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THE PREDICTION OF SOUND PRESSURE LEVELS ON AN AIRCRAFT FUSELAGE SURFACE USING A CONTRA-ROTATING PROPELLER AS EXCITATION

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1.0 INTRODUCTION

In recent years the operating costs for large fleet operators have escalated. Pressure has been applied to both the airframe and engine manufacturers to produce designs which have lower operating costs and are more fuel efficient. This has resulted in the development of advanced turboprop aircraft. However, these turboprop aircraft produce high levels of cabin noise at discrete tones which coincide with the blade passing frequencies. Considering the demands of passengers for increased comfort and the increasing competition amongst airframe manufacturers especially those from the USA, South America and South East Asia, it is extremely important to reduce the cabin noise to levels comparable with turbofan powered aircraft.

A cabin noise reduction research and development program has been running at British Aerospace Regional Aircraft Limited for a number of years. The objectives are to derive guidelines for passive and active control mechanisms; prediction methods and algorithms. The research work is being carried out in collaboration with Dowty Aerospace Propellers and is partly funded by the Department of Trade and Industry.

One method which may assist in the reduction of the interior cabin noise is a modification to the exterior fuselage loading. This paper describes the work undertaken to predict the sound pressure level (SPL) on a fuselage surface with and without reflections from the surrounding environment. Acoustic sources have been derived for both a single propeller (748 aircraft) and a contra-rotating propeller (Fairey Gannett aircraft), both types of propeller are supplied by Dowty Aerospace Propellers. Two different prediction techniques have been employed and the results compared. The effects on the predicted sound pressure levels with varying propeller (contra-rotating) kissing angle were also investigated.

2.0 THE PREDICTION MODELS

Two methods, namely Succi [1] and Garrick and Watkins [2], were used to predict the SPL at a number of observation points using a propeller as the source. The Succi method, which was developed at MIT, is based upon a time domain formulation and is used at

British Aerospace to predict the SPL in the free field. The Garrick and Watkins equations, which are based in the frequency domain, can be used in conjunction with SYSNOISE (an acoustic prediction program) to predict the SPL at the observation points taking into account a variety of surrounding surface impedances and reflective boundaries. The following sections briefly describe the methods used.

2.1 THE SUCCI COMPUTER CODE

Dowty Aerospace Propellers has supplied a computer code based on the Succi method to BAe for exterior noise prediction work. This Succi program [1] is divided into three sections: the propeller blade description, the blade pressure signature, and the Fourier analysis. The blade is described in the input file by a polynomial expansion of its shape and by similar expansions for the in plane and out of plane loading. In addition, there is information regarding the mesh size for segmenting the blade.

The propeller blade is modelled as an array of rotating point sources, each with a unique force vector and volume. To do this the blade mid-chord is described and the blade span divided into strips by cutting perpendicular to radii drawn to specified stations on the centreline. These strips are further divided in the chordwise direction to produce the blade segments (mesh). The volume displacements and forces on the fluid due to each blade segment are assigned to points at the centre of these segments.

The next step is to calculate the blade pressure signature. The observer location is specified at time t; with the option of a stationary observer or one moving with the forward velocity of the propeller. With the time t, there is an associated emission time for each blade segment which is calculated by an iterative scheme. Given the retarded time, the contribution of a particular segment is evaluated for the steady loading and thickness noise.

A summation over all the blade segments yields the pressure signature at observer time t. The above procedure is repeated for other observer times to obtain the acoustic pressure signatures. Given the pressure signature, the program then undertakes a Fourier analysis to calculate the SPL at the blade passing frequency and its harmonics.

2.2 STEADY LOADING NOISE CODE

An alternative simple prediction technique, makes use of the Garrick and Watkins equations [2], which only considers the steady load noise (the noise due to the force on the fluid). It is assumed that the thickness noise (volume displacement) contribution is small and is thus ignored. The acoustic sources are again distributed on the entire propeller disc. Each source on the propeller disc travels rectilinearly. A simple geometrical construction is used to obtain the source position at the emission time and the relative position of the source relative to the observer. The pressures at the observer points due to the thrust and torque loading on the propeller blades are calculated and summed.

