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ON-SITE VIBRATION MEASUREMENT, DYNAMIC TRACKING AND BALANCING

by

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ABSTRACT

1. Vibration is the destructive force at the heart of helicopter unserviceability. If the vibration is left undetected, expensive and often unobtainable major components are severely damaged necessitating lengthy and costly re-builds and untimely overhauls. If it is detected early, preventive maintenance can be planned. Rotors can be balanced, eliminating the major sources of vibration. Components can be removed before they fail, for specific repairs at low cost.

2. The paper will relate the old and new methods of vibration analysis and tracking, to the current methods. Examples will be given of the effective use of the equipments and techniques showing how the cost of operating helicopters is reduced. The guesswork and uncertainty of rectification-by-elimination is replaced by a positive course of action to cut direct operating costs, reduce down time, eliminate penalty payments, increase availability and hence lead to profitable, dependable and safe operations.

IDEA : THEORY : DESIGN : PRACTICE

3. Helicopter evolution follows the sequence of idea, theory, design, practice. We have heard a great deal about the first three. I will concentrate on the last. Practice. Once the helicopter has left the factory and has been accepted by the operator it is up to the maintenance engineer to keep it flying. Never mind the idea, design or theory. Keep it flying, keep it safe, make it make money, not eat it. They are very good at eating it; not so good at making it.

4. My task today is to show how we can cut the direct operating costs of helicopter operations. The major enemy in this battle is vibration. This powerful force is insidious, creeping up on us by day and night. It attacks our vital parts with rapier-like precision and penetration. Yet our bodies cannot feel all but the most obvious. Artificial horizons, compasses, avionics, rod ends, bearings and even the very fabric of the structure - skins, frames, stringers and diaphragms - fall to its attacks. The tell-tale cracks appear in our armour. We can either dream up stronger and thicker repair schemes,

fit doubler plates, go up a gauge, use steel, or we can tackle the problem at source and reduce the forces which excite the enemy. Using the former techniques we contain the local skirmish, but the enemy always breaks through elsewhere. Our enemy thrives on out-of-balance forces often beyond our range of detection. He wages a psychological war, inflicting damage apparently unrelated to an overt cause.

5. I suggest we follow the first principle of war - Selection and Maintenance of the Aim. My aim is to measure and locate the sources of vibration in a helicopter and where possible, to eliminate them.

SOURCES OF VIBRATION

6. From where do vibrations emanate? Here are some of the causes:

a. Mass unbalance of main and tail rotors, compressors, turbines, shafts, pumps, generators.

b. Looseness in linkages, anchor points, mountings, couplings.

c. Misalignment of shafts, pulleys, gears.

d. Backlash in gears, poor tooth meshing, defective gear teeth.

e. Rotors running out of track or with unequal angular spacing between blades. (I will refer to this as out-of-phase).

METHODS OF DETECTION

7. Flag Tracking: I will not dwell on flag tracking. This method is severely limited because it can only be done on the ground. Hence we cannot detect a blade which climbs with airspeed relative to its neighbours. Also we cannot detect uneven spacing between blades. (Tower testing of rotor blades has similar limitations). Thus we cannot assess the serviceability of the dampers.

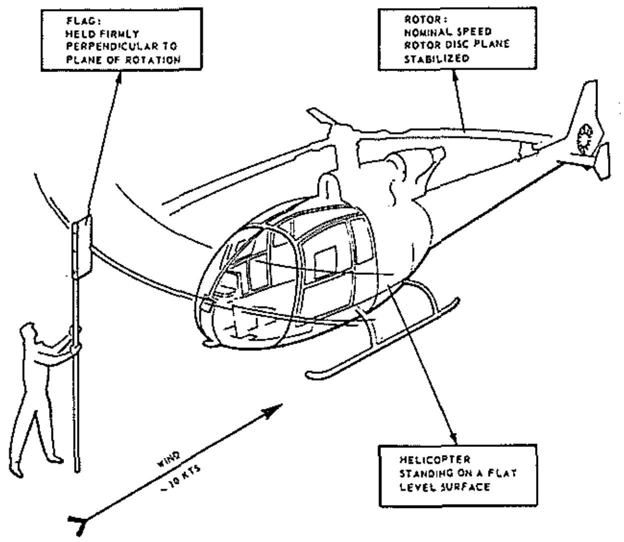


Fig. 1: Flag Tracking

8. <u>Hand Held Vibrograph.</u> The clockwork driven hand held vibrograph was the first step towards analysing the sources of vibration. However, a trained operator could only discern about 3 or 4 frequencies by this method (Fig. 2) after a laborious graphical analysis when he returned to his office.

