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Noise and Performance of the MIT and Production Propellers for a 150 HP Single Engine Aircraft

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NOISE AND PERFORMANCE OF THE MIT AND PRODUCTION PROPELLERS FOR A 150 HP SINGLE ENGINE AIRCRAFT

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INTRODUCTION

MIT was engaged to study the noise and performance of general aviation propellers. One task was to use computer models based on curren theoretical developments to design a quiet propeller with similar efficiency to an existing propeller. We chose to design a two-blade propeller for a 150 HP Cessna 172 Skyhawk, an aircraft that already complies with the FAR-36 noise regulations (1). Flight tests demonstrate the maximum noise of the new propeller during a full power 1000 foot flyover was 4.8 dBA less than the production propeller. In addition, the preliminary tests indicate the aerodynamic performance of the new propeller was similar to the production propeller.

There are three tasks in the MIT study of general aviation propellers. First, the aerodynamic and acoustic theory of propellers was reviewed (2,3). Computer programs based on these theories were encoded and parametric studies were made to explore methods of reducing noise. Two constraints were imposed on the study. First, only the propeller could be altered; no other modification to the existing engine or aircraft is allowed. This constraint means that we couldn't achieve the noise reduction by introducing a gear box, or larger engine, to produce the same power at lower RPM. Second, the new propeller must perform about the same as the production propeller. To achieve this goal we concentrated on aerodynamically optimum propellers.

An aerodynamically optimum propeller has a radial load distribution that minimizes the induced losses. Since this load distribution was an aerodynamic extremum, perturbations in the load distribution caused only second order changes in the efficiency. The load pattern, however, was not an acoustic optimum. Thus we expect first order changes in the sound field with regard to perturbations in the load distribution. This effect was exploited as a strategy to reduce noise with little or no loss in efficiency. The technique was to move the peak of the radial load distribution inboard.

The second task was to verify our calculations. To do this we tested three one-quarter scale models of general aviation propellers in the anechoic wind tunnel at MIT. The first propeller was a replica of the production propeller for a Cessna 172 Skyhawk. We designed the other two propellers to have the radial load distribution moved inboard (4). Wake measurements revealed that the aerodynamic theory accurately described the radial load distribution of a lightly loaded subsonic tip speed propeller. The acoustic experiments demonstrated that the pressure time signatures can be predicted within a few percent of their measured value even in the near field. These results are obtained given only the shape and motion of the propeller; no empirical adjustments are made.

The final task was to design and flight test a quiet propeller. One of the model propellers, which had the same radius as the production propeller, was designed to match the power absorption of the production propeller at the high speed flyover point. However, off-design calculations indicated this propeller absorbed too much power at low speeds. To improve the low speed performance, the radius was reduced by $7^1/2\%$. This alteration did not change the high speed performance, since the tips were unloaded, and improved the low speed characteristics. In addition, slight alterations of the pitch distribution were made to fine tune the design.

The danger of overspeeding the engine was another matter of concern. To avoid this problem the new propeller was designed conservatively, in fact, it turns 100 RPM slower than the production propeller during the 1000 foot flyover at full engine throttle.

Each of the modifications mentioned above, changes in the radial load distribution, reduced diameter, and reduced RPM, contribute to the observed reduction in noise. Nonetheless, the strategy of moving the load inboard is the most important in reducing the flyover noise. One way to demonstrate this is to calculate the level changes of the individual noise components. Our calculations indicate that the new propeller has a reduction in the loading noise and a small increase in the thickness noise when compared to the original.

We should mention that the new propeller was 50% heavier than the old one. Some of this weight gain was necessary as we need increased chord to support the inboard loading. However, a good portion of the weight gain was due to overly conservative design of the hub and the radial thickness distribution. For example, the hub is 5 inches thick as opposed to the usual $3^3/8$ inches. At the 50% radial station the thickness to chord ratio of the new propeller was 14% as compared to 10% for the production propeller (Table 1). These choices were made to give a good structural failure safety margin.

