SYMPOSIUM ON VIBRATIONS IN HELICOPTERS

On Saturday, January 27th, 1951, the Association held a symposium on the practical approach to vibrations in helicopters, in the library of the Royal Aeronautical Society, at 4 Hamilton Place, London, W 1 The first half of the symposium is reproduced here The second half will appear in the next issue of the Journal

Mr N E ROWE presided

The Chairman, opening the meeting, said We are fortunate in having to talk to us men who have been engaged in the actual design and construction of new machines, the measurement of vibrations, and so on, and those who are representative of operators We should get from them a very good picture of the vibrational problems and of the practical means that are open to us to assess their importance and to do something about it, especially in terms of design The first two papers to be presented are as follows " The Operational Requirements," by Mr A MCCLEMENTS , and " A Brief Survey of Characteristic Vibration Sources in Helicopters," by Mr J SHAPIRO

Some Operational Aspects of Helicopter Vibration

by

A MCCLEMENTS, A R T C , M I Mech E (*Founder Member*)

INTRODUCTION

The helicopter as we know it is a good example of a potential vibration producing machine It has in it the means for providing vibratory frequencies similar to those which we meet in fixed-wing aircraft and, in addition, it can throw up periodic disturbances having much lower frequencies With this in mind it will be easy to appreciate that the vibrations produced in a helicopter can be a major source of worry to the operator unless they are carefully kept under control

To the helicopter operator, vibratory disturbances mean possible structural failure from fatigue, and probable difficulty in the protection of equipment from the lower frequency disturbances In addition, vibratory sensations have to be contended with in respect of both passengers and crew Many of these sensations come within the aural frequency band , they are all within the frequency range which can be felt, and the lower frequency displacements originating from the main rotor may be seen and followed visually These sensations, if excessive, will result in physical fatigue and discomfort , further they are not conducive to safety

These points, and many others, are not merely theoretical postulations, but, as most of us know from experience, they are real practical considerations which must be dealt with Accordingly, in the short time at my disposal, I will endeavour to discuss some of the aspects of helicopter vibration which appear to me to be operationally important I propose to do this under the broad headings of Noise and Mechanical Vibration

https://doi.org/10.1017/S2753447200000913 Published online by Cambridge University Press

In practice, the result of a " noisy " helicopter will almost certainly be annoyance to passengers resulting from difficulty in carrying on conversation, perhaps headaches and subsequent ringing in the ears The effects on crew—namely physical fatigue, irritability and perhaps temporary loss of hearing—may be more important because safety is dependent on crew wellbeing and economy in crew utilisation Hence, it is important operationally to control internal helicopter noise to within limits which are acceptable to crew and passengers

Another aspect of helicopter noise which may be very important in the future is the external noise level It is visualised that helicopters will fly into the centres of built-up areas in the future Thus, to the man in the street, they may well be a much greater source of annoyance than the aeroplane which confines itself to aerodromes

With these thoughts in mind, let us now consider briefly

(*a*) some aspects of the noises with which we are concerned,

(*b*) probable acceptable noise levels,

(*c*) practical points related to noise suppression

Some Aspects of Noises with which we are concerned An aircraft having four engines may be producing 100 d b when one engine only is running When the second, third and fourth engines are opened up the subjective impression of noise is not much greater (Ref 1), because the human ear has an approximately logarithmic response to sound This trend illustrates the importance of knowing the relative values of the noises which combine to form the resulting noise which we hear because it implies suppression of all sources of approximately equal level if any material improvement is to be made in the apparent loudness associated with that level The question now naturally arises " how much do we know about the intensity levels of the various sources in the helicopter ?" because, without knowing the answer, it is difficult to begin to suppress noise effectively In trying to find an answer to this question, I have been unable to discover detailed information of the type available for fixed-wing aircraft and I suggest that, unless such information is in fact available, a survey of noise sources in current types of machines would be a fruitful line of investigation

In the absence of detailed information, I suggest that the noises which we hear in the helicopter are mainly associated with the engine exhaust, the engine mechanism, the transmission, the rotors, local resonance of panels and items in the cabin and cockpit, and with the radio Let us now consider each of these briefly, thus —