For a contra-rotating propeller, the Garrick and Watkins equations have to be modified to take into account the two propellers rotating in opposite directions [3].

3.0 RESULTS

A few simple test cases using the two techniques [3,4] have been undertaken. These predict the SPL at a number of observation points using both the single and contra-rotating propellers under typical operating conditions in the free field at the fundamental blade passing frequency. The results have been found to be similar. The thickness noise contribution is small at the fundamental blade passing frequency which justifies its exclusion in the total SPL calculation.

The prediction is extended to estimate the SPL on a full scale aircraft fuselage surface. Figure 1. shows the British Aerospace fuselage rig used for the cabin noise control theoretical and experimental research work. Figures 2a and 2b give the free field SPL at the observer points on the fuselage surface (the middle fuselage section includes the wing box and undercarriage bay) predicted using the Dowty codes and G&W/SYSNOISE method respectively at the fundamental blade passing frequency under a typical contra-rotating propeller operating condition. The predicted trends and levels are very similar. Figure 3 shows the thickness noise contribution, note the level is low compared with that due to the steady load noise which reafirms the decision to ignore the thickness noise in this particular calculation (contra-rotating propeller).

The simple alternative prediction technique, which employs the G&W equations and SYSNOISE, has been used to predict the SPL on the fuselage surface (rigid condition) and a typical result excited by contra-rotating propeller is shown in Figure 4. By including the surrounding environment such as ground reflection, the maximum predicted SPL has increased by about 2dB as given in Figure 5. Two maximum SPL peaks have occurred and the contour shapes are very different from those with only a single propeller excitation (Figure 6 and 7) [4]. All the above comparisons are conducted with contra-rotating propeller having a kissing angle of zero degrees (relative to T.D.C).

Since the thrust and torque of each propeller blade element are constant with varying kissing angle, the current Garrick and Watkins equations used in conjunction with SYSNOISE cannot predict the change of SPL. As a result of this, an investigation was carried out to try to establish the effects of varying kissing angle on the predicted SPL.

Various kissing angle settings were used and the SPL predicted at a number of observation points. A simple relationship has been obtained between the variation of kissing angle and the predicted SPL [3]. This enables the SPL with different kissing angle to be predicted using the SYSNOISE modelling philosophy.

4.0 CONCLUSIONS

The sound pressure level at the observer points on a full scale aircraft fuselage surface using a single and contra-rotating aircraft propeller under representative operating conditions have been predicted using SYSNOISE and the Dowty Aerospace Propeller SUCCI codes. The predicted SPL contour shapes are very different for the free field and rigid fuselage conditions, with and without reflection from the surrounding environment. The relationship between predicted SPL and kissing angle has also been found. This enables the SPL to be predicted using the SYSNOISE modelling philosophy.

ACKNOWLEDGEMENTS

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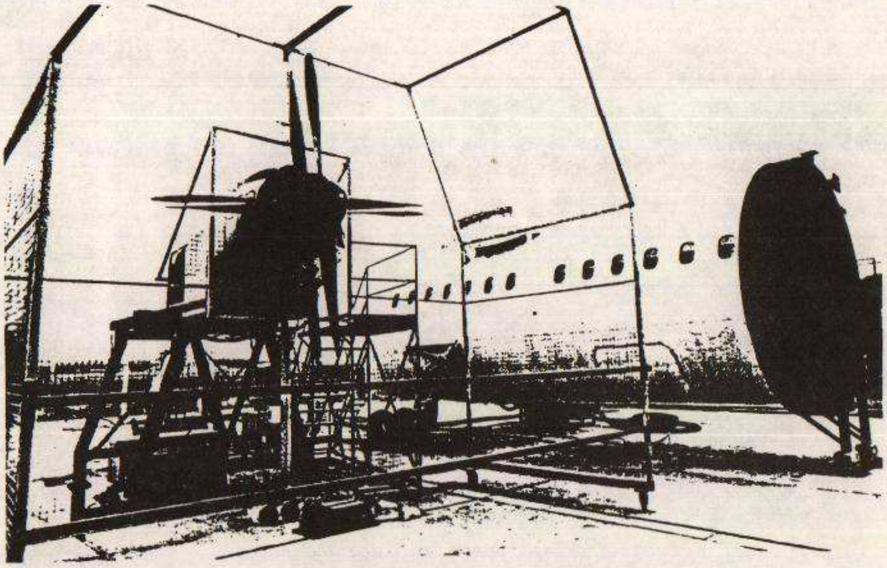

