REPORT 1377

MEASUREMENTS OF FREE-SPACE OSCILLATING PRESSURES NEAR PROPELLERS AT FLIGHT MACH NUMBERS TO 0.72[†]

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SUMMARY

In the course of a short flight program initiated to check the theory of Garrick and Watkins (NACA Rep. 1198), a series of measurements at three stations were made of the oscillating pressures near a tapered-blade plan-form propeller and a rectangular-blade plan-form propeller at flight Mach numbers up to 0.72. These measurements were made at a single radial station and at three axial positions (ahead of, in the plane of, and behind the propeller disk). Despite the limited scope of the tests, agreement with the theory was obtained to the extent that:

(a) The oscillating pressures near the propeller tend to decrease with increase in flight Mach number up to a Mach number of approximately 0.5 and to increase rather rapidly at higher Mach numbers.

(b) The sound-pressure levels of the higher harmonics of the propeller noise increase at a higher rate with increase in flight Mach number than the lower propeller harmonics.

In contradiction to the results found for the propeller studied in NACA Rep. 1198, the oscillating pressures in the plane and ahead of the propeller were found to be higher than those immediately behind the propeller. Factors such as variation in torque and thrust distribution, since the blades of the present investigation were operating above their design forward speed, may account for this contradiction.

The effect of blade plan form shows that a tapered-blade plan-form propeller will produce lower sound-pressure levels than a rectangular-blade plan-form propeller for the low blade-passage harmonics (the frequencies where structural considerations are important) and produce higher sound-pressure levels for the higher blade-passage harmonics (frequencies where passenger comfort is important).

INTRODUCTION

The effects of the near-field noise generated by propellers in flight are of continuously increasing concern to the aviation industry. With regard to air transportation, the oscillating pressures in the form of noise directly affect passenger comfort and the field of public relations. For the airplane structural engineer, these oscillating pressures are creating serious fatigue problems. The severity of the problems increases with the continual trend toward higher powers and higher flight speeds. Detailed knowledge of the pressure fields about propellers is necessary for design and also, it is hoped, will eventually indicate a means of reducing the oscillating pressures.

In the field of propeller-generated pressures, both the theoretical and experimental backgrounds are rather extensive. The Gutin theory (ref. 1) for the far-field pressures is well known. This theory has been extended in reference 2 to predict the pressures in the near field. Both references 1 and 2 deal strictly with stationary propellers but the results of investigations under static conditions have been applied with some success, as in reference 3, to low flight speeds. In reference 4, Garrick and Watkins have further extended Gutin's theory to take into account the effect of forward speed. This extended theory includes the stationary propeller and the far-field simplifications as special cases.

The purpose of the flight tests reported herein was to obtain in-flight measurements of propeller noise with which to check, if possible, the theory of reference 4 and to investigate parameters affecting propeller noise such as propeller-blade plan form, power, and tip speeds at a range of forward speeds up to the maximum permissible Mach number of 0.72.

SYMBOLS

b	blade width, ft
c_l	section design lift coefficient
D	propeller diameter, ft
h	blade thickness, ft
M_∞	flight Mach number
M_R	rotational tip Mach number
M_t	helical tip Mach number, $\sqrt{M_\infty^2+M_R^2}$
N	engine speed, rpm
P	power absorbed by propeller, hp
p	root mean square of oscillating pressure, lb/sq ft or decibels, as indicated
p_∞	static pressure, lb/sq ft
R	propeller tip radius, ft
r	radius to a blade element, ft
T	thrust of propeller, lb
t_∞	free-air temperature, °F
V	airspeed, ft/sec

[†] Supersedes NACA Technical Note 3417 by Arthur W. Vogeley and Max C. Kurbjun, 1955, and NACA Technical Note 4068 by Max C. Kurbjun, 1957.

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x longitudinal position of microphone, measured positive forward of propeller disk, ft
y radial position of microphone, measured from propeller center, ft
β section blade angle, deg

TEST EQUIPMENT

The airplane available for this investigation was a single-place fighter type equipped with a liquid-cooled inline engine. The engine was equipped with individual jet-ejector exhaust stacks.

Two types of propellers, differing principally in blade plan forms, were used in this investigation. The difference in the propeller-blade shapes is shown in the photographs of the two propellers mounted on the airplane (fig. 1). Figure 1 (a) shows the tapered blade and figure 1 (b), the rectangular blade. The characteristics of the two blade designs are shown in figures 2 (a) and 2 (b), respectively. Both propellers had a diameter of 11 feet 2 inches and were driven through a reduction gear providing a ratio of engine speed to propeller speed of 0.479.

The oscillating pressure pickup used was a commercial condenser-type microphone modified to operate under the rapidly varying static pressures encountered in the tests. A frequency-modulation system was used to transmit the pressure signals to a ground-located station where the signals were recorded with a magnetic-tape recorder. A complete description of the pickup, transmitter, receiver, and analyzer equipment is contained in reference 5.

The microphone was installed in a boom mounted in the center gunport of the right wing. This location placed the microphone at a radial distance of 7.31 feet from the propeller axis. The boom was constructed in such a manner that the microphone could be shifted forward and backward through a distance of approximately 4 feet before each flight. Figures 1 (a), 1 (b), and 3 show the microphone-boom installation.

Before the start of the flight-test program, the boom was tested in a wind tunnel to check for background noise over the anticipated flight speed range. It was found that the self-generated overall noise level of the microphone in the band width 80 to 1,000 cps was below 113 decibels. This level of self-generated random noise is considered acceptable in the measurement of sound-pressure levels as low as 100 decibels for discrete frequencies. The response of the system used was flat within ± 1 decibel between 80 to 1,000 cps.

