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Some thoughts on a proposed in-flight experiment to study the effect of external noise on a swept laminarised wing

- by -

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SUMMARY

A transducer-horn arrangement has been suggested as a suitable noise source to be installed in the Lancaster aircraft so that the Handley-Page suction fin could be subjected to large acoustical disturbances.

The object of this note is to clarify this proposal with a view to recommending actions to be taken.

CONTENTS

1. Introduction

Pfenninger[1] has investigated the effect of acoustical disturbances on the behaviour of a swept laminar suction wing in the Norair 7 × 10 foot tunnel. An in-flight study of this problem would have the following main advantages over Pfenninger's work:

(a) minimisation of sound reflections, thus eliminating standing waves and enabling the effect of propogation direction to be studied.
(b) representative free air turbulence levels.
(c) three-dimensional conditions, as distinct from Pfenninger's skewed two-dimensional tests.

2. The Noise Required at the Suction Fin Surface

2.1 Overall sound pressure level.

Because of the limitations indicated above, Pfenninger's results should only be used to provide an approximate guide for the required levels. Note also that with increasing wing chord Reynolds number (R_c), the corresponding critical sound particle velocity ratio decreases at a slightly slower rate than inversely proportional to R_c. Thus at 150 knots E.A.S. and 10,000 ft altitude, $R_c = 10.3 \times 10^6$ based on the geometric mean chord of the Handley Page fin; the corresponding critical sound particle velocity ratio for 'increased suction' (see Ref. 1) is $\frac{u'}{U_\infty} = 0.002$, which corresponds to an overall sound pressure level of 128.5 decibels (535 μbar) on the assumption of plane waves.

However, the sound pressure level present at the fin under normal cruise conditions has been measured[2] as 118 dB (167 μbar), and so the additional sound to be generated at the fin is 125.3 dB (368 μbar)[*].

The significance of Pfenninger's criteria for the 'increased suction' case should not be overemphasised as this merely corresponded to the maximum sound pressure levels obtainable with his particular experimental arrangement. Remembering also the basic differences between the tunnel tests and the flight experiment, it would seem prudent to allow a considerable margin over the calculated levels and to specify a required sound pressure level above ambient of up to 130 dB.

[*] In the case of the high R.P.M. cruise condition, the additional sound required is only 120.3 dB (207 μbar) - but it must be recognised that the spectrum of the ambient noise levels is controllable via engine R.P.M. only in a limited sense.

2.2 Frequency range

The simulation of both jet exhaust plus turbulent boundary layer noise (by white noise) and compressor noise (by sound of discrete frequencies) is desirable. Fatigue life of the structure and the basic horn design will be affected by the frequency range (the lowest frequency being virtually inversely proportional to the required horn size).

3. Location of the noise sources

Ideally it would be desirable to investigate the effect of sound generated in all three directions of freedom. However, the normal to the surface case would require the noise source to be located at the Lancaster wing tip which does not appear feasible because of ducting problems for the services required by the noise generator and also the more acute fatigue problem at the wing tip.

The transverse case gives the easiest practical solution as the horn can be laid adjacent to the root chord. The longitudinal condition involves a compromise between (a) increasing attenuation and (b) more truely longitudinal propogation as distance from the fin along the top of the fuselage is increased. Also, if the horn is positioned aft of the fin, complications due to the propagation of the sound through a wake might occur and the transducer compressed air requirement could be increased due to the ram air effect on the horn mouth; positioning the horn forward of the fin seems desirable, although possibly more difficult structurally.

Precise location of the noise source cannot be decided until more exact information on both the attenuation and directional properties of sound are known. A representative horn and frequency range should be used.

The actual size of the horn would be dictated by the lowest frequency to be transmitted and the degree of beaming achieved by the higher frequency sound (the lower frequencies propogate more nearly as spherical waves). Low frequency sounds are radiated most efficiently by exponential horns and using classical results[3] for good low frequency reproduction down to, say, 150 c.p.s. at 10,000 ft altitude gives:

$$\text{Major dimension at mouth} \geqslant \frac{2.c}{\pi.f} = 4.58 \text{ ft.}$$

$$\text{Flare constant} \qquad m \leqslant \frac{4\pi f}{c} = 1.60 \text{ ft.}$$

Using the throat area of the Altec-Lensing Type 6786 transducer (0.0107 sq.ft.) and a minor dimension at the mouth of 1 ft., the length of the horn, x, would be:

$$x \doteq \frac{\log_e\left(\frac{A}{Ao}\right)}{m} = 3.8 \text{ ft.}$$

It may be possible to relax the requirement for the major mouth dimension by increasing the cut-off frequency to, say, 300 c.p.s.; also for this work absolutely pure reproduction is not essential and some reduction in horn dimensions would follow. However, minimum horn size will also be affected by the primary requirement of a uniform sound field over the whole of the middle zone of the suction wing.