ACOUSTIC MEASUREMENTS

Five simultaneous acoustic measurements were made. Three microphones were mounted on vertical pole at 0', 4', and 9'1" above the ground and used to record the pressure time signature of the airplane during a full power flyover. Two microphones, attached to General Radio type 1982 level meters, were mounted 4' above the ground and used to record the unweighted and A-weighted sound level. Here we report the maximum A-weighted sound level detected during the aircraft flyover. This is the quantity specified in FAR-36 (1).

The tests are mixed so that accurate comparisons can be made between the two propellers. For a given test six flyovers were made at 1000 feet and six at 500 feet. The pilot then called the flight mechanic by radio and advised him that he would land shortly. It was possible to land, change propellers and be airborne again within an hour. The following table contains the average A-weighted sound level and RMS error for six runs. On each line, the tests were made sequentially so as to minimize errors due to changes in atmospheric conditions. The average of all the runs is indicated at the bottom.

Runs	Standard Propeller (dBA)	MIT Propeller (dBA)	Level Difference (dBA)
		1000' Flyover	
6	77.1 ± .7	72.0 ± .4	- 5.1
6	77.9 ± .3	73.8 ± .2	- 3.5
6	77.3 ± .2	72.1 ± .8	- 5.2
36	77.4	72.6	- 4.8
		500' Flyover	
6	84.5 ± .7	78.0 ± .6	- 6.5
6	83.7 ± 1.0	80.8 ± .5	- 2.9
6	83.1 ± .7	79.5 ± .7	- 3.6
36	83.8	79.4	-4.4

The tests indicate the new propeller was 4.8 dBA quieter at 1000 feet and 4.4 dBA quieter at 500 feet. The .4 dBA difference is within the bounds of experimental error. The Cessna 172 Skyhawk qualifies for a 5 dBA performance correction. This correction was not made. Here we report the actual measurements.

AERODYNAMIC MEASUREMENT

In addition to the noise measurements a preliminary performance test was done. We did the tests on two separate days, between 8 and 9 a.m., in calm. At ground level (133' MSL) the barometric pressure was 30.31" and 62°F for the standard propeller tests and 30.02" and 57°F for the MIT propeller tests. All tests were performed with full fuel tanks and two persons on board, the engineer and the pilot. The aircraft weight was approximately 2000 lbs. The conical spinner usually fitted to a Cessna 172 did not fit over the MIT propeller hub. To make the tests similar both propellers were fitted with a 5" diameter hemispherical "skullcap." This was also done during the acoustic tests.

To measure the performance, the aircraft velocity was stabilized, the engine RPM was measured and the time to climb from 1833' to 2333' MSL was measured. To minimize the variation caused by decreasing weight due to fuel consumption, the tests were done in 20 MPH increments which started at 60 MPH and then at 20 MPH increments which started at 70 MPH. Fig. 1 indicates that the RPM versus velocity for the two propellers was similar. This implies that the power absorption of the new propeller matches that of the existing propeller. Fig. 2 indicates the rate of climb for the two propellers was also similar. This implies the efficiency of the two propellers was the same. Some decrement in rate of climb is observed at the maximum velocity. This was caused by the slower RPM of the MIT propeller at the high speed point. Note, however, that the engine RPM was identical for the two propellers at the velocity for maximum rate of climb. There was some indication that the MIT propeller climbs better; this was misleading as the difference was within the experimental error of the measurement. The reported measurements were not corrected for temperature or altitude; they are for comparison only.

CONCLUSIONS

The modern theory of the aerodynamic and acoustic characteristics of propellers is sufficiently accurate to enable the design engineer to reduce propeller noise at little or no loss in efficiency. Here we use a noise reduction strategy suited to propellers with sound fields dominated by loading noise. Similar strategies can be developed for propellers with sound fields dominated by thickness noise. The point is that the theoretical description of the propeller sound field can describe the influence of small design changes.