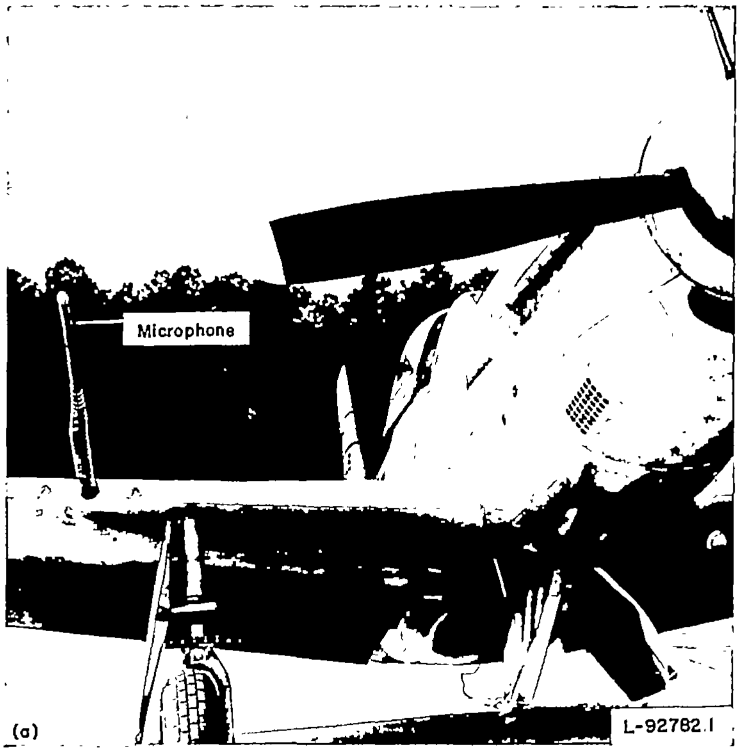
Standard NACA recording instruments were used to record dynamic pressure, altitude, free-air temperature, engine speed, and manifold pressure.

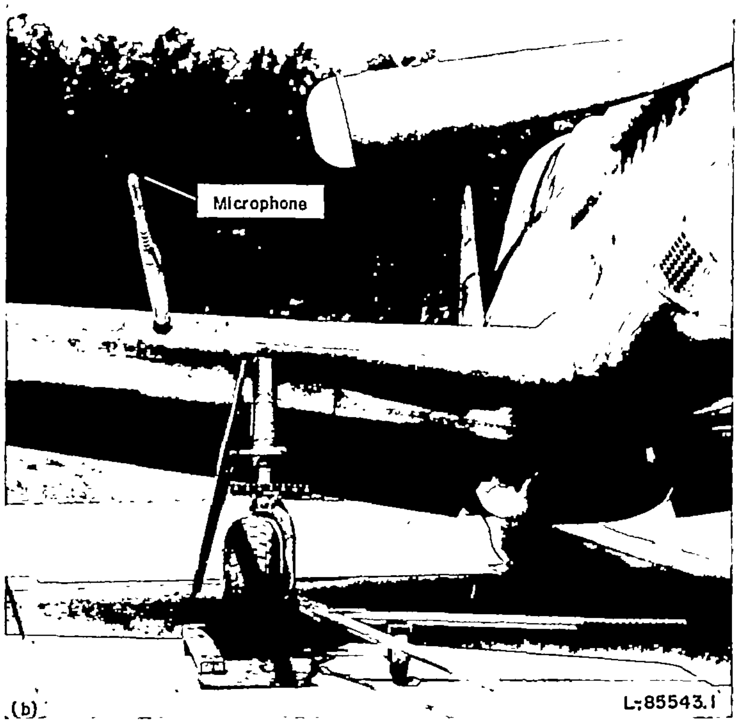
TEST PROCEDURE

All static ground tests and flight tests were made with the microphone located at a fixed radial distance of $y=0.655D$. Tests were made at three values of longitudinal distance $x=-0.125D$, 0, and $0.125D$. Flight tests were arranged to investigate the effects of flight Mach number, engine speed, and engine power on propeller noise, as follows:

(1) Flight Mach number: At engine speeds of approximately 2,700 rpm with the manifold pressure adjusted to produce a power output of approximately 1,000 horsepower, flight tests were made on both propellers at flight Mach numbers from approximately 0.2 to 0.7 by varying the flight attitude. Static ground tests were also made at the same power and engine speed setting.

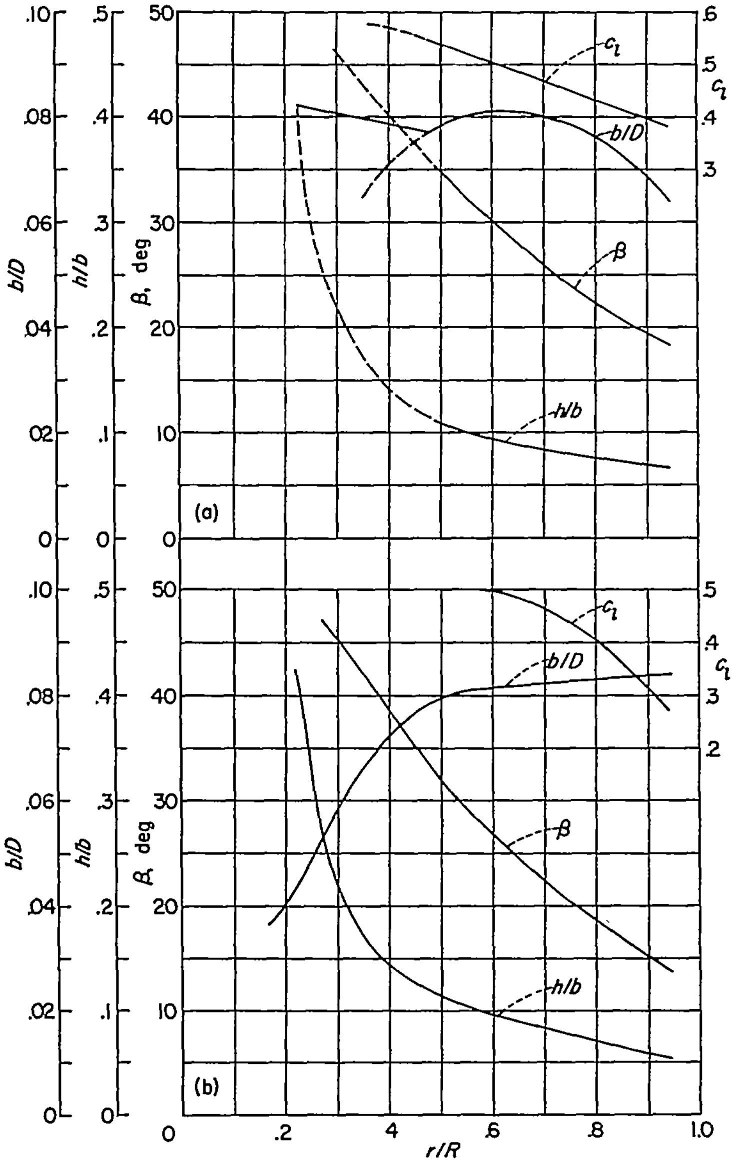
(2) Engine speed (rotational Mach number): At a flight Mach number of approximately 0.5 and engine output of approximately 1,000 horsepower, tests were made with the