Figure 1 Fuselage rig used for noise control work

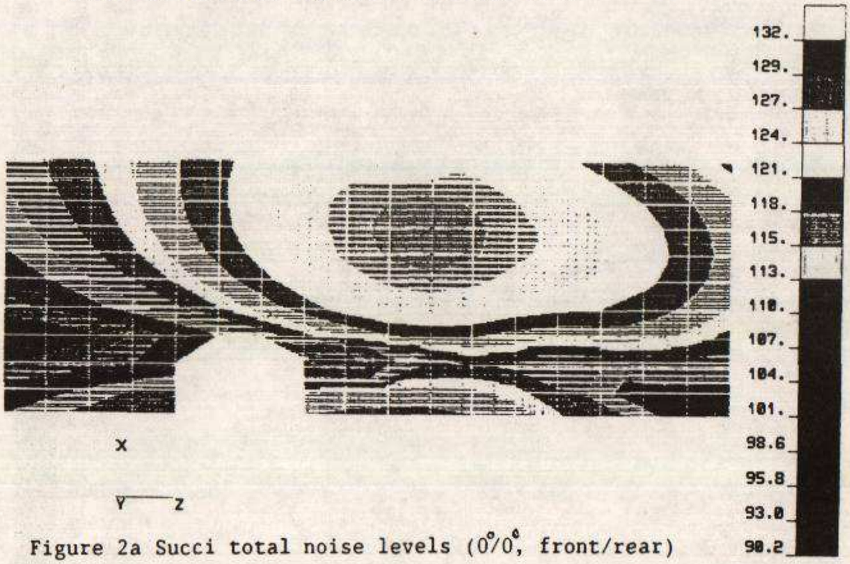

Figure 2a Succi total noise levels (0°/0°, front/rear)