References

1. FAR 36, Appendix F, "Noise requirements for propeller-driven small airplanes."

2. Larrabee, E.E., "Practical design of minimum induced loss propellers," Transactions 1979 SAE Business Aircraft Meeting, paper 790585.

3. Succi, G.P., "Design of quiet efficient propellers," Transactions 1979 SAE Business Aircraft Meeting, paper 790584.

4. Succi, G.P. et al, "Experimental verification of propeller noise prediction," 1980 AIAA 6th Aeroacoustics Conference, paper AIAA-80-0994.

Figure 1

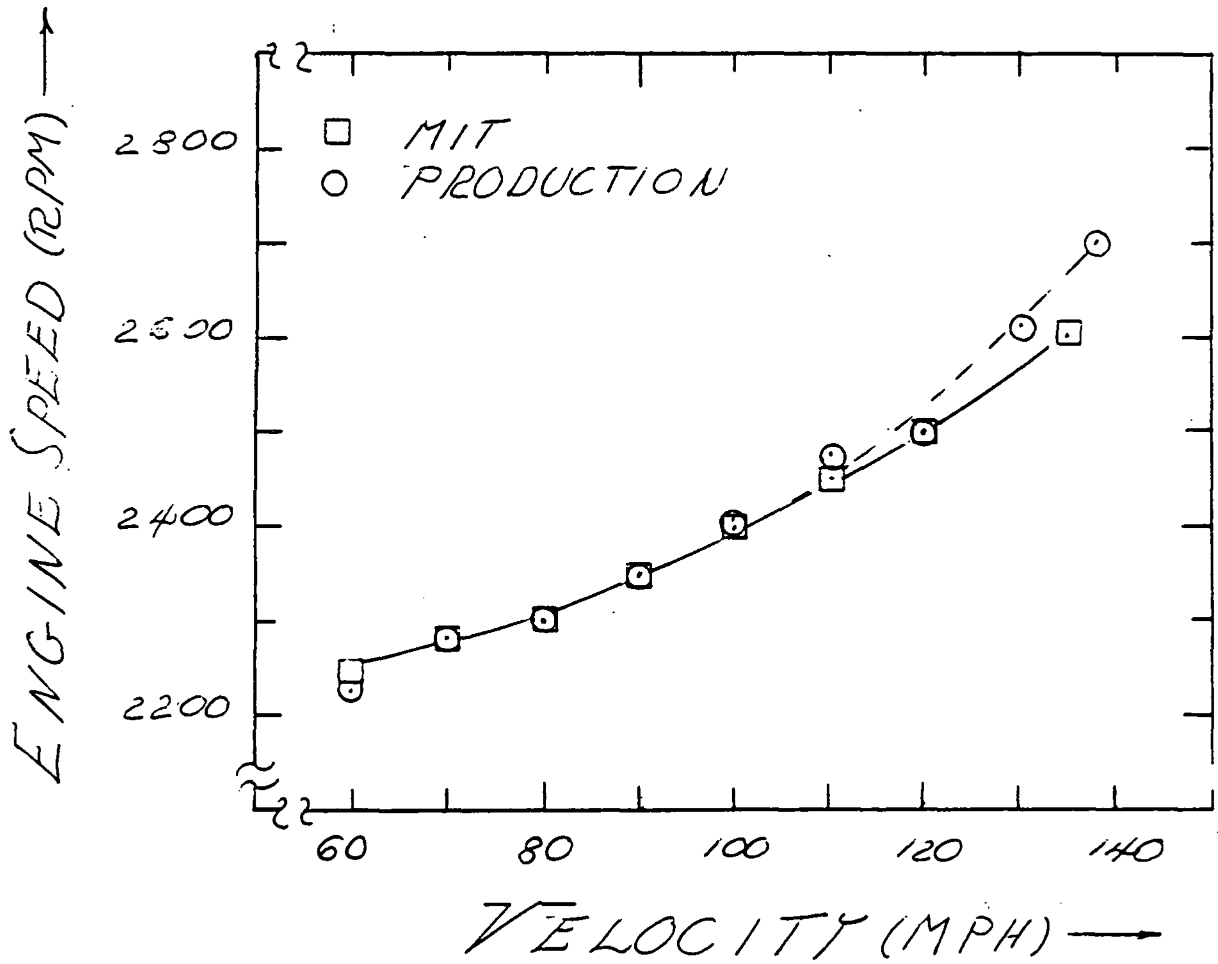
ENGINE SPEED (RPM)
2800
2600
2400
2200
MIT
PRODUCTION
60
80
100
120
140
VELOCITY (MPH)