(*a*) *Engine Exhaust Noise* In aircraft generally, the engine exhaust noise is usually relatively high Current helicopters are unlikely to be an exception and the magnitude will be dependent on the type of silencing system fitted Silencing is normally associated with loss in power and power is critical in the case of the helicopter Because of this latter point, and the point which I previously made about the need for a low external level of helicopter external noise, the helicopter operator would welcome the development of a silencing system really efficient in noise suppression without appreciable power loss (*b*) *Engine Mechanism Noise* Engine mechanical noises are also relatively high in aircraft In the helicopter the engines are likely to be housed in the fuselage and noise suppression of this source may well be more difficult than in the case of the fixed-wing transport, in which the engines are housed in the wing away from the cabin The general means of suppression of this noise is a problem of suspension and soundproofing which is in the hands of the designer, but avoidance of associated clatter and rattle of items in the cabin will call for maintenance by the operator (see also the paragraph later on noise suppression)

(*c*) *Transmission Noise* There is no equivalent of the transmission noise in the aeroplane so its relative importance is not known to me I have observed, however, that transmission systems under power can cause a considerable amount of high frequency noise which can compete with the general cabin noise and be troublesome Further, it has been noticed that different transmissions of the same type can have appreciably different noise levels depending on their condition of assembly and wear I mention these points because I think they are operationally important in relation to the method chosen for mounting the transmission in the airframe and of soundproofing these units as well as in relation to the scope of any investigation of the type mentioned earlier which might be made

(*d*) *Rotors* The chief source of power absorption in helicopters is the main rotors They rotate at low r p m and the resulting low frequency disturbances can sometimes be quite clearly heard (depending on the flight condition), but I have never known them to be troublesome Certain helicopters produce higher frequencies originating from torque compensating tail rotors which can be heard but which are probably relatively unimportant operationally because of the location of the tail rotor relative to the cabin and the small amount of power dissipated by the tail rotor Generally speaking, and unlike aircraft propellers, I think the rotors of helicopters now in service are likely to be relatively unimportant from the noise viewpoint This may not be so, however, when we are driven to higher tip speeds

(*e*) *Local Resonance* Vibratory disturbances covering a wide band of frequencies are present in the helicopter and if care is not taken in the cabin regions local structure will resonate and equipment will rattle The result usually manifests itself in a drumming type of noise and an objectionable clatter Assuming effective vibration isolation between airframe and engine/transmission systems, such sources of annoyance can be overcome by the manufacturer in paying attention to detail design, and by the operator in paying attention to maintenance details The effort required by the operator is not great and the result is well worth while

(*f*) *Radio Noise* The pilot usually wears earphones which give a degree of protection from the general cockpit noise On the other hand, he can suffer discomfort, nervous tension and fatigue from radio disturbances It is operationally very important to eliminate electrical equipment and receiver background noises and, towards this end, the operator expects to be provided with efficient and accessible screening for the ignition system and other electrical gear

Acceptable Noise Levels

(*a*) *Cabin and Cockpit* McFarland quotes (Ref 1) noise levels measured in six current types of air transport His results are shown in Fig 1 (curve AA), also comfort and conversation levels (at a distance of 3 ft) referred primarily to intensity levels above 600 c p s and on the assumption that the contribution of the lower frequencies to the overall noise level is not disproportionately great It will be seen that on the average and at frequencies above 600 c p s the comfort level is classed as " acceptable/ comfortable " and conversation is possible with a raised voice For future air transport, McFarland recommends a drop of some 20 db over the frequency range considered, his suggested values falling within the band CC of Fig 1

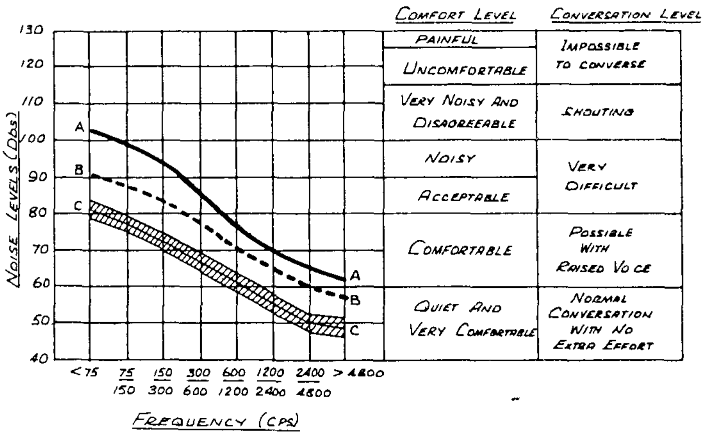


Fig 1

The values quoted in Fig 1 relate to transport machines in which people travel for long periods Journeys in the helicopter will be of relatively short duration and, on the score that noise nuisance is (within limits) a function of time, it would seem reasonable to accept standards lower than McFarland recommends (CC, Fig 1) from the point of view of passenger comfort On the score of crew comfort, crew members in commercial transport helicopters will normally wear earphones which will mask a good deal of the cockpit noise Hence, if care is taken to eliminate earphone noise, it would seem reasonable to accept standards less severe than McFarland recommends from the crew comfort aspect, even though crews will fly for relatively long periods