SOUND PREDICTION ON AN AIRCRAFT FUSELAGE

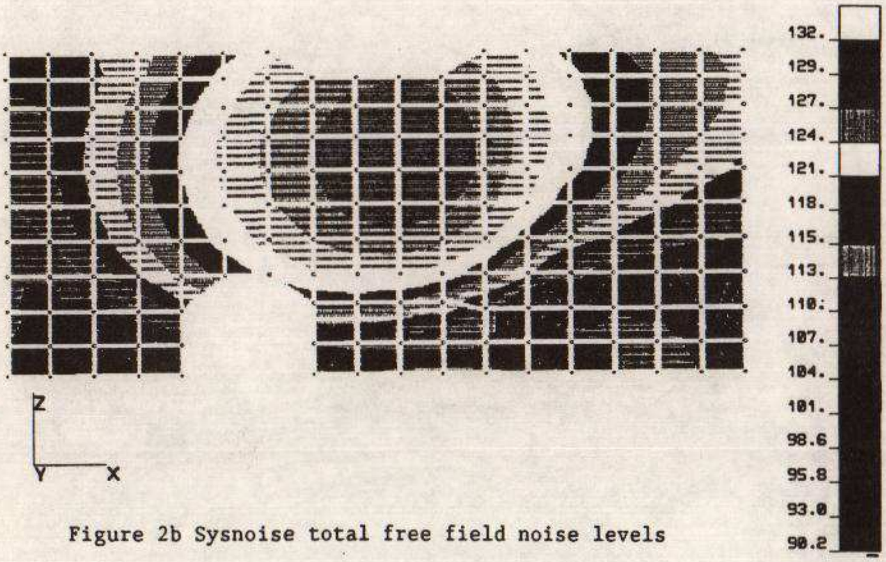

Figure 2b Sysnoise total free field noise levels

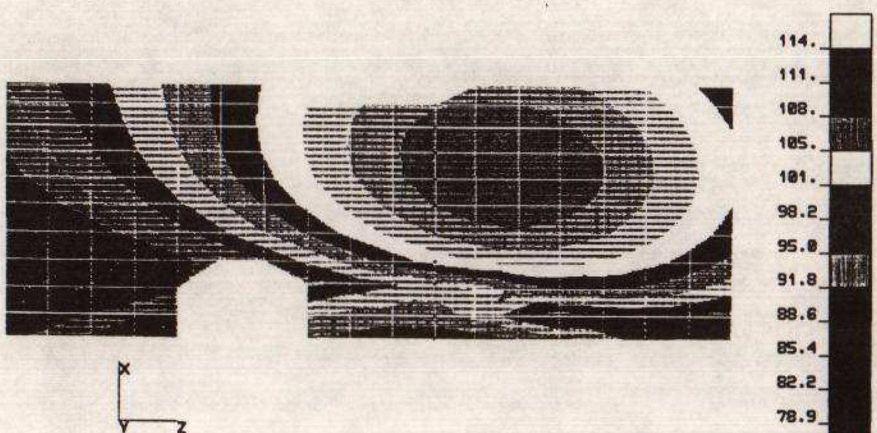

Figure 3 Succi thickness noise levels

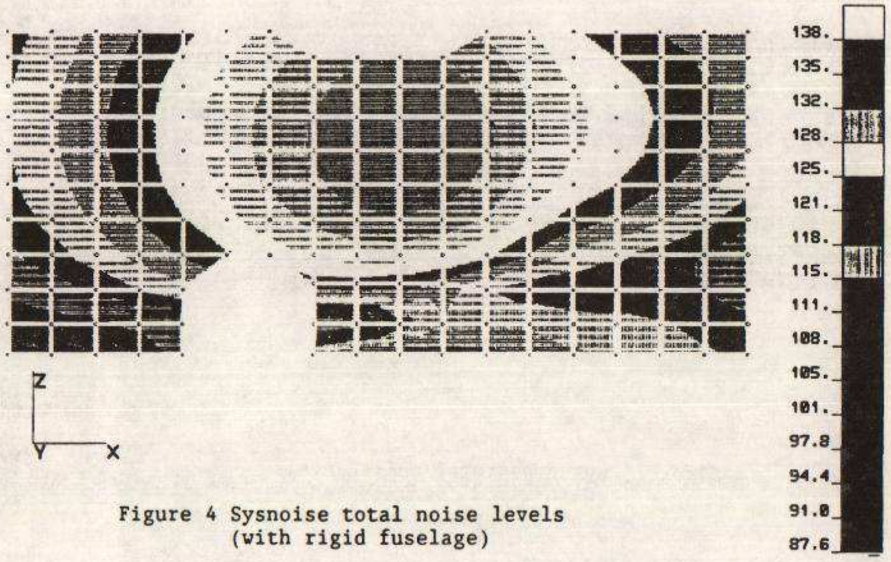

Figure 4 Sysnoise total noise levels
(with rigid fuselage)

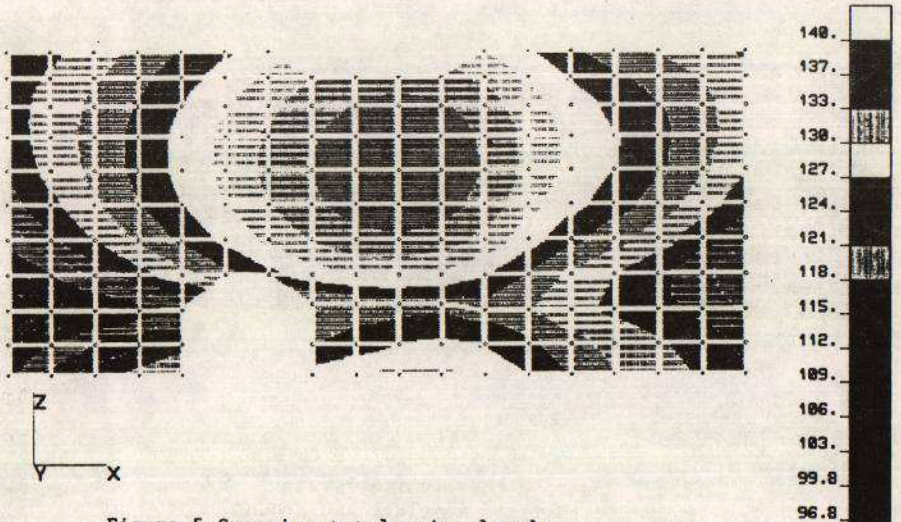

Figure 5 Sysnoise total noise levels
(with rigid fuselage and ground)

