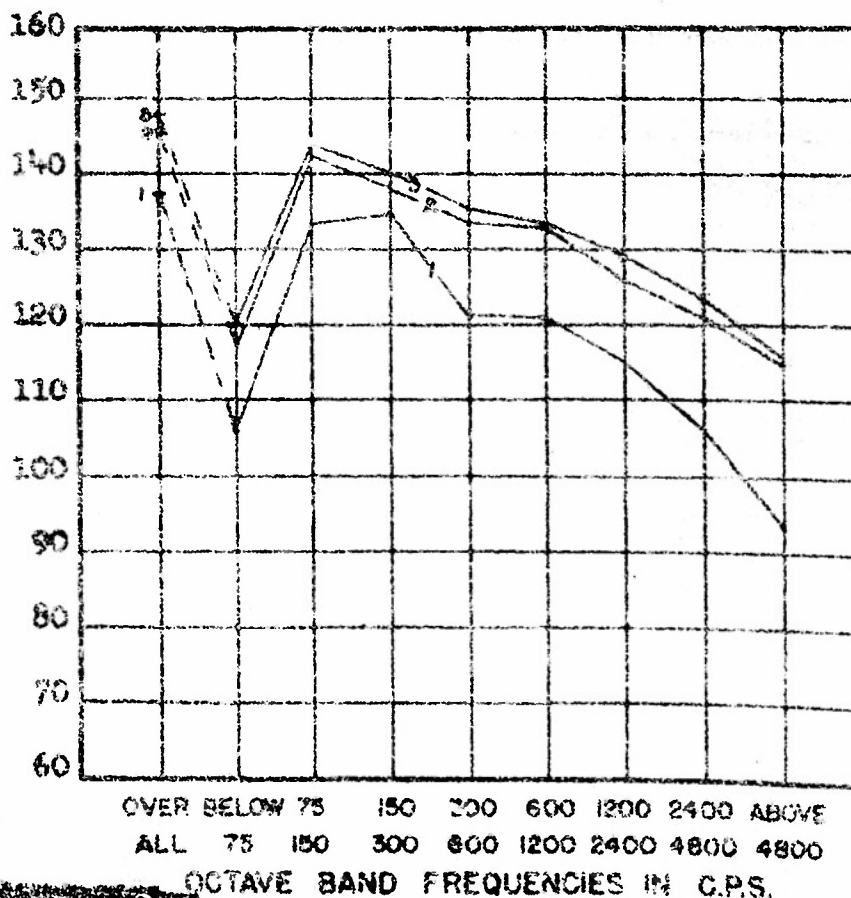
Microphone Position
3' - 90°OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .002 DYNE CM⁻²

FIGURE 6

COMPARISON OF
NOISE SPECTRA VS.
ENGINE SIZE

1. 5" Engines 21.4
lb. at 75 pphr-140 cps
2. 6.75" Standards:
36.4 lb. at 140 pphr-
141 cps
3. 7.5" Engines:
45.5 lb. at 150 pphr-
125 cps
4. 9.4" Engines:
98 lb. at 240 pphr-
93 cps
5. 12.5" Engine:
190 lb. at 550 pphr-
80 cps

Microphone Position
3' - 90°

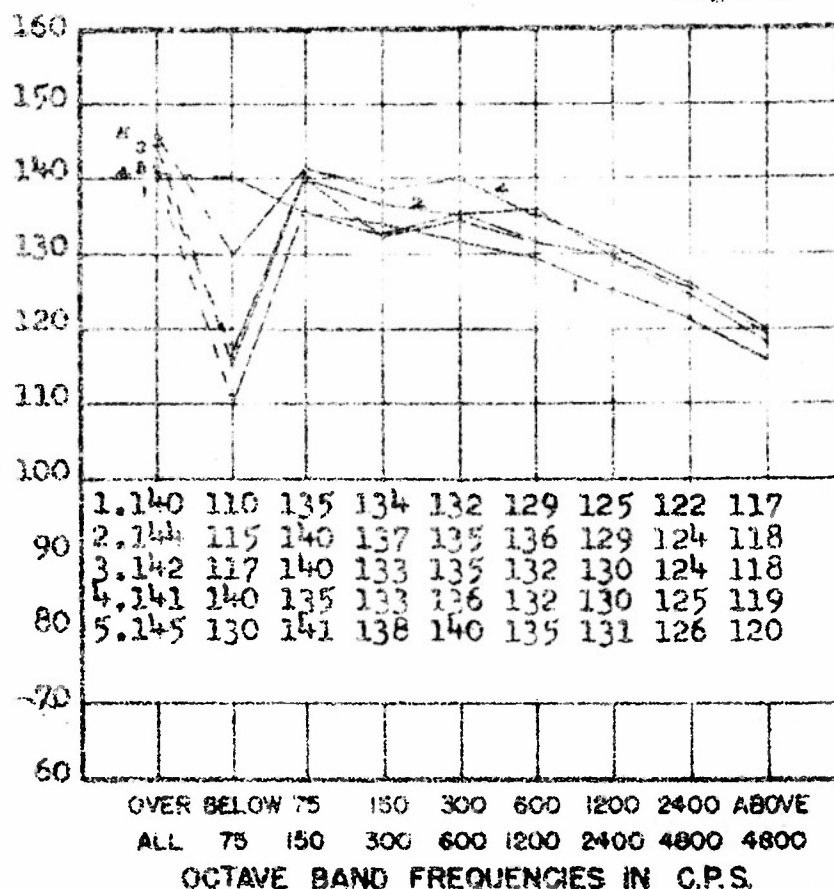
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DB RE .0002 DYNE CM⁻²