(a) Tapered-blade plan form.
(b) Rectangular-blade plan form.

FIGURE 1.—Front view of the microphone installation showing the propeller-blade shape.



(a) Tapered-blade plan form.
(b) Rectangular-blade plan form.

FIGURE 2.—Characteristics of the propeller blades tested.

tapered-blade propeller at engine speeds of approximately 2,500, 2,600, 2,700, 2,800, 2,900, and 3,000 rpm.

(3) Engine power: At a flight Mach number of approximately 0.5 and engine speeds at approximately 2,700 rpm, tests were made with the tapered-blade propeller at engine powers of approximately 0, 500, 1,000, and 1,500 horsepower.

RESULTS AND DISCUSSION

Because it was necessary to make separate flights for each propeller and for each boom setting, it was impossible to repeat the test conditions exactly. All test conditions are given in tables I and II for the tapered and rectangular blades, respectively. In the discussion to follow, the small differences in test conditions are disregarded, and the data are compared and examined in only a general manner.

The effects of propeller-blade plan form are shown in a series of figures comparing the noise emitted from the two propellers tested with changes in operating parameters of flight Mach number, engine speed (rotational Mach number), and power. Correlation of theory with measured results follows the discussions of changes in the operating parameters.

FIGURE 3.—Three microphone locations used on the test airplane during the investigation. $y=0.655D$ for all positions.

TABLE I.—RESULTS WITH TAPERED-BLADE PLAN-FORM PROPELLERS

[$y=0.655D$]

Test conditions											Sound-pressure level, db (Reference pressure level, 0.0002 dynes/cm²)									
x	T, lb	V, ft/sec	p_∞, lb/sq ft	t_∞, °F	P, hp	N, rpm	M_∞	M_R	M_t	Blade-passage frequency, cps	Order of harmonics									
											1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
Ground tests																				
0.125D	2,800	0	2,110	81	1,030	2,693	0	0.66	0.66	86.0										
.104D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)	(a)
.089D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0										
.075D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	128.6	122.6	116.7	110.0	109.3	108.7				
.060D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	128.9	121.5	116.5	112.7						
.045D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	128.7	122.3	117.1	112.9						
.030D	2,800	0	2,110	.81	1,030	2,693	0	.66	.66	86.0	127.2	122.0	116.8	111.3	109.9					
.015D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	127.5	121.0	116.3	111.3	108.0					
0	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	127.1	120.3	115.6							
−.015D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	131.0	124.5	120.5	114.5						
−.030D	2,800	0	2,110	81	1,030	2,693	0	.66	.66	86.0	126.7	120.3	114.0	109.9						
−.045D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	126.5	118.1	115.1	109.2						
−.060D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	126.7	120.5	115.1	109.5						
−.075D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	126.8	118.0	116.0	108.5						
−.089D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6										
−.104D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	126.5	116.1	116.3			109.7				
−.125D	2,800	0	2,110	81	1,030	2,681	0	.66	.66	85.6	126.1	115.5	110.8							
.125D	1,400	0	2,110	81	570	2,418	0	.59	.59	77.2	126.1	116.2	110.8							
.125D	1,850	0	2,110	81	710	2,568	0	.63	.63	82.0	128.0	119.8	113.8							
.125D	2,500	0	2,110	81	960	2,681	0	.66	.66	85.6	128.6	120.8	116.0	110.0						
.125D	3,100	0	2,110	81	1,200	2,919	0	.72	.72	93.2	130.5	124.7	120.5	115.0						
0	1,490	0	2,110	81	570	2,405	0	.59	.59	76.8	122.1	113.2	109.5							
0	1,850	0	2,110	81	710	2,593	0	.64	.64	82.8	125.0	117.0	113.0	108.0						
0	2,500	0	2,110	81	960	2,693	0	.66	.66	86.0	127.8	121.5	117.7	112.0	110.5					
0	3,100	0	2,110	81	1,200	2,944	0	.72	.72	94.0	129.9	123.9	120.1	115.3	113.5					
−.125D	1,490	0	2,110	81	570	2,380	0	.58	.58	76.0	119.9	109.0	110.0	104.7	104.5					
−.125D	1,850	0	2,110	81	710	2,590	0	.64	.64	82.9	128.5	113.5	113.5							
−.125D	2,500	0	2,110	81	960	2,768	0	.68	.68	88.4	127.2	120.0	117.5	109.0						
−.125D	3,100	0	2,110	81	1,200	2,937	0	.72	.72	93.8	129.9	123.0	120.0	113.5						

[a] Lost due to infiltration of extraneous noise at receiving station.