SOUND PREDICTION ON AN AIRCRAFT FUSELAGE

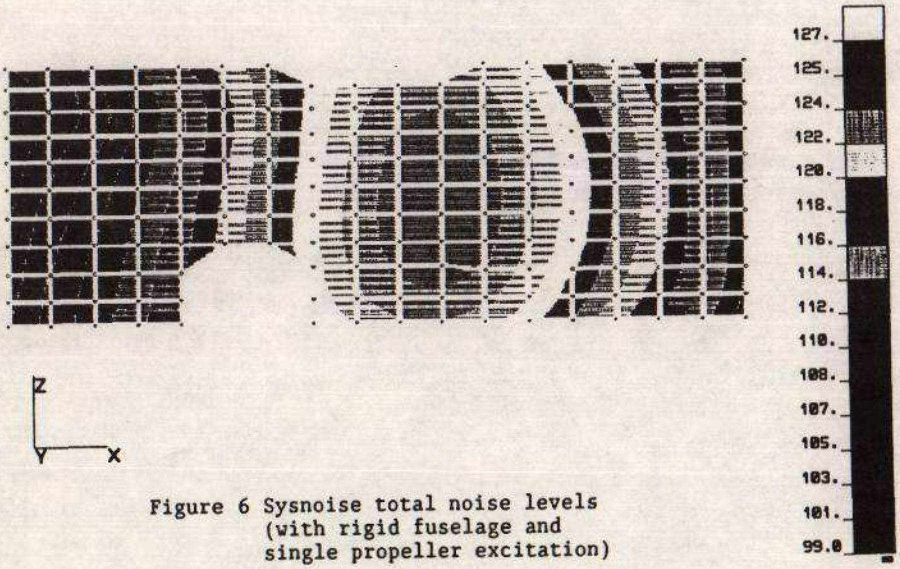

Figure 6 Sysnoise total noise levels (with rigid fuselage and single propeller excitation)

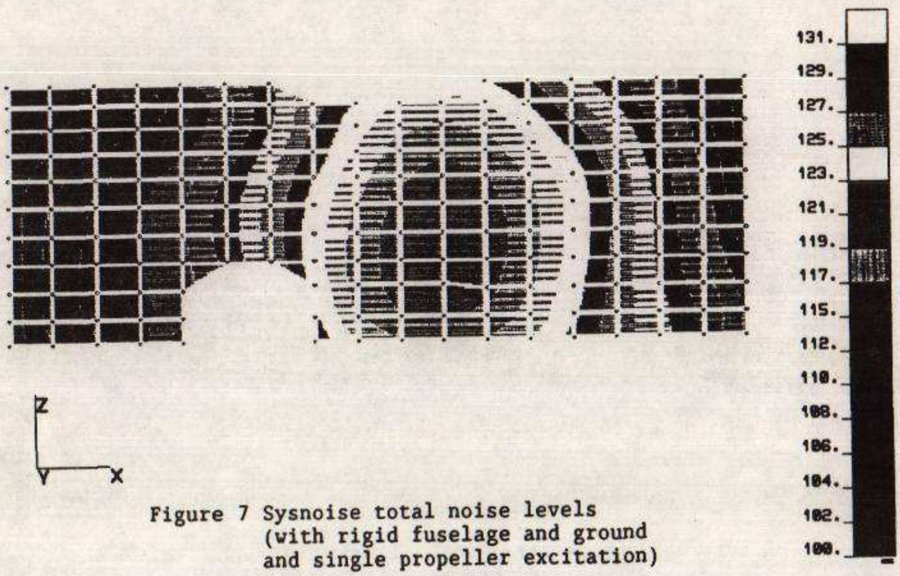

Figure 7 Sysnoise total noise levels (with rigid fuselage and ground and single propeller excitation)