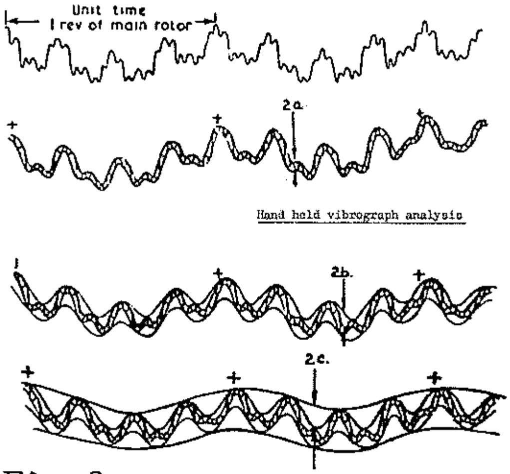


Fig. 2

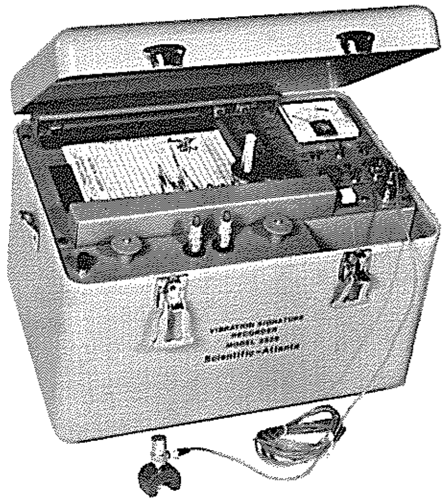
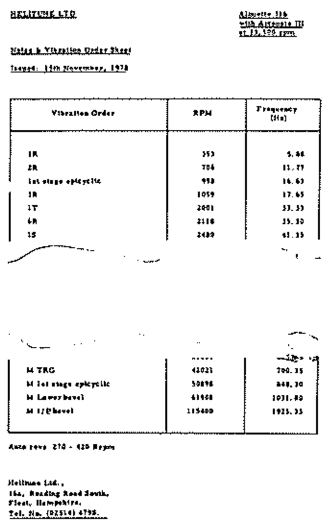


Fig. 3

SCIENTIFIC ATLANTA VIBRATION SIGNATURE ANALYSER

9. The Scientific Atlanta vibration signature analyser SA2538 (Fig. 3), widely used by the Services and civil helicopter operators, is a very powerful maintenance tool. It gives a hard copy read out in one minute, for the press of one button. The helicopter's vibration signatures in the hover, at mid-speed and at cruise, are recorded in the vertical, lateral and fore and aft planes. Nine cards in all. We can record 0-100 Hz (covering main and tail rotor frequencies) or 0-1500 Hz (for high orders, e.g. gear meshing frequencies). By relating the peaks back to a vibration order sheet (Fig. 4) we can pin point the sources and choose our tactics to reduce or eliminate them. This cuts out the time wasting, the guesswork, the needless changing of components familiar in trial and error methods. "No fault found" cases vanish. We can rectify with confidence.



HELITUNE LTD

Noise & Vibration Order Sheet

Issued: 15th November, 1978

Vibration Order	RPM	Frequency (Hz)
1R	353	5.88
2R	706	11.77
1st stage epicyclic	998	16.63
3R	1059	17.65
1T	2001	33.35
6R	2118	35.30
1S	2489	41.15
M TRG	42021	700.35
M 1st stage epicyclic	50898	848.30
M Lower bevel	61908	1031.80
M I/P bevel	115400	1923.33

Auto revs 270 - 420 Rrpm

Helitune Ltd.,
1[illegible], Reading Road South,
Fleet, Hampshire.
Tel. No. (02514) 4795.