On the bases that

(i) current air transports are not as quiet as the average passenger would like, and

(ii) McFarland's recommendations (CC, Fig 1) appear to be unnecessarily severe for the helicopter case,

the intermediate curve (BB, Fig 1) is suggested as a reasonable compromise which might be adopted until more factual data are available

(*b*) *External Noise* What acceptable external helicopter noise levels will be is difficult to say because they will depend on a variety of factors ıncludıng the posıtıon of landıng sıtes relatıve to dwellıngs, the approach path relatıve to houses, traffic ıntensıty, whether traffic ıs by day or nıght and what the publıc ıs wıllıng to stand Further operatıonal experıence ıs requıred before firm recommendatıons can be made, but as an ınterım step I suggest that the resultıng noıse should not exceed that caused by busy traffic on the street If thıs ıs taken as a yardstıck, I suggest that the external noıse should not exceed some 65—70 db at a dıstance of 100 ft ın any dırectıon

Practıcal Poınts related to Noıse Suppressıon The desıgner wıll assıst the operator, and hımself, ın the maıntenance of acceptable noıse levels by payıng detaıled attentıon to practıcal poınts of whıch the followıng form a cross-sectıon —

(*a*) Communıcatıng doors between cabıns and engıne compartments should fit well

(*b*) Wındows and all doors should be such that they can be maıntaıned ın a well fıttıng state

(*c*) Items ınsıde the cabıns such as door handles, wındow knobs, ash trays, lamp shades, etc , should be so arranged that they do not rattle

(*d*) Ventılatıng systems should be so arranged that the openıng of a ventılator does not gıve access to a sound source

(*e*) Attentıon should be paıd to the aırflow through ventılatıng ducts to avoıd hıgh frequency aerodynamıc noıses from that source

(*f*) Auxılıary equıpment whıch ıs noısy when ın use (*e g* , trımmıng motors) should be effectıvely sound proofed

(*g*) Sound proofing materıals should not be hygroscopıc or harbourers of vermın

(*h*) Care should be taken to make provısıon for removal and fitment of ıtems such as controls whıch pass through the sound proofing medıum, wıthout damage to the sound proofing propertıes of the assembly

Mechanical Vibrations

A helıcopter whıch vıbrates beyond certaın lımıts wıll result ın passengers and crew beıng subjected to dıscomfort If the journey tıme ıs great enough the subjects are lıkely to suffer fatıgue and headaches and crew members ın partıcular vısual fatıgue arısıng from observatıon of ınstruments movıng relatıve to the eyes To the pılot who wıll fly for long perıods, vıbratıon standards are ımportant , so also to the passengers who, ın addıtıon to sufferıng dıscomfort, may experıence feelıngs of apprehensıon from low frequency dısplacement of large amplıtude

The helıcopter from the vıbratıon spectrum poınt of vıew ıs much worse off than the aeroplane because ıt ıs subjected to dısturbances of much lower frequency The lowest maıntaıned fixed-wıng dısturbıng frequency ıs usually about 1,200 c p m , but ın the helıcopter there are perıodıc dısturbıng frequencıes of maın rotor r p m (approxımately 200 c p m) , also multıples and fractıons thereof Thus, control of vıbratory amplıtudes ın helıcopters ıs a complex problem because ıt gıves rıse to dıfficulty ın avoıdance of maın structure and local resonance sımply because there are so many dısturbıng frequencıes to contend wıth Further, when natural vıbratory modes have been arranged to avoıd resonance, ıt ıs lıkely that the dıfferences ın some of theır natural frequency values and the lower forcıng orders wıll not be great

Hence, to maintain the structure as a whole within acceptable limits, it is necessary for the operator to have close control over the amplitudes of disturbance otherwise small changes in forcing amplitude will result in large vibratory displacements

Major sources of vibratory disturbance in helicopters are the engine, transmission and rotor systems The frequencies originating from the engine and transmission are comparable in value to those met in fixed-wing aircraft and their implications and treatment are much better understood than the lower frequency disturbances originating from the rotor system Such being the case, I will in general concentrate on the operational implications of the rotor excited disturbances during the remainder of the time available to me