FIGURE 7

12.5" SINGLE SHELL
ENGINE

	Thrust lb.	Fuel Flow pphr	Freq. cps
1.	38	270	94
2.	72	350	94
3.	190	550	80
4.	190	650	73

Microphone Position
6' - 90°

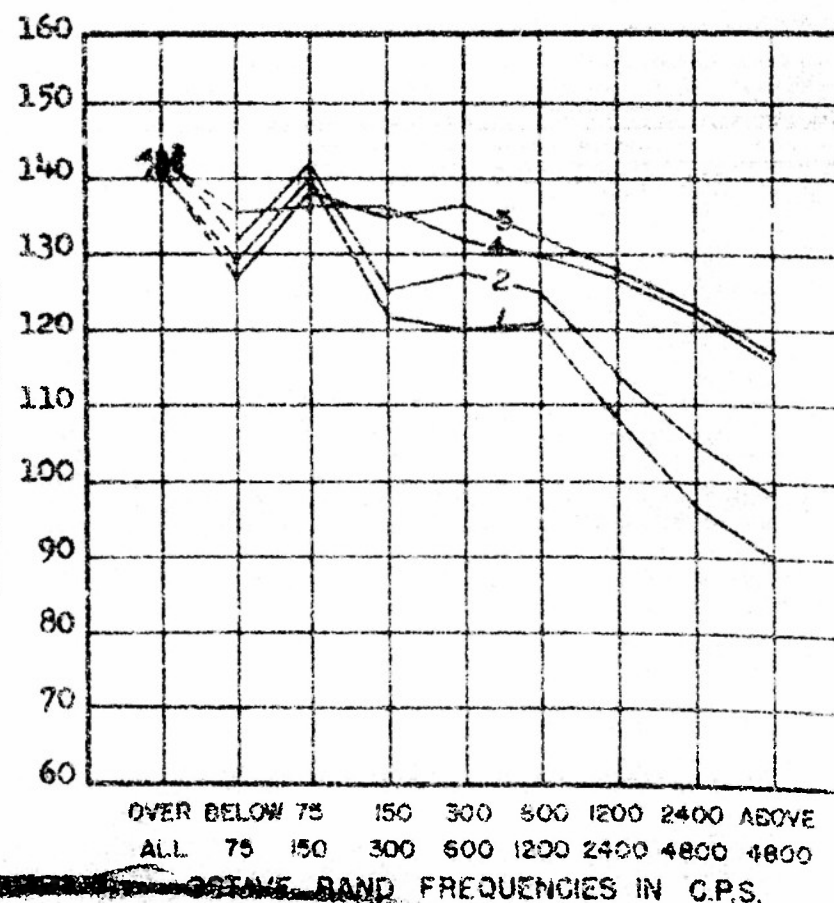
OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .0002 DYNE CM⁻²

FIGURE 10

TWIL 6.75" ENGINES
PARALLEL CONFIGURATION

1. Without Noise Shroud:
69.7 lb. at
151 pphr each

2. With treated
Shroud:
70.1 lb. at
155 pphr each

(Shroud was hand-
held.)

