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Noise and Vibration in Transport

Design for acceptable Aircraft Vibration

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1. Introduction

During the design of an aircraft the vibration characteristics of the structure have to be assessed for several reasons. The primary concern is for the integrity of the structure. Usually the assessment of the acceptability of an aircraft for crew and passenger comfort has, in the design stage, been a secondary consideration and these problems have been dealt with after the aircraft has been built.

I will confine my paper to my experiences on aircraft designed at Hawker Siddeley Aviation, Hatfield, which incorporates the former de Havilland Aircraft Company.

2. Past Problems

a) Flight Vibrations

One of the earliest Pilot vibration problems that I can recall occurred on the de Havilland 110 in the early 50's. The test pilots complained of a lateral vibration when in turbulence which was likened to flying a jelly. The aircraft could be flown safely but it was considered unacceptable by the Company pilots. The problem was cured by stiffening the tail booms, and no further complaints arose.

The next problem of a similar nature arose on the Comet III. Complaints of unpleasant vibration, when flying in moderately turbulent air and during landing approach, were made by the pilots. Measurements of the vertical vibrations in the cockpit were made and these showed that the predominant frequency was 4.1 to 4.3 Hz with peak accelerations of ±0.5g and general levels of ±0.2 to 0.4g. It was decided to stiffen the front fuselage by the addition of a 12 s.w.g. sheet, 5ft. wide and 20ft. long, on the top surface. This increased the frequency by 10% to 4.5 Hz and the amplitude in the cockpit was reduced by 20%. This modification involved a weight penalty of approximately 150 lb. and resulted in the aircraft being acceptable to the crew.

When the Comet IV B was designed the front fuselage length was increased by a further 7ft. and a weight penalty of approximately 100 lb. for stiffening purposes was included.

The Trident in its various versions has since been built. This aircraft is quite acceptable in turbulence from the pilot and passenger comfort point of view and, as predicted, no additional fuselage stiffening has been necessary. Figure 1 shows a comparison of the front fuselage characteristics of the Comet and Trident variants.

b) Runway Response

It was clear after the first few flights of the Trident 1 in 1962 that the runway response was unacceptable. Measurements of acceleration at the pilots station and top and bottom of the nose and main undercarriage were made at taxi speeds of up to 90 knots. Analysis of these records showed pilot accelerations of up to ±.4g at 5.5 Hz compared to acceptable levels of ±.3g at 4.5 Hz for the Comet IV C. From these measurements it was concluded that this vibration was caused by large forces produced at the main undercarriage due to friction. A new levered suspension main undercarriage which would reduce friction levels was designed. Taxying trials with this new undercarriage proved satisfactory. Figure 2 shows a comparison of the acceleration levels experienced at the pilot's seat, for the fuselage bending mode, before and after modification and a comparison with the Comet level.

All subsequent Tridents have been acceptable until the long bodied Series 3B which is about to enter service now. On this aircraft minor modification of the undercarriage characteristics were needed to give an acceptable ride.

3. Simulation

In order to obtain information to assess the acceptability of the calculated response for various projects, a literature survey was made in 1962. This revealed that at the time, although work on human response to low frequency sinusoidal vertical vibration had been reported, there was little evidence of results for sinusoidal lateral vibration. Work on random vibration and acceptability seemed to be non-existent. It was therefore decided to carry out vibration tests. Accordingly a moving seat test rig was constructed and used to judge the acceptability of certain designs by simulating the response to low frequency sinusoidal and random vibrations. Later work of a more general nature was also attempted, to provide background information that was lacking at that time (see Ref.1.).

Flight records of pilot seat accelerations in turbulence were played back through the ground simulation system to check the realism and provide comparisons with acceptable situations. This work proved extremely useful and, in particular, subsequently allowed the design of the Trident 3B to proceed without the weight penalty of additional fuselage stiffening.