Fig. 4

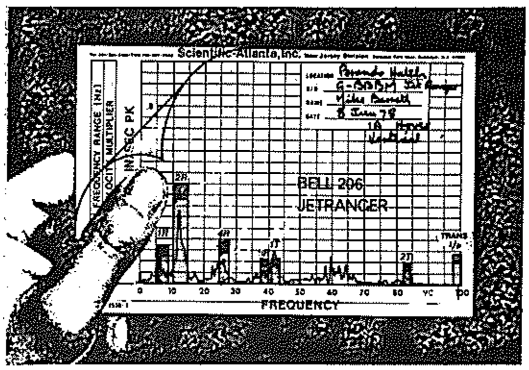


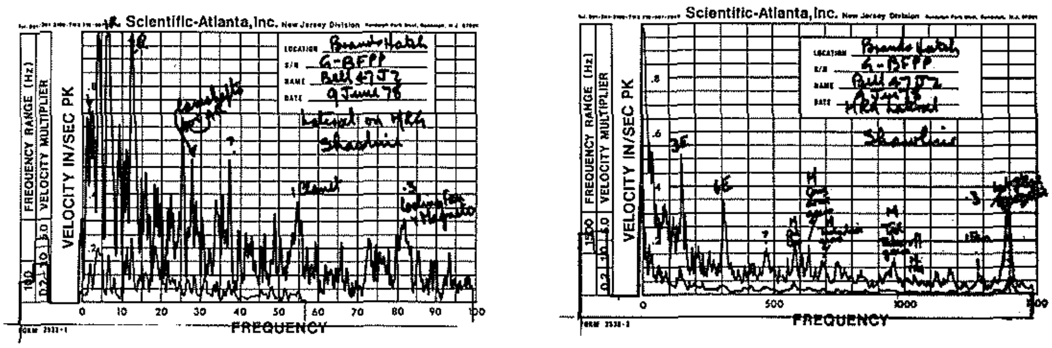
Fig. 5

Limits can be set for each peak (Fig. 5):

a. <u>Yellow.</u> No maintenance action required.

b. <u>Red.</u> Maintenance action required to prescribed procedure within a given time.

c. <u>Above Red.</u> Maintenance action immediately.



<u>Fig. 6</u>

10. Here are some examples:

a. <u>Bell 47J2 Main Rotor Gearbox.</u> (Fig. 6). These cards show the extremely unhealthy state of the gearbox. Almost every gear and shaft is showing damage with the 1st stage epicyclic the most worrying. After dismantling the box the following faults were observed:

(1) Lower sun gear alignment bearing spinning.

(2) Clutch shoes worn out.

(3) Clutch bearing U/S.

(4) Fan drive gear teeth severely pitted.

(5) 2 out of 4 gimbal pin bearings U/S.

(6) 1st stage epicyclic gears heavily worn.

(7) 1st stage epicyclic planet bearings heavily worn.

Needless to say, I probably owe my life to these cards!

b. Agusta Bell Jet Ranger. (Fig. 7). This card, taken in the cockpit, shows a seriously out-of-balance tail rotor. As the analyser was printing the engineer said, "Don't bother to look at the tail rotor. It's perfectly O. K." We didn't argue. We just balanced it.

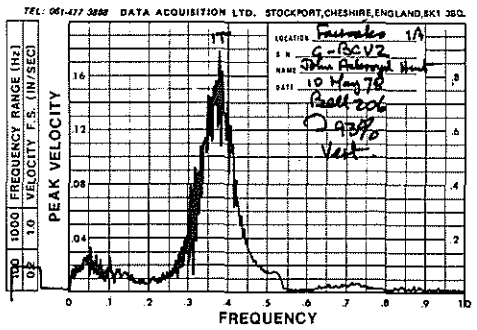


Fig. 7

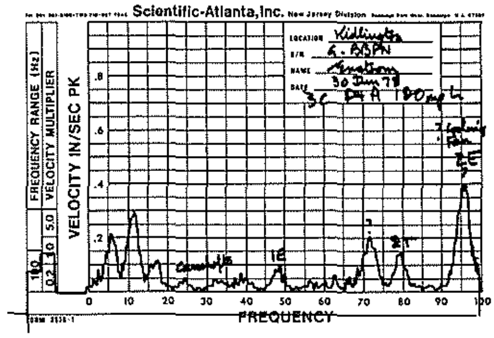


Fig. 8

c. Enstrom. (Fig. 8). The pilot of this aircraft had been throwing the helicopter back to the engineers for one month to "fix the main rotor vibration". The main rotor is perfect. It was the engine causing the vibration.

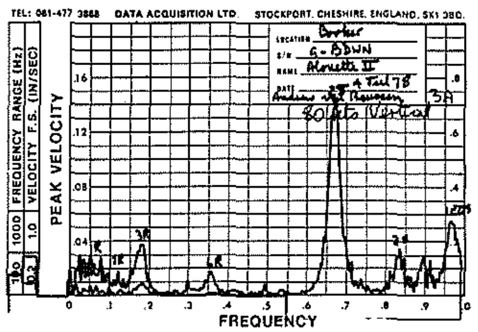


Fig. 9

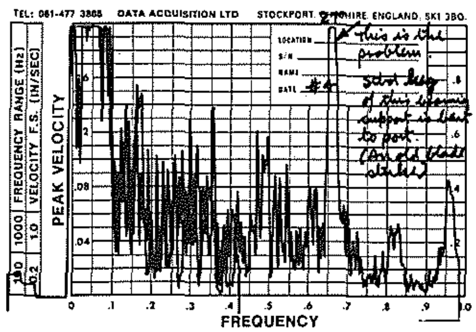


Fig. 10

d. Alouette II. (Fig. 9 & 10). This vibration had never been reported by the pilot. We traced it quickly to this bearing. An old blade strike had bent a bearing support, passed unnoticed, yet bowed the shaft out of line.

Having pin-pointed the sources of vibration, and corrected any alignment or gear meshing problems, let us now turn to the main sources of vibration - the main rotor and the tail rotor.

PHASE AND TRACK

11. The first phase of Helituning - after obtaining the vibration signatures - is to check and correct the main rotor blade phasing.

12. **Phase.** During some recent flight testing on the S61 fleet at KLM Helikopters we made some very important discoveries relating to the effects of incorrect phase and track, which affected the 5 times main rotor rpm (5R) and $\frac{1}{2}$R levels. Using a stroboscope we observed one blade lagging periodically with an irregular period. Such movements coincided with an excessive build up of 5R and $\frac{1}{2}$R lateral levels. As would be expected, the 1R lateral also increased since the centre of gravity of the rotor system was no longer concentric with the main drive shaft. Once the suspect damper was replaced (and incidentally confirmed defective on KLM's forced velocity test rig) the $\frac{1}{2}$R, 1R and 5R levels all reduced dramatically.

13. Track. The next line of attack in our war of attrition is to observe and correct main rotor blade track. Our aim is to make all blades fly round the rim of an imaginary saucer. If they don't, a rotor wobble will cause some lateral and rolling motion, but mainly pitching motion which is perceived by the pilot and passengers as vertical bounce. The more the blades are out of track, the worse the vertical bounce. Not very good for serving coffee or flying IFR to a rig! By using the stroboscope again, we can call for appropriate corrections. Track problems in the hover are corrected with pitch link adjustments. Blades which climb or dive with increases in airspeed are corrected with tab adjustments. Once we achieve a good hover track and no track deviations with airspeed, only then can we move onto the next stage of the battle.

IN-PLANE BALANCING

14. Main Rotor. We will now correct the in-plane out-of-balance forces. These can be caused by:

a. Uneven spacing of the blades - a fixed phase angle error as opposed to a damper problem.

b. One blade heavier than the others.

c. An out-of-balance rotor head.

d. On a Hiller, the wrong weight on one paddle.

15. Method. Using a small balancer and a lateral accelerometer on the main rotor gearbox, we measure the size and direction of the out-of-balance force. By reference to a polar chart we determine the corrective action which could be to:

a. Add weight to blade tip/s.

b. Add weight to blade root/s.

c. Sweep one blade aft in the lead/lag plane.

d. Add weight to paddle.

The measurements are repeated, results plotted and minor refinements added until the mass unbalance - and hence lateral vibrations - have been eliminated.

16. Tail Rotor. The same principles are applied to tail rotor balancing. First we observe and correct the track of the blades, then we balance the rotor with tip weights or pitch arm weights to correct spanwise and chordwise out-of-balance respectively.

VERTICAL BOUNCE

17. Just because the blades all have the same track, it does not follow that they will all generate the same lift. Weight and