Microphone Position
3' - 90°

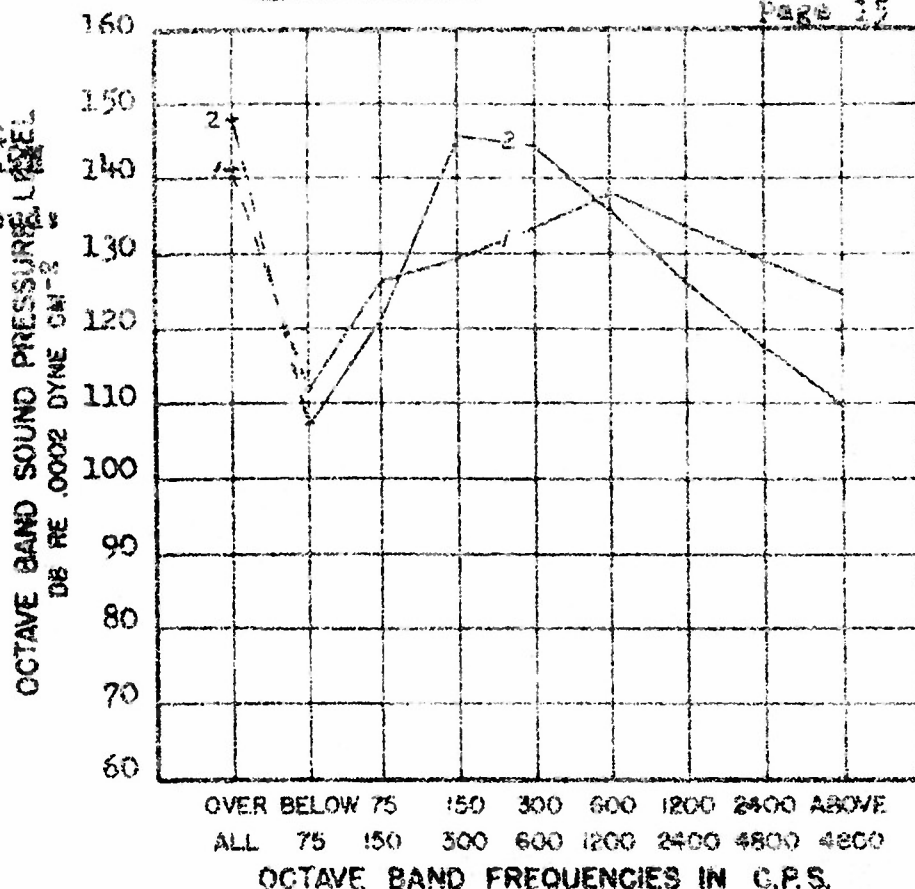
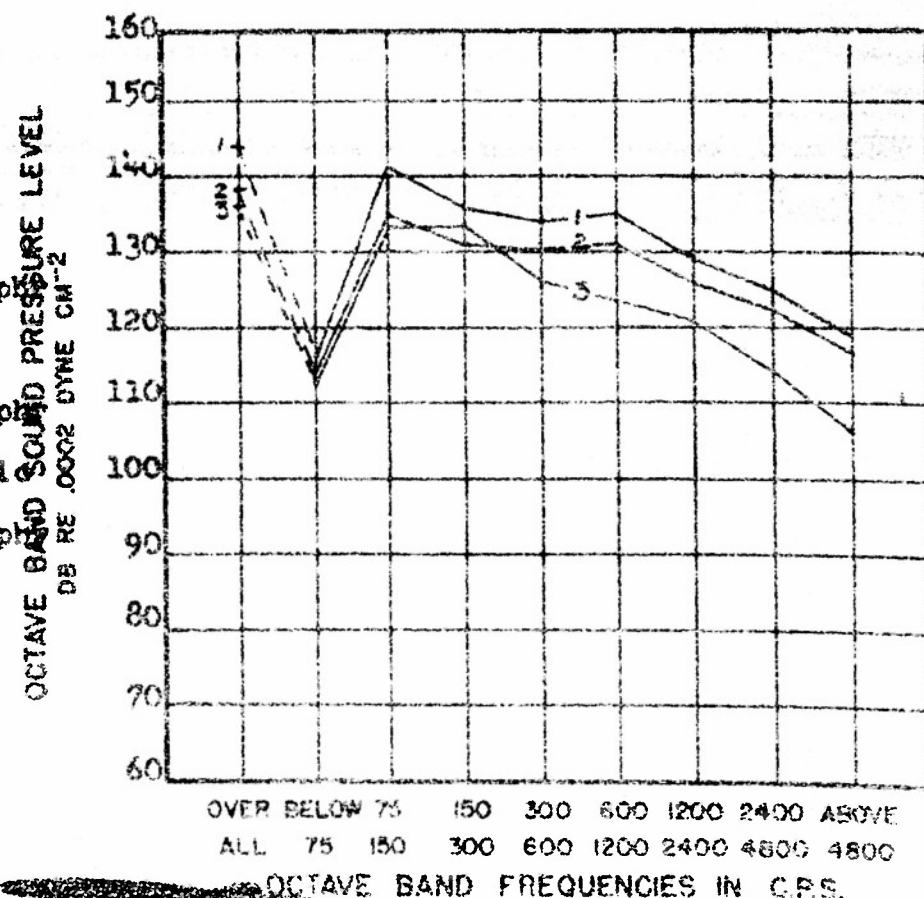