TABLE I.—RESULTS WITH TAPERED-BLADE PLAN-FORM PROPELLERS—Concluded

[y=0.655D]

Test conditions											Sound-pressure level, db (Reference pressure level, 0.0002 dynes/cm²)									
											Order of harmonics									
x	T, lb	V, ft/sec	p_∞, lb/sq ft	t_∞, °F	P, hp	N, rpm	M_∞	M_R	M_t	Blade-passage frequency, cps	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
Flight tests																				
−0.125D	2,040	235	965	13	1,030	2,699	0.22	0.71	0.74	86.2	123.5	117.5	112.0	107.8	104.0	100.0				
−.125D	1,275	375	975	15	1,030	2,687	.35	.71	.70	85.8	118.8	111.7	107.5	107.0	102.0					
−.125D	1,240	385	945	14	1,030	2,699	.36	.71	.70	86.2	120.7	113.7								
−.125D	908	524	988	15	1,030	2,490	.49	.65	.82	79.5	118.3	113.5	108.2	100.3	105.5					
−.125D	914	530	970	14	1,050	2,584	.50	.68	.84	82.5	117.7	112.7	110.1	100.7	106.5					
−.125D	914	530	955	14	1,050	2,687	.50	.71	.86	85.8	117.2	114.2	111.5							
−.125D	914	530	948	14	1,050	2,787	.50	.73	.88	89.0	117.9	115.3	113.7	113.5						
−.125D	924	524	935	14	1,050	2,847	.49	.74	.89	90.9	118.0	116.0	117.0	116.2	115.0					
−.125D	924	524	935	13	1,050	2,951	.49	.74	.89	94.3	119.0	118.2	119.5	118.8	116.7	114.9	111.9	109.5	108.0	
−.125D	0	526	1,005	17	0	2,677	.49	.70	.85	85.5	118.1	114.9	111.8	108.8						
−.125D	545	526	1,014	17	600	2,687	.49	.70	.86	85.8		112.4	110.9	108.8	105.9					
−.125D	800	526	1,000	16	900	2,690	.49	.70	.86	85.9		111.5	109.5	108.5	110.5					
−.125D	1,280	526	990	15	1,400	2,701	.49	.71	.86	86.3	119.9	115.7	112.5	110.5	106.5	105.3				
−.125D	743	632	970	15	1,040	2,697	.59	.71	.92	86.1	119.0	116.7	115.1	113.0	110.0	108.5	106.0			
−.125D	575	775	1,040	20	1,040	2,672	.72	.70	1.00	85.3	132.1	134.0	133.2	132.0	129.7	127.2	124.0	121.0	120.5	
−.125D	568	785	1,010	20	1,040	2,682	.72	.70	1.00	85.6	132.7	135.5	134.5	132.8	130.0	127.3	124.0			
−.125D	698	785	960	26	1,280	2,926	.72	.77	1.05	93.5	133.8	136.9	136.7	134.5	133.5	127.8	123.8	121.2	118.0	117.0
0	2,050	231	938	−1	1,020	2,677	.22	.71	.75	85.5	124.8	121.1	117.6	113.8	109.5	106.3	102.0			
0	2,080	233	980	4	1,020	2,677	.22	.71	.74	85.5	123.8	119.6	115.7	110.0	108.2	106.4	104.0			
0	1,100	349	970	4	1,020	2,677	.33	.71	.78	85.5	123.6	119.5	116.1	112.8	109.0					
0	908	516	940	0	1,020	2,498	.49	.66	.82	79.6	121.6	118.3	114.9	111.0	109.7					
0	915	516	940	0	1,030	2,577	.49	.68	.84	82.3	122.5	120.1	117.3	114.6	110.3	108.7	103.0			
0	910	521	920	−2	1,040	2,681	.50	.71	.87	85.6	123.3	121.5	120.1	118.2	115.0	112.5	108.5	106.0		
0	915	525	900	−4	1,050	2,778	.50	.74	.89	88.7	124.3	123.3	122.5	121.3	119.1	116.9	114.1	110.5	108.0	105.0
0	920	522	880	−6	1,050	2,878	.50	.77	.91	91.9	125.4	126.3	126.3	126.2	125.7	124.4	122.4	119.9	117.3	114.0
0	945	507	860	−8	1,050	2,940	.49	.79	.93	93.9	125.9	127.6	128.3	128.1	127.2	125.0	123.3	120.7	117.5	
0	0	528	950	3	0	2,712	.50	.72	.88	86.6	120.3	120.9	119.7	117.3	114.7	111.5	107.1			
0	540	532	1,010	8	600	2,706	.50	.71	.87	86.4	120.7	120.5	119.3	117.0	113.6	116.8	108.5	105.0	103.0	
0	870	525	995	6	1,000	2,702	.50	.71	.87	86.3	121.6	120.6	119.3	116.8	114.1	111.4	108.0	105.5	100.0	
0	723	650	1,040	12	1,040	2,702	.61	.71	.94	86.3	126.9	127.7	127.7	126.8	125.4	123.0	120.5	117.9	114.9	113.0
0	652	702	850	−5	1,040	2,702	.67	.72	.99	86.3	131.2	134.4	135.2	134.1	131.2	127.0	121.8	119.8	119.8	118.8
0	808	707	860	0	1,300	2,928	.67	.78	1.02	93.5	134.8	139.5	140.3	138.0	131.9	120.0	125.5	125.9	123.4	119.0
.125D	2,170	222	965	3	1,030	2,702	.21	.72	.75	86.3	125.7	121.3	115.8	112.7	108.2	102.5				
.125D	1,295	370	960	3	1,030	2,702	.35	.72	.80	86.3	124.7	120.7	116.9	112.7	110.9					
.125D	900	528	970	4	1,030	2,493	.50	.66	.88	79.6	123.5	119.4	114.6	109.1	104.5	103.5	102.5			
.125D	912	528	960	3	1,000	2,587	.50	.69	.85	82.6	124.3	118.1	116.7	112.9	108.0	105.8				
.125D	920	528	955	2	1,050	2,690	.50	.71	.87	85.9	125.3	122.5	119.3	115.0	111.5	105.0				
.125D	910	532	940	1	1,050	2,778	.50	.73	.92	88.7	125.9	123.7	121.5	118.8	115.6	110.9	107.0	104.0	102.5	
.125D	912	527	928	−1	1,050	2,881	.50	.77	.92	92.0	126.6	124.0	122.8	120.1	117.0	113.7	111.0	108.0	106.0	
.125D	878	520	915	−3	1,050	2,953	.50	.79	.93	94.3	127.3	127.5	127.0	125.8	123.7	120.7	117.5	114.5	111.5	110.0
.125D	0	517	960	3	0	2,677	.49	.71	.86	85.5	119.5	119.3	116.7	112.9	109.7	107.3				
.125D	400	537	1,010	7	550	2,671	.51	.70	.87	85.3	122.2	120.2	117.6	113.6	109.8	106.0	103.5			
.125D	775	532	1,025	9	900	2,728	.50	.72	.87	87.1	123.4	120.7	117.5	113.5	109.9	105.6	103.5			
.125D	780	640	1,045	12	1,040	2,703	.60	.71	.94	86.3	128.2	126.3	125.5	122.9	119.7	116.2	111.7	107.0		
.125D	644	704	900	10	1,030	2,652	.66	.71	.97	84.7	131.3	133.0	132.0	129.7	125.6	126.9	119.3	118.3	116.5	114.5
.125D	643	698	950	5	1,020	2,702	.66	.71	.97	86.3	131.0	132.4	131.6	129.5	125.8	120.9	118.2	119.2	115.5	113.5
.125D	800	698	950	5	1,270	2,953	.66	.78	1.02	94.3	135.1	138.0	136.5	132.2	124.6	125.5	125.8	122.5	119.4	117.5