Figure 2

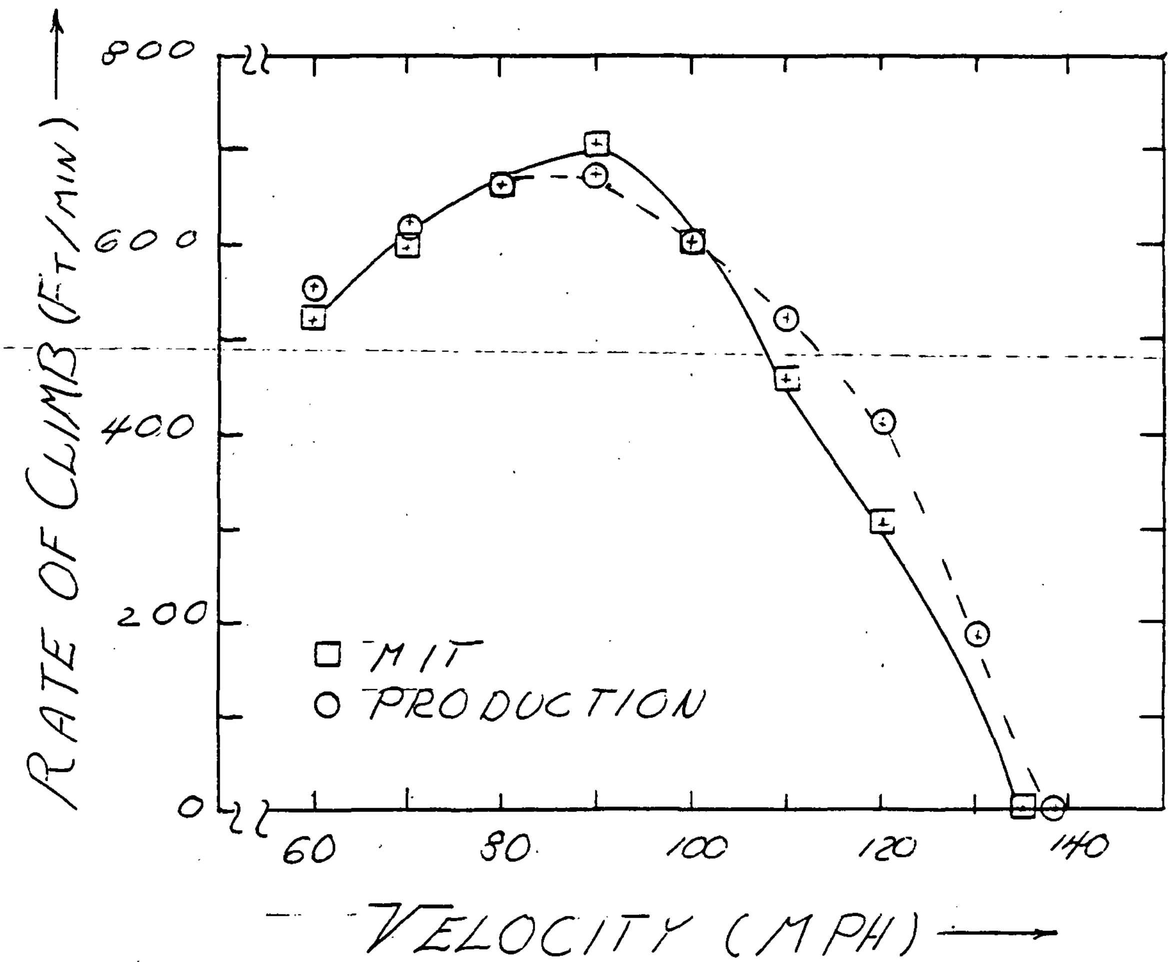
RATE OF CLIMB (FT/MIN)
800
600
400
200
0
60
80
100
120
140
VELOCITY (MPH)
MIT
PRODUCTION