FIGURE 11

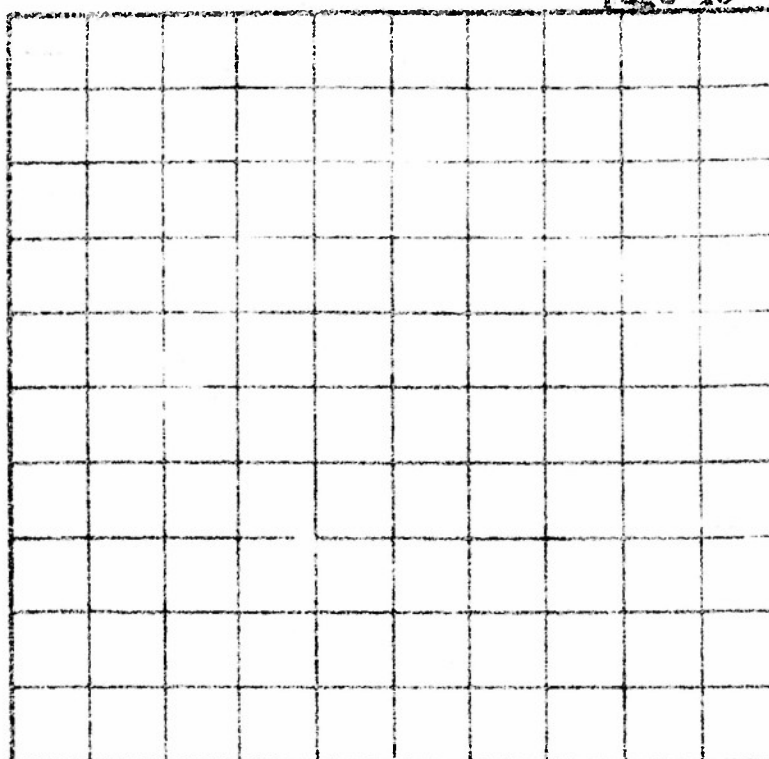
COMPARISON OF 6.75" ENGINES

1. 6.75" Standard:
36.4 lb. at 140 pphr
2. 6.75" With Long
Tail Pipe:
45.8 lb. at 150 pphr
3. 6.75" with Acoustic
Filter:
22.8 lb. at 150 pphr

Microphone Position
3' - 90°



OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .0002 DYNE CM⁻²



OVER BELOW 75 150 300 600 1200 2400 ABOVE
ALL 75 150 300 600 1200 2400 4800 4800
OCTAVE BAND FREQUENCIES IN C.P.S.

FIGURE 20

TWIN 6.75" ENGINES -
OPPOSED CONFIGURATION
WITH UNTREATED DUCT.

Fuel Flow:
80-190 pphr. each

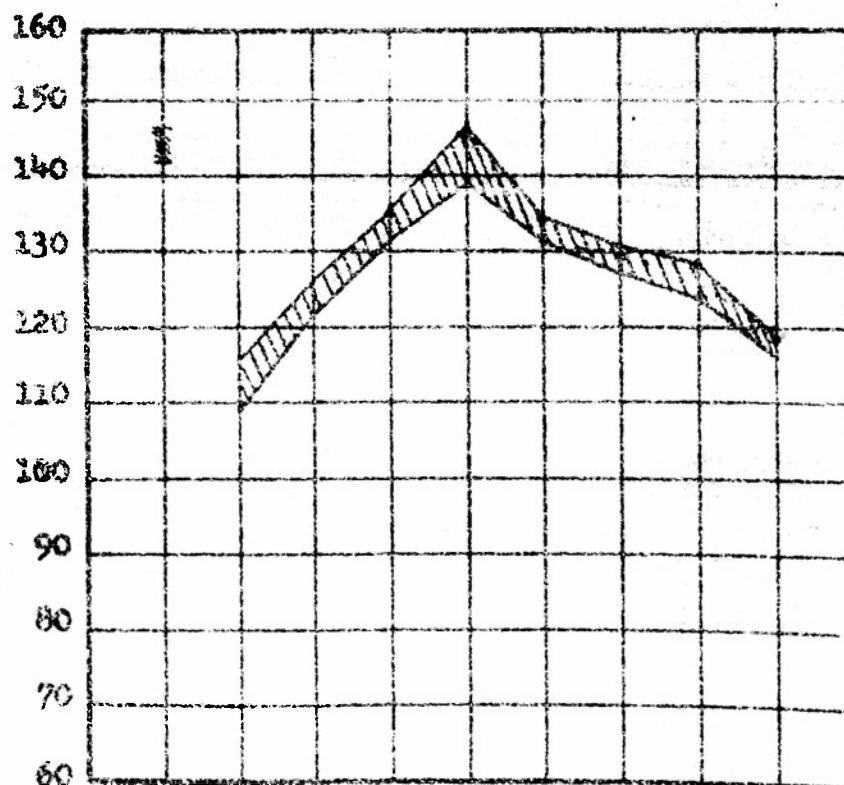
Thrust:
9.5 - 14 lb.

Frequency:
169-185 cps (each
engine)

(Order of runs
uncertain.)

Microphone Position
3' - 90°

OCTAVE BAND SOUND PRESSURE LEVEL
DB RE .0002 DYNE CM⁻²



OVER BELOW 75 150 300 600 1200 2400 ABOVE
ALL 75 150 300 600 1200 2400 4800 4800
OCTAVE BAND FREQUENCIES IN C.P.S.