TABLE II.—RESULTS WITH RECTANGULAR-BLADE PLAN-FORM PROPELLERS

[$y=0.055D$]

Test conditions											Sound-pressure level, db (Reference pressure level, 0.0002 dynes/cm²)									
											Order of harmonics									
x	T, lb	V, ft/sec	p_{∞}, lb/sq ft	t_{∞}, °F	P, hp	N, rpm	M_{∞}	M_R	M_t	Blade-passage frequency, cps	1st	2d	3d	4th	5th	6th	7th	8th	9th	10th
Ground tests																				
0.125D	2,800	0	------	69	1,030	2,705	0	0.67	0.67	86.4	131.5	125.5	118.0	111.0	112.0					
0	2,800	0	------	69	1,030	2,700	0	.67	.67	86.2	129.5	123.0	118.5	113.0						
−.125D	2,800	0	------	69	1,030	2,700	0	.67	.67	86.2	129.0	120.0	119.0	108.0						
Flight tests																				
−0.125D	2,160	222	960	5	1,030	2,697	0.21	0.72	0.75	86.2	125.0	119.0	118.5	109.0						
−.125D	1,340	359	962	0	1,040	2,715	.34	.73	.80	86.7	123.5	117.8	112.5	109.5	107.0					
−.125D	915	520	947	−7	1,080	2,497	.50	.67	.84	79.5	120.5	115.6	109.5	107.5						
−.125D	942	513	969	−11	1,050	2,597	.49	.70	.86	82.9	120.5	116.0	112.0	109.5						
−.125D	946	522	961	−5	1,060	2,712	.49	.72	.88	86.6	121.5	116.5	112.5	108.0						
−.125D	960	515	961	−6	1,070	2,893	.49	.75	.92	92.3	122.5	118.5	116.0	112.5	107.5	104.5				
−.125D	963	516	966	−6	1,075	2,940	.49	.78	.93	94.0	122.0	120.0	118.0	114.5	110.4	106.5				
−.125D	756	628	980	−6	1,060	2,717	.60	.73	.94	86.6	124.5	121.5	118.0	112.5						
−.125D	583	757	1,075	0	1,030	2,730	.72	.72	1.02	87.2	135.0	130.5	134.0	131.0	126.0	121.5				
−.125D	738	747	1,040	−8	1,280	2,910	.71	.79	1.07	93.0	137.0	139.0	137.0	133.0	126.5					
0	1,880	270	947	9	1,048	2,710	.25	.71	.76	86.6	129.5	125.0	120.0	115.5						
0	1,310	374	943	9	1,048	2,710	.35	.72	.80	86.6	128.0	124.0	119.5	114.5						
0	955	523	951	10	1,080	2,705	.49	.71	.87	86.4	126.5	123.5	120.5	115.5	111.0					
0	1,350	524	955	10	1,530	2,945	.49	.77	.92	94.0	131.0	130.0	128.0	125.0	121.5	117.0	113.0			
0	774	633	983	11	1,080	2,700	.59	.71	.93	86.2	129.0	128.0	126.0	122.5	117.5	112.0	107.5			
0	574	767	1,000	13	1,080	2,685	.72	.71	1.01	85.8	138.5	142.0	141.5	138.0	131.0	124.5	128.5	127.0	128.5	121.5
0	710	768	1,030	18	1,270	2,910	.72	.76	1.04	92.9	148.5	146.0	142.0	129.5	128.5	129.5	128.0			
.125D	2,180	226	952	4	1,040	2,695	.21	.71	.74	86.0	120.5	124.5	120.0	115.0						
.125D	1,300	369	945	3	1,035	2,700	.35	.71	.78	86.2	128.0	123.0	119.0	113.5						
.125D	950	531	968	5	1,070	2,690	.50	.71	.87	85.8	128.5	125.5	122.0	117.5	114.0					
.125D	1,360	517	966	5	1,530	2,945	.49	.78	.92	94.0	131.0	130.5	129.0	126.5	123.0	119.5	114.5			
.125D	762	629	985	7	1,060	2,682	.59	.71	.92	85.6	130.5	129.5	127.0	123.5	119.5	115.0				
.125D	606	761	940	6	1,080	2,665	.72	.71	1.01	85.0	138.0	139.5	135.1	124.0	126.0	126.5	122.0	120.5	119.0	
.125D	890	744	940	5	1,530	2,920	.70	.77	1.04	93.2	142.5	143.5	133.5	132.5	133.0	121.0	128.0	123.5	124.5	125.0

EFFECTS OF FLIGHT MACH NUMBER

The effects of flight Mach number at the three axial microphone locations are shown in figure 4. A trend is shown for the lower blade-passage harmonics of both blade designs to decrease slowly in sound-pressure level as the flight Mach number increases to approximately 0.5 and to increase rapidly with further increase in flight Mach number. For the lower blade-passage harmonics the tapered blade shows a lower sound-pressure level than the rectangular blade.