Table 1.--The following table describes the propellers we built. Here the section properties are approximated as follows:

$$C_\ell = \frac{dC_\ell}{d\alpha} \frac{1}{\sqrt{1-M^2}} (\alpha - \alpha_o) \qquad [1] \qquad\qquad C_D = C_{D_o} + \frac{dC_D}{dC_\ell^2} (C_\ell - C_{\ell_o})^2 \qquad [2]$$

The table gives the appropriate constants. Keep in mind that the data for the production propeller was computed at the model scale Reynolds number whereas the data for the MIT propeller was based on experimental data at $Re \approx 10^6$.

The last two digits of the series designation for the MIT propeller indicate the design section lift coefficient. The sections are fabricated by wrapping the appropriate thickness distribution around an a=1 camber line scaled to the design section lift.

Radius inches	Chord C/R	Thickness t/C	Pitch β	Zero Lift Angle α_o	Section Lift Slope $dC_\ell/d\alpha$	Minimum Section Drag C_{D_o}	Section Lift for Minimum Drag C_{ℓ_o}	Section Drag Curvature dC_D/dC_ℓ^2	Series
				Production Propeller		R = 37.5"			
5.0	.149	.430	31.5°	-2.14	.224	.0231	.360	.0342	RAF-6
9.0	.153	.204	30.9°	-7.30	.074	.0231	.360	.0342	RAF-6
12.0	.153	.156	29.5°	-8.80	.083	.0188	.393	.0337	RAF-6
15.0	.154	.127	25.7°	-7.07	.086	.0212	.409	.0277	RAF-6
18.0	.153	.109	23.0°	-5.87	.088	.0178	.405	.0246	RAF-6
24.0	.141	.092	18.8°	-4.82	.089	.0074	.415	.0253	RAF-6
30.0	.119	.082	15.8°	-4.58	.087	.0039	.414	.0244	RAF-6
33.0	.103	.080	14.6°	-4.21	.088	.0034	.407	.0230	RAF-6
36.0	.079	.080	13.6°	-3.96	.091	.0036	.407	.0232	RAF-6
37.5	0.	0.		-3.92	.092	.0040	.406	.0234	RAF-6
				MIT Propeller		R = 34.688"			
5.25	.173	.293	47.2°	-4.00	0.	.00573	.471	.00665	64-.6
7.50	.193	.244	41.0°	-3.98	.104	.00573	.471	.00665	64-.6
11.25	.206	.200	34.9°	-3.98	.104	.00573	.471	.00665	64-.6
15.00	.208	.170	30.9°	-3.98	.104	.00573	.471	.00665	64-.6
18.75	.204	.145	27.3°	-3.98	.104	.00573	.471	.00665	64-.6
22.50	.193	.122	22.3°	-3.98	.104	.00573	.471	.00665	64-.6
26.25	.176	.101	18.3°	-3.31	.107	.00591	.235	.00622	64-.45
30.00	.150	.079	15.1°	-1.95	.100	.00975	.109	.01065	16-.3
32.813	.112	.053	13.2°	-1.40	.092	.00797	.022	.00800	16-.15