FIGURE 27

6.75" SINGLE SHELL
WITH LONG TAILPIPE
AND TAIL

	Thrust lb.	Fuel Flow gphr.	Temp. °R
1.	26.6	110	115
2.	43.5	150	112
3.	51.3	190	112
4.	45.9	150	112

(with-
out tubes)

Microphone Position
3' - 90°

OCTAVE BAND SOUND PRESSURE LEVEL
DB RE 0.002 DYNE CM⁻²

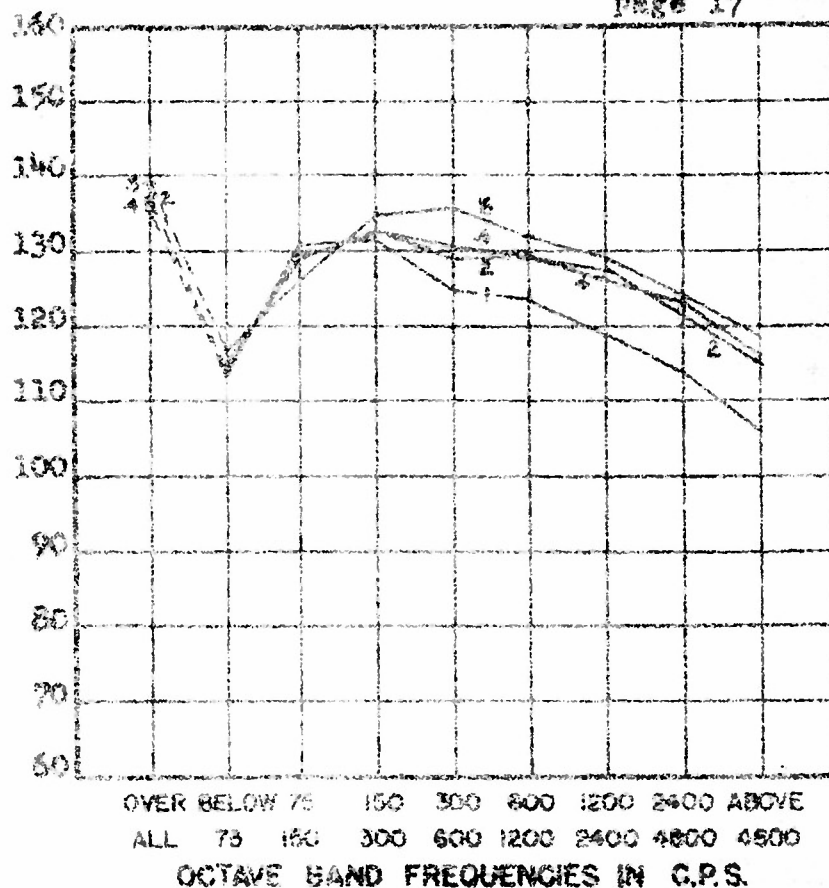


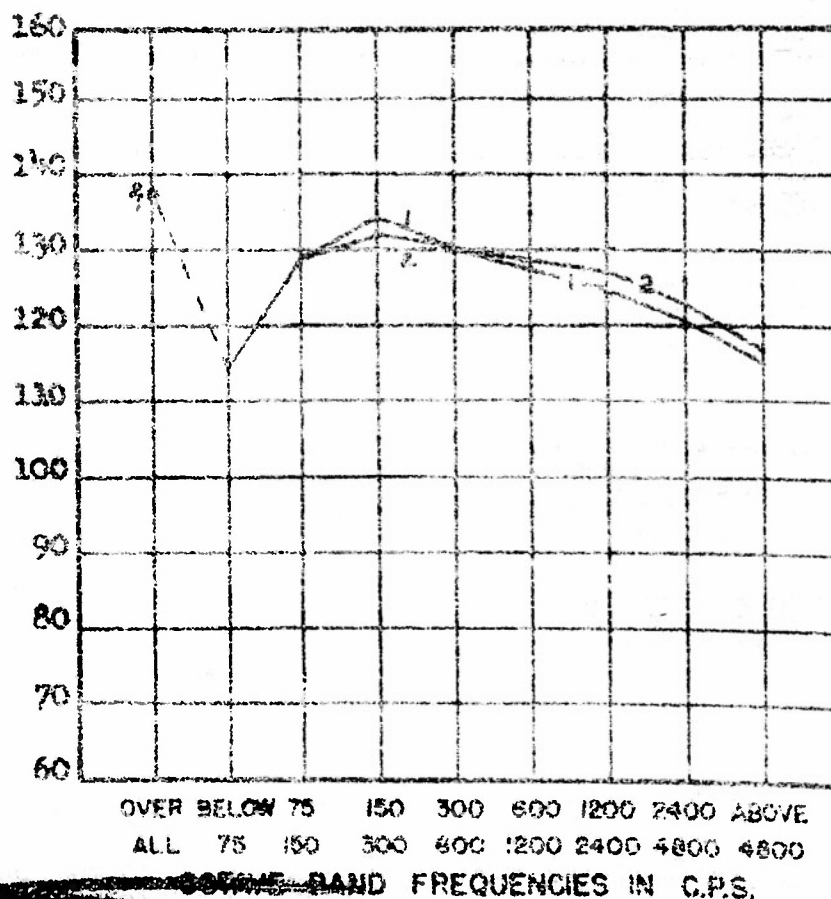
FIGURE 28

6.75" SINGLE SHELL
WITH LONG TAILPIPE
AND SLOTTED PLANE

- 40 lb. Thrust at
150 gphr. - 111 ops
- 45.9 lb. Thrust at
150 gphr. - 112 ops
(without slots)