The higher harmonics show a slight increase in sound-pressure level for both blade designs up to $M_\infty \approx 0.5$ with rapid increases for higher flight Mach numbers. Above $M_\infty = 0.5$ the tapered-blade design shows a more rapid increase in sound-pressure level with Mach number than the rectangular-blade design. This trend, which is more pronounced for the higher harmonics, produces higher sound-pressure levels in the higher harmonic range for the tapered-blade design than for the rectangular-blade design.

EFFECTS OF ENGINE SPEED (ROTATIONAL MACH NUMBER)

The effects of changing the engine speed (rotational Mach number) on the sound-pressure levels at a constant forward Mach number and power are shown in figures 5 and 6 for the tapered- and rectangular-blade designs, respectively. The results for both blade designs show small increases in the oscillating pressures with rotational Mach number for the first harmonic, but the increase for the higher harmonics becomes increasingly greater.

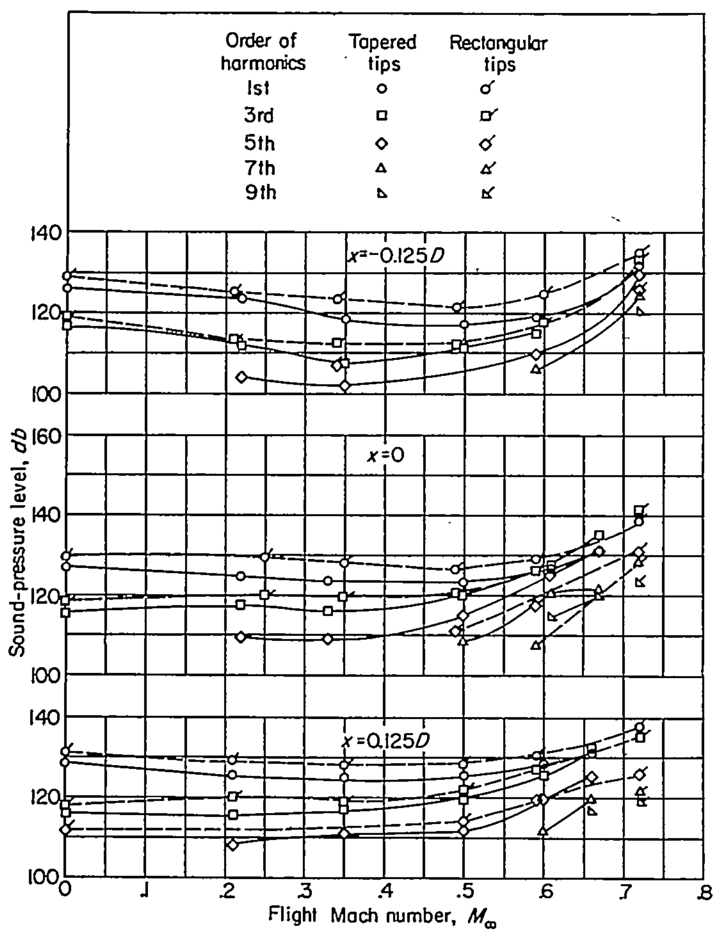


FIGURE 4.—Variation of propeller noise harmonic content with flight Mach number. $N \approx 2{,}700$ rpm; $P \approx 1{,}000$ hp; $y = 0.655D$.

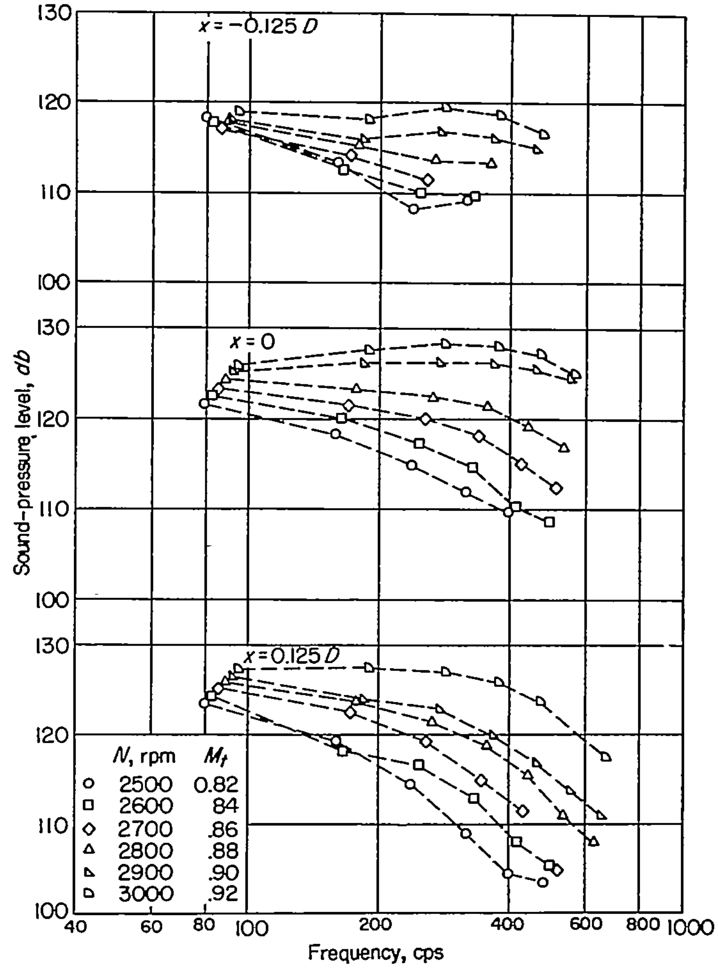


FIGURE 5.—Variation of sound-pressure levels with engine speed for the tapered-blade propeller. Blade-passage harmonics are connected with dashed lines for identification purposes only. $M_\infty \approx 0.5$; $P \approx 1{,}000$ hp; $y = 0.655D$.