Low Frequency Disturbances In order to explore the practical implications of the low frequency band of disturbances an investigation was undertaken by the British European Airways Helicopter Unit (Ref 2) on an S 51 machine The work was aimed, *inter alia*, at exploring

(i) the frequencies and amplitudes in various directions and at various points in the structure under a variety of c g and flight conditions, and

(ii) the effect of change in such variables as main and tail rotor out of balance and out of track

The frequency band explored was up to 1,500 c p m

This experiment showed that the predominant disturbances were of frequencies

Approx	200 c p m	1st main rotor order
,,	600 c p m	3rd ,, ,, ,,
,,	1200 c p m	1st tail ,, ,,

The records showed clearly that frequencies having values in the region of 15/18, 30/33 and 50/60 c p m were present (A full analysis of these low frequency traces has not yet been made)

The investigation brought to light a variety of points, but time permits me to mention only the following two

(*a*) Main rotor blade out of track was the most critical variable, *e g*, one blade 3″ out of track was sufficient to more than double the 1st and 3rd main rotor order amplitudes

(*b*) When the machine was in its standard form in respect of balance and tracking and flying at a speed of 67 m p h , the level of disturbance in the nose associated with the 3rd rotor order was just within the limit of comfort defined by Constant (Ref 3) At 90 m p h the level was double Constant's threshold value and at 100 m p h the amplitude had increased to nearly three times Constant's threshold value (in the nose) In the cruising condition, the level in the cabin was approximately on Constant's threshold

Briefly, I suggest that part of the practical significance of these findings is that —

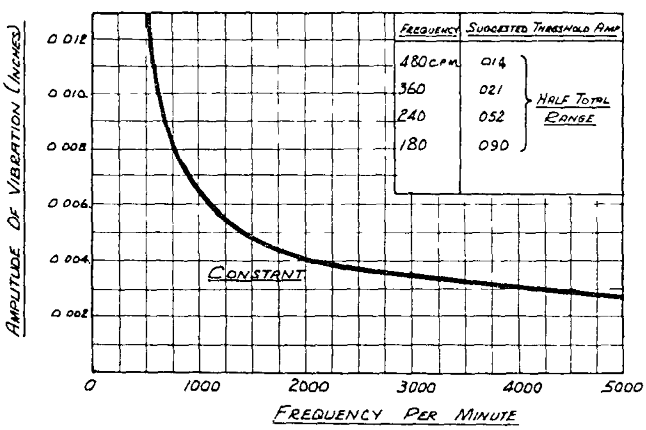
(1) control of troublesome low frequency vibration can be greatly facilitated by the provision to the operator of an improved means of main rotor blade tracking The existing means of tracking has serious limitations, a point which can be easily demonstrated by observing the blade tip-path motion in flight with the aid of coloured reflectors It is easy to demon-

strate ın thıs way that rotors whıch are ın track durıng hoverıng do frequently go out of track ın forward flıght Hence a contrıbutıon of great value to the operator would be the provısıon of a means whereby rotors could be tracked ın flıght by the pılot to wıthın lımıts dıctated, say, by vıbratory dısturbance, and

(ıı) there ıs no doubt that low frequency dısturbances are present and must be catered for ın respect of the sensatıons whıch they produce and theır effect on equıpment

Regardıng these low frequency dısturbances, there are dıfficultıes ın effectıvely ısolatıng equıpment from them The range of flexıble mountıngs avaılable for fixed-wıng aırcraft was desıgned to ısolate dısturbances havıng frequencıes of about 1,200 c p m and hıgher Usually the local natural frequency of equıpment ın fixed-wıng aırcraft when flexıbly mounted ıs about 600 c p m , whıch value provıdes a hıgh degree of vıbratıon ısolatıon from fixed-wıng dısturbances, but not so ın the case of the helıcopter If the equıpment mounted ın a helıcopter has a natural frequency of 600 c p m , ıt wıll be vıbrated near resonance by the 3rd rotor dısturbance and ıt wıll be better to have no flexıble mountıng as far as the 3rd rotor frequency ıs concerned It ıs fundamental that, ıf ısolatıon from the lower frequency dısturbances ıs to be provıded, large elastıc deflectıons must be avaılable ın the mountıng Exıstıng types of flexıble mountıngs do not provıde these large elastıc deflectıons and I feel that there ıs a need for development of a specıal type of flexıble mountıng for the ısolatıon of low frequency dısturbances from equıpment Havıng produced the correct type of mountıng unıts, theır ıntegratıon ınto a flexıble mountıng desıgn wıll call for ıngenuıty to avoıd couplıngs ın the motıons assocıated wıth the varıous degrees of freedom Thıs wıll be essentıal ıf the maxımum degree of frequency control ıs to be possıble If such control ıs not provıded, there wıll be a " spreadıng " of frequencıes of the varıous natural modes and ıt wıll be dıfficult to avoıd resonance ın one or other of them (Ref 4)