Microphone Position
3' - 90°

OCTAVE BAND SOUND PRESSURE LEVEL
DB RE 0.002 DYNE CM⁻²



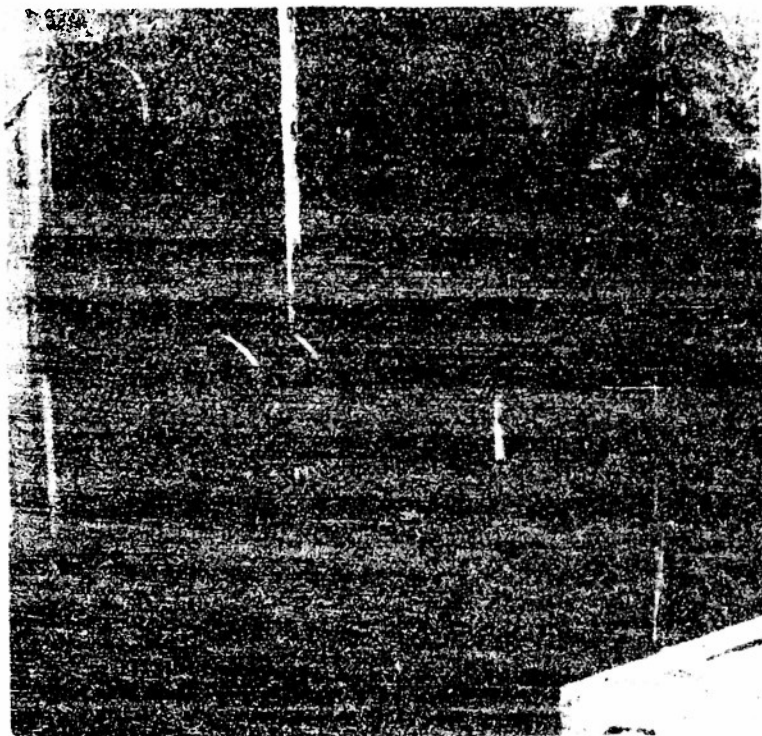


FIGURE 1



FIGURE 5



FIGURE 16

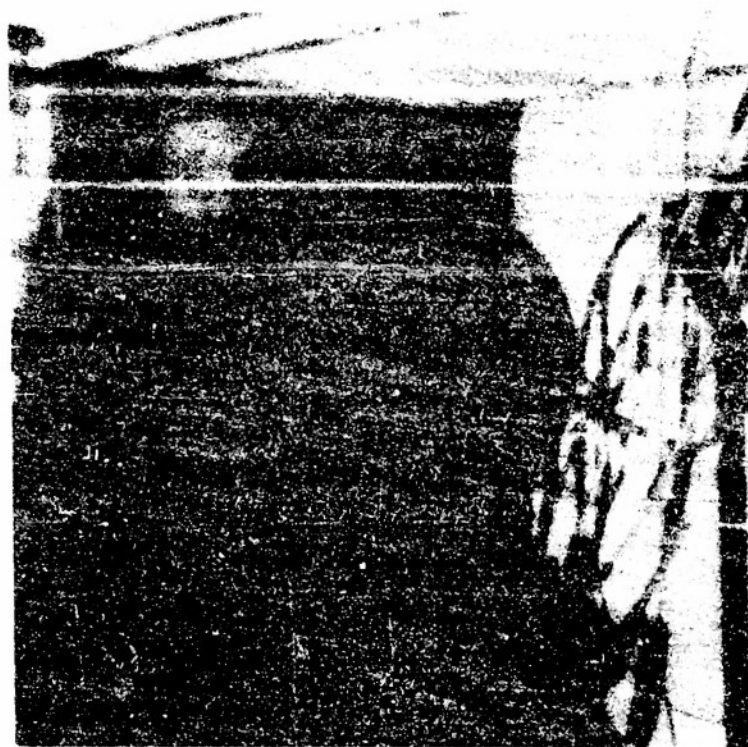


FIGURE 9

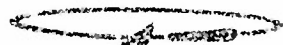


FIGURE 12

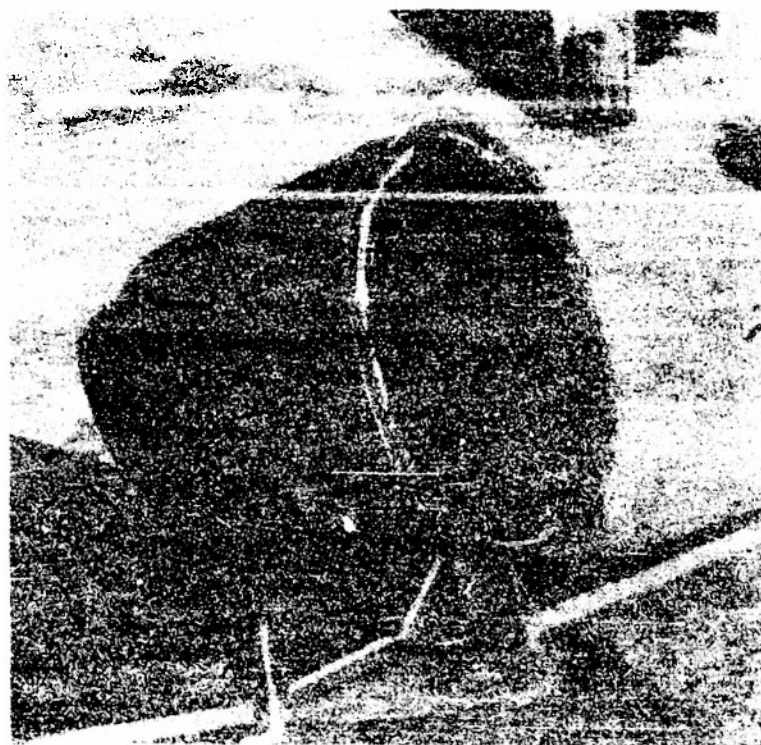
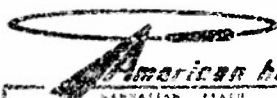


FIGURE 13



FIGURE 11.