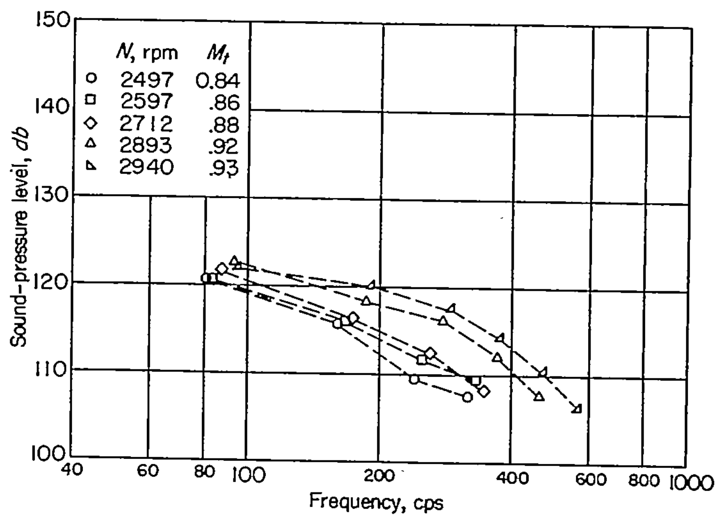
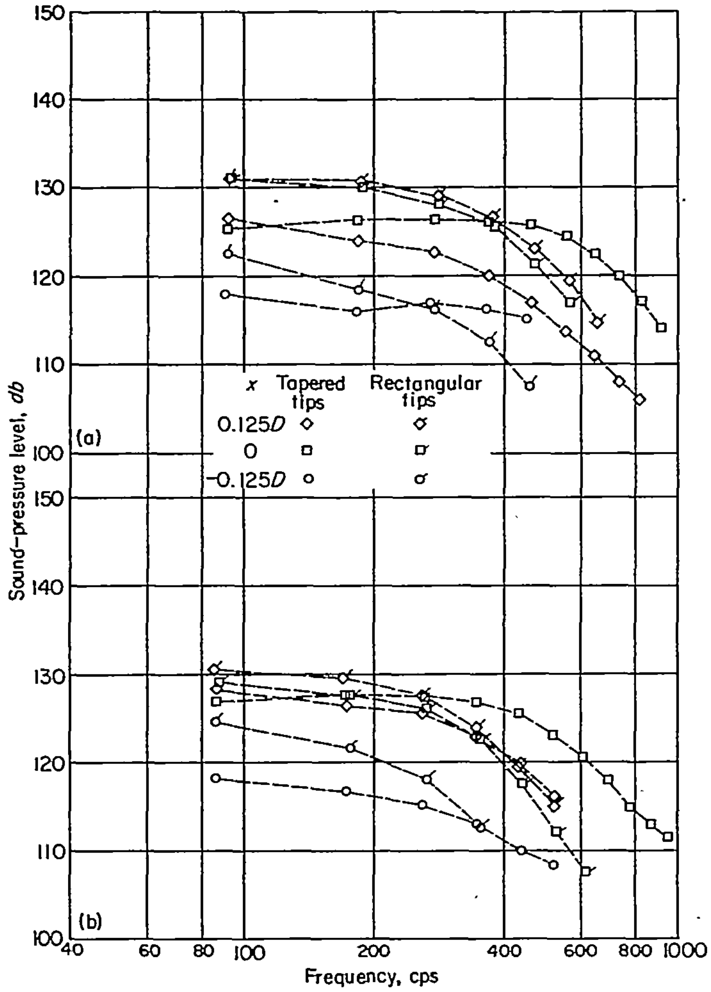


FIGURE 6.—Variation of sound-pressure levels with engine speed for the rectangular-blade propeller. Blade-passage harmonics are connected with dashed lines for identification purposes only. $M_\infty \approx 0.5$; $P \approx 1{,}050$ hp; microphone location, $x = -0.125D$.

Figures 7 (a) and 7 (b) show that the effects of flight Mach number are similar to those of rotational Mach number. Data for figure 7 (a) were obtained at a flight Mach number of approximately 0.5 and an engine speed of 2,900 rpm. Data for figure 7 (b) were obtained at a flight Mach number



(a) $M_\infty \approx 0.5$; $N \approx 2{,}900$ rpm; $P \approx 1{,}000$ hp; $y = 0.655D$.
(b) $M_\infty \approx 0.6$; $N \approx 2{,}700$ rpm; $P \approx 1{,}000$ hp; $y = 0.655D$.

FIGURE 7.—Variation of sound-pressure levels with axial microphone location. Blade-passage harmonics are connected with dashed lines for identification purposes only.