In the early design stage of the Trident 3B analogue simulation was used to estimate the nose wheel bounce during take-off.

As a result the nosewheel oleo was redesigned to have a double stroke so that the stiffness characteristics depended on the nosewheel load and were suitable for low take-off and high landing nosewheel loads.

During the initial flying there was no complaint regarding bounce but the cockpit vertical acceleration while taxying and on take-off was uncomfortably high. Levels of up to ±0.5g at the fuselage bending frequency of 4.66 Hz were recorded when taxying. It was decided to simulate this problem.

It was concluded from these tests that:-

1. The levels of vibration experienced during taxying could be caused by running over quite small discontinuities.

2. The forcing was proportional to the effective tyre stiffness.

3. Only 10 to 25% of the structural vibration was produced by forcing through the nosewheel.

Modifications were carried out to reduce the extension damping of the main undercarriage for small movements, and tests on the aircraft indicated satisfactory runway response.

4. Acceptability

It is obvious that more severe vibration conditions can be expected to be tolerated by passengers on taxying, take-off and landing where the duration is shorter than in flight. Pilots will accept vibration up to levels where the operation of the aircraft is not impared.

If requirements for vibration levels in aircraft are formulated they will have to be much more precise than any that have so far been published. We cannot accept an imprecise criterion that would involve design changes which are not absolutely necessary. Any design change that involves weight increase must be considered in relation to the expected improvement in comfort.

5. Conclusions

Since the Comet III problems in 1956 all new aircraft at Hatfield have been assessed in the design stage for comfort on the runway and in flight. I have discussed the few cases in which problems have shown up after first flight and in all cases these have been cured.

If a marginal vibration problem can be cured by stiffening the aircraft structure, with a corresponding increase in weight, then it is very necessary to consider the increase in comfort in relation to the reduced payload that will result.

Although no discomfort due to engine vibration has been experienced on the Comets or Tridents, this could become more of a problem in the future. I am thinking particularly of VTOL aircraft where there will be many lift engines operating for short periods. The correct mounting of these engines will require detailed calculations in the design stage.

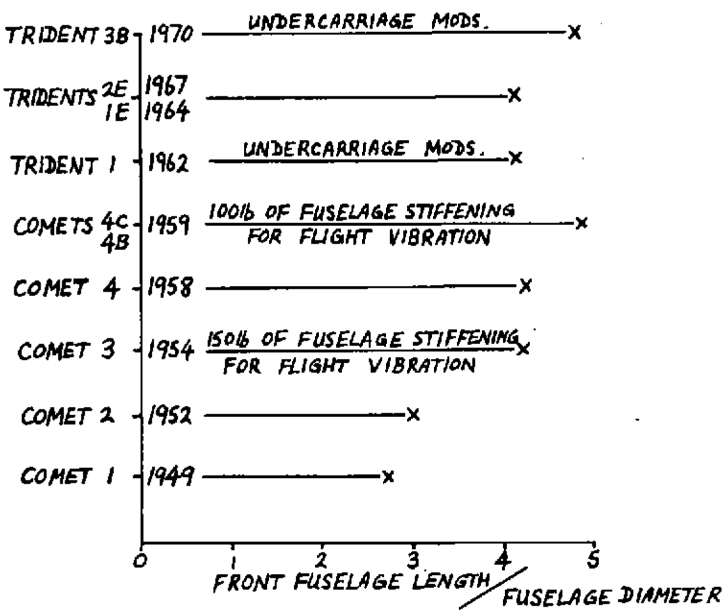
Accurate criteria for comfort are still lacking and there is a need for the measurement and analysis of acceptable vibration levels on aircraft in service.

Reference

1. A. G. Woods — Human response to low frequency sinusoidal and random vibration. Aircraft Engineering. July, 1967.

FUSELAGE COMPARISONS

FIGURE 1.



COCKPIT ACCELERATIONS ON TAXYING AT 50kts

FIGURE 2.