American helicopter co. inc
SAN ANTONIO, TEXAS 78228

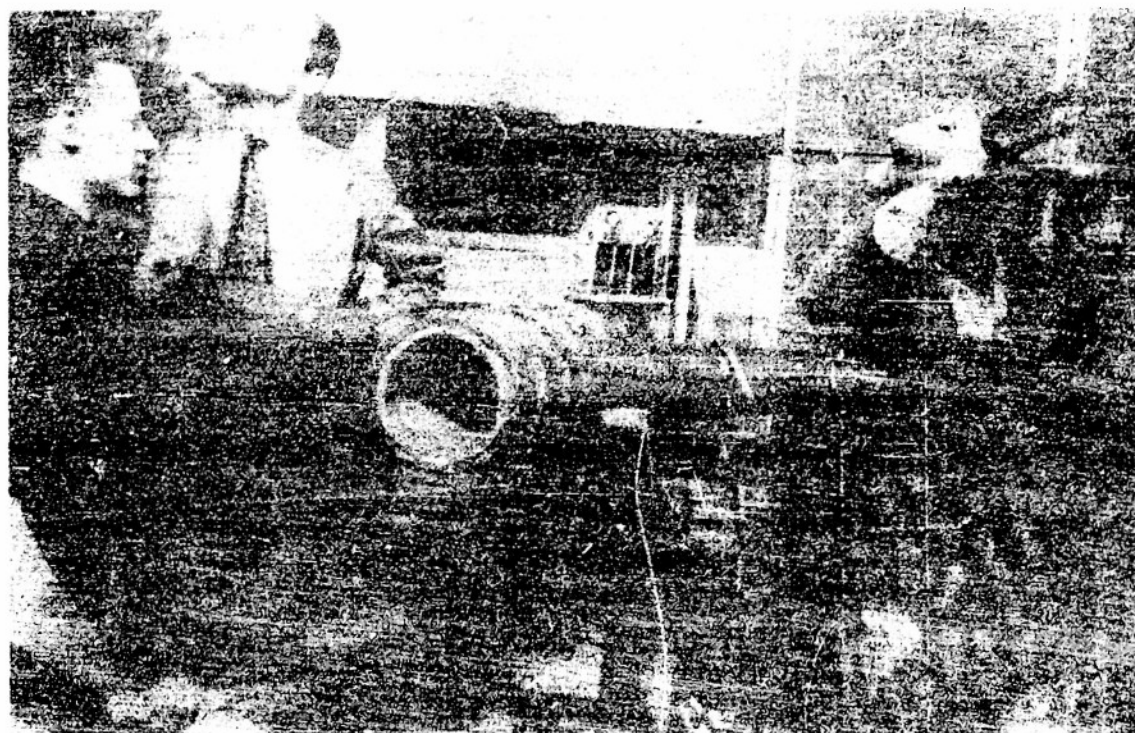


FIGURE 17

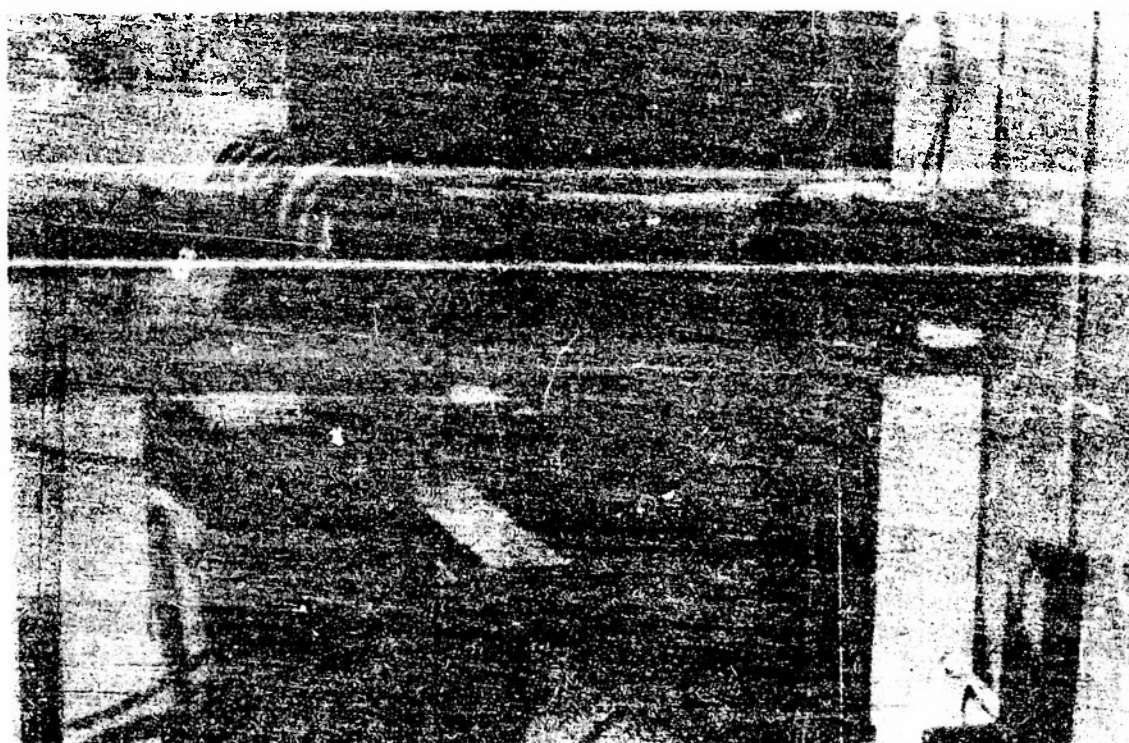


FIGURE 18

TAL



FIGURE 19

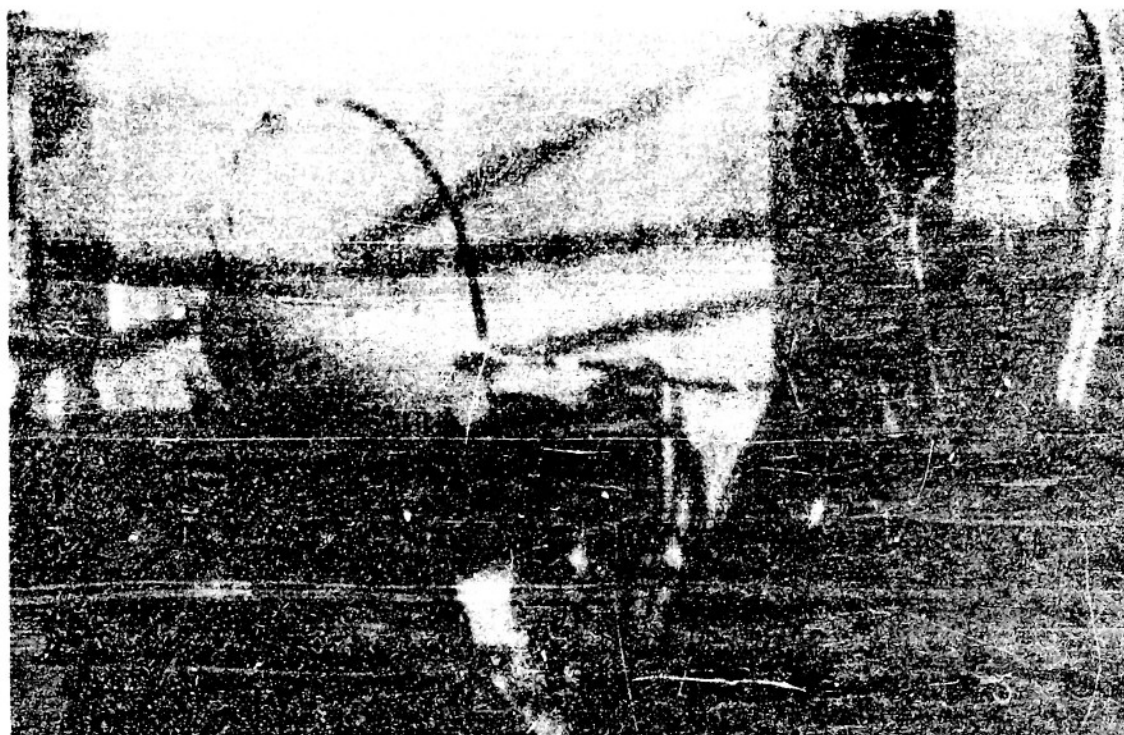


FIGURE 21



FIGURE 23

Changed to
to partly
Don-
The main rotor hub
is located through the main rotor hub

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