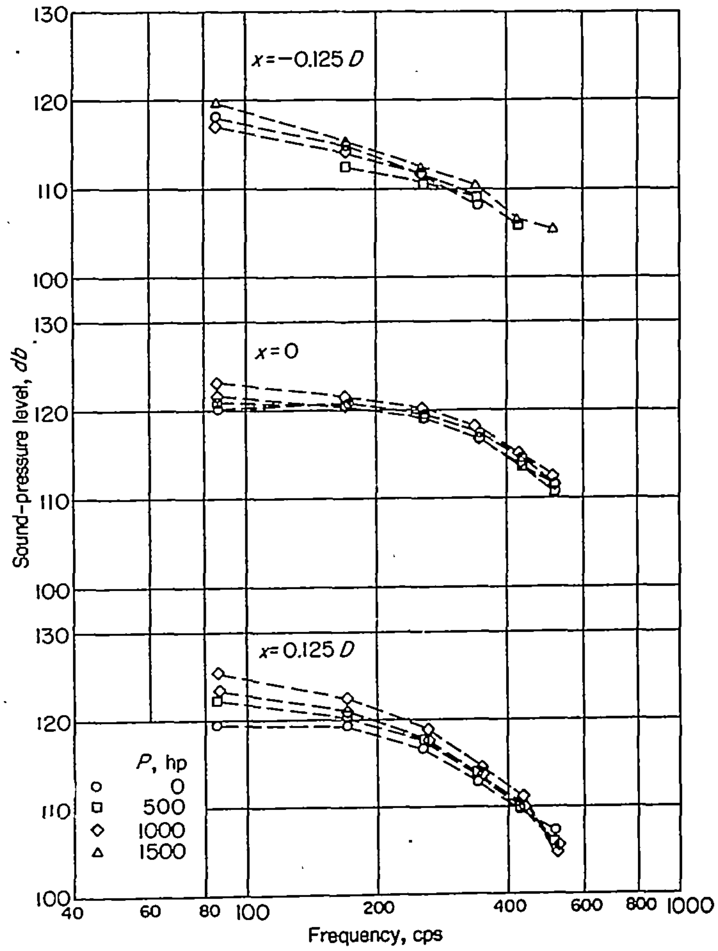


FIGURE 8.—Variation of sound-pressure levels with engine power for the tapered-blade propeller. Blade-passage harmonics are connected with dashed lines for identification purposes only. $M_\infty \approx 0.5$; $N \approx 2{,}700$ rpm; $y = 0.655D$.

of approximately 0.6 and an engine speed of 2,700 rpm. The resultant tip Mach number for both conditions is approximately 0.95. The similarity of the two figures shows that in the range of the two conditions the effects of increase in flight Mach number are the same as increases in rotational speeds.

EFFECTS OF ENGINE POWER

The effects of engine power delivered to the tapered-blade propeller on the noise emitted from the propeller are shown in figure 8 for the three axial microphone locations. Data of this type were not obtained for the rectangular-blade propeller. The relatively small change in noise level with large changes in power displayed by the tapered-blade propeller seems to indicate that the propeller is also producing thickness noise of at least the same order of magnitude as the loading noise.

The power delivered to the propeller is seen to affect the noise emitted by the order of 6 decibels. This order of magnitude is far less than would be expected from consideration of only the blade-loading noise as was done in reference 4. However, calculations of thickness noise made in reference 6 show that the magnitude of the thickness noise, for the rectangular-blade propeller operating under the same flight conditions shown for figure 8, is within 6 decibels of the blade-loading noise.

It should be noted that the propellers used in the present investigation are designed for a flight Mach number of 0.5. At speeds above the design condition the outer portions of the blades tend to unload. Also, for a given horsepower input, the average thrust necessarily drops in proportion to the forward-speed increase. The combination of these two factors and the near location of the microphone to the tip would cause the results found in the present investigation to overemphasize the thickness noise in comparison with the loading noise at the higher speed conditions. This may be, in part, the reason that the results of the present investigation do not completely substantiate the theory of reference 4, as will be discussed subsequently.

CORRELATION WITH THEORY

Due to the nature and limitations of the present investigation, it was not possible to obtain a complete check of the theory of reference 4 for the effects of forward speed on the sound-pressure field around propellers. The results obtained allow a few broad generalizations to be made which are as follows:

(1) In agreement with the theoretical results of reference 4, the results of the present investigation, as shown in figure 4, show an initial gradual decrease in the oscillating pressures with a more rapid increase at flight Mach numbers above 0.5. This was also shown in the results of reference 7, which utilizes the theory of reference 4. When account is taken of the differences between the flight-test configuration and the configuration examined theoretically in references 4 and 7, the pressure levels and changes in level with Mach number are also in rather satisfactory agreement.

(2) In agreement with the theory of reference 4, the test results show that the level of the higher harmonics of the propeller noise increases at a higher rate than that of the lower harmonics with increase in flight Mach number. This trend is shown in figure 5 of reference 8. The calculations of reference 8 utilize the theory of reference 4.

(3) For the propeller studied in reference 4, the oscillating pressures in the plane of the propeller disk and ahead of the disk were found to be lower than those immediately behind the disk. This theoretical result is contrary to the results found in the present tests, as is shown in figures 5 to 8. This contradiction does not, however, invalidate the theory. Rather it indicates that other effects such as variation in torque and thrust distribution should be investigated. As noted in the previous section, the outer portion of the blades was operating under unloaded condition for forward Mach numbers above 0.5.

CONCLUSIONS

As part of a brief flight program initiated to check the theory of Garrick and Watkins (NACA Rep. 1198), a brief set of measurements were made of the oscillating pressures in the vicinity of a blade of tapered plan form and a blade of rectangular plan form at flight Mach numbers up to 0.72. Measurements were made at a single radial station and at positions ahead of, in the plane of, and behind the propeller disk. The scope of the tests was found to be insufficient to obtain complete verification of the theory for the effect of forward speed on the sound-pressure field around propellers, but it was possible to substantiate the following two phenomena:

(a) The oscillating pressures near the tips of a propeller tend to decrease slowly with increase in flight Mach number up to a Mach number of approximately 0.5 and then to increase rather rapidly at higher Mach numbers.

(b) The sound-pressure levels of the higher harmonics of the propeller noise increase at a higher rate with increase in flight Mach number than do the lower propeller harmonics.

In contradiction to the results found for the propeller studied in NACA Rep. 1198, the oscillating pressures in the plane of and ahead of the propellers of the present investigation were found to be higher than those immediately behind the propeller. Factors such as variations in torque and thrust distributions, since the blades in the present investigation were operating above their design forward speed, may account for this contradiction.

The effect of blade plan form shows that a tapered-blade plan-form propeller will produce lower sound-pressure levels than a rectangular-blade plan-form propeller for the low blade-passage harmonics (the frequencies where structural considerations are important) and will produce higher sound-pressure levels for the higher blade-passage harmonics (frequencies where passenger comfort is important).

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *July 1, 1958*.

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