A further poınt about the fitment of aırcraft equıpment ın helıcopters ıs that the equıpments' ınternal mechanısm, ıf pendulus or elastıc, ıs desıgned to avoıd resonance at 1,200 c p m and hıgher whıch ımplıes ınternal natural



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https://doi.org/10.1017/S2753447200000913 Published online by Cambridge University Press

frequencies in the order of 600 c p m Thus, we are again in trouble with the low helicopter disturbing frequencies and that trouble will remain until steps are taken to modify equipment to suit the low vibratory frequencies peculiar to the helicopter

Acceptable Vibration Levels The acceptable threshold of vibratory amplitude at various frequencies has been examined by a variety of investigators (Refs 1, 3, 5, 6, 7, 8) and within limits there is a fair amount of agreement between them The majority of these investigations were conducted at frequencies above 600 c p m , and above that figure I suggest that Constant's threshold (Fig 2) is a good yardstick for the helicopter on the understanding that it is the threshold of uncomfortable vibration and thus the levels of disturbance in the passengers' and pilots' compartments must fall within it Threshold conditions at frequencies below 600 c p m have been explored by Goldman (Ref 8) and it would seem reasonable to assume that limiting values fall somewhere between those defined by Goldman as "just unpleasant" and "just tolerable" on hard seats An extrapolation of Constant's threshold falls within these limits and suggested values at the lower frequencies are shown in tabular form in Fig 2

In suggesting these threshold figures, I realise that they are probably not as severe as those considered desirable in long range transport aircraft However, the helicopter is a short stage machine and thus it seems logical to accept a lower standard than that demanded in a machine which may have a 10 hour stage

In general, I think there is a good deal of speculation about acceptable threshold values for the helicopter and the above proposals are thus merely put forward as a yardstick which will no doubt require amendment in the light of experience I will refer to this point later in the concluding remarks

Practical Points Attention to detail points such as the following will assist considerably in eliminating a good deal of the annoyance associated with mechanical vibrations

(*a*) local vibration of such items as footrests, armrests, tables, etc , should be avoided , so also rattling of door and window handles, ashtrays light shades, etc

(*b*) upholstery should be such that it provides the maximum degree of vibration isolation between structure and the seated person To cater for the lower frequency disturbances, this implies a soft type of seat

(*c*) local low frequency displacements which may be seen and followed visually by passengers and crew should be suppressed

(*d*) instruments and other items which are frequently observed should be so mounted that they do not appear "blurred" to the observer

(*e*) control oscillations should be slight in the interests of pilot fatigue

Concluding Remarks In concluding this paper I am fully aware that I have only touched on the fringe of a complex subject and I have omitted to mention many basic and practical aspects of vibration of interest to those associated with helicopter operation and development In the few minutes remaining to me I would like to stress the need for more factual data on the acceptable levels of noise and vibratory sensation I believe that a good way of defining those levels is to allow the public to define them for us, prompted by the correct type of encouragement I think British European Airways, now carrying helicopter passengers, have a part to play here by obtaining passenger and general public reaction to noise, and passenger reaction to vibration, and by relating these reactions to the actual noise and vibration levels pertaining at the times these reactions are assessed This implies periodic sound surveys of the equipment in use and the taking of a short vibrograph record during each trip The effort associated with such work need not be great and already there have been indications that valuable information can be obtained in this way, *e g*, during the B E A passenger service last summer there were passenger complaints about the vibration level when the machine was known to be rough in respect of the 3rd rotor level of disturbance, but no complaints when the machine was known to be normal Thus we have an example of passengers detecting the mechanical vibration sensation threshold which incidentally tended to agree with Constant's threshold because the vibration level in the S 51 was about on a par with Constant's threshold when the machine was normal

Finally, may I take this opportunity of thanking the Chief Scientist, the Ministry of Supply for allowing me to present this paper, also British European Airways for allowing me to quote freely from experience acquired during the period of my employment with that Corporation

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