4. The Transducer

(i) Noise Unlimited Stenton 204B Wide Band Noise Generator. Price $12,000. Delivery approximately 20 weeks. Services required: 290 S.C.F.M. at 20 p.s.i.g. and 10 KVA at 220 volts A.C. Output 1,500 acoustic watts.

This acoustic siren device appears to be unsuitable, mainly because of the power requirement, but it now seems possible to operate it with reduced electrical power on 28 volts D.C. and enquiries are being continued.

(ii) Altec Lansing 6786 Electro-Pneumatic Transducer Mark III. Price $3000. Delivery approximately 3 weeks. Services required: 250 C.F.M. at 44 p.s.i.g. and 200 watts. Output 2,000 acoustic watts.

The transducer was redesigned last year and detailed information is difficult to obtain. Note that a horn of 3 sq.ft. mouth area would limit the maximum overall level to 158.6 dB for the quoted acoustic power.

An A.P.U. has been suggested as a solution to the compressed air supply problem*. A Palouste 3 is available in the Lincoln[4] and, although this engine has run 161 hours, it is inhibited and serviceable. At the maximum R.P.M. of 34,000 and standard sealevel conditions, the unit can deliver between 980 and 1860 C.F.M. at a delivery pressure of between 41.5 and 43 p.s.i.g.[5] Unfortunately, altitude compensation for fuel metering is not fitted and it must, therefore, be throttled back as altitude increases to maintain the J.P.T. within limits. Napiers estimate that a delivery pressure of 26 p.s.i.g. and 1.1 lbs/sec. would be available at 10,000 ft. The Palouste 500 Series,[6] currently in production, give delivery pressures at sealevel standard conditions

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* It would appear that a useful total operating time of, say, 20 to 30 minutes per flight would preclude the use of air bottles as a standard bottle (8 ft. by 8 ins. diameter) at 4,000 p.s.i. would give only about 10 seconds running time.

of 44.8 p.s.i.g. (5 minute limit) or 41.1 p.s.i.g. (continuous), dropping to approximately 30 p.s.i.g. at 10,000 ft. altitude.

5. The Lancaster Structure

The effect of the noise on the old Lancaster fuselage must be examined carefully. Some fatigue tests on a 4 ft. × 3 ft. Lincoln fuselage panel at Southampton University[7] using intensities of 135, 140, 145 and 150 dB (88-1400 c.p.s.) have shown no damage with 5 hours testing at each level. However, the whole test structure shook viciously and some doubt was expressed as to whether this was a representative exercise.

Further tests should be carried out with, if possible, more realistic boundary conditions on the specimen at the sound levels and frequency ranges to be used in the flight experiment.

6. Recommended Actions

(a) Finalise the frequency ranges of discrete frequency noise and white noise. (It is suggested that an acceptable lower cut-off frequency is 300 c.p.s. which would reduce the horn dimensions and increase the available sound pressure level for a given acoustic power output. An upper limit of 4 kc/s for discrete frequency work and 8 kc/s for white noise is considered reasonable).

(b) Obtain detailed information on Altec-Lansing 6786 Transducer including:
    (1) horn dimensions to cover (a)
    (2) tolerance on air supply (as Palouste is a convenient A.P.U., but of marginal performance).

(c) Measure attenuation and directional properties of sound from an exponential horn at the frequency ranges given in (a), up to distances of 30 ft. from the source.

(d) Extend fatigue tests on Lancaster/Lincoln specimens, as advocated by D.R.B. Webb[8], at the frequency ranges given in (a).

7. Conclusion

In terms of potential gain versus time, technical difficulty and expense it is possible that this project may not be attractive as currently envisaged.

It is concluded that the actions above should be proceeded with, but that alternative basic techniques, such as formation flying a jet aircraft with the Lancaster should also be investigated (although conditions would obviously be less 'controlled', the comparative simplicity of such a scheme is now an obvious attraction).

8. References

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3. Wood, A. — Acoustics. Blackie. 1945.

4. - — The operation of the Turbomeca Palouste Air Compressor in Lincoln RF342. D. Napier and Sons Ltd. Report CE/REP/4. 31st Jan. 1957.

5. - — Provisional Handbook for the Palouste Air Compressor.

6. - — Palouste 500 Series (Aircraft). Technical Data Issue 1. Publication No. E.1003. Blackburn Turbomeca/Bristol Siddeley.

7. Richards, E.J. — Handley Page Laminar Flow Fatigue Specimen Results. Southampton University, 28th November, 1962.

8. Webb, D.R.B. — Letter to D.J. Raney, M.o.A. Aircraft Research, dated 28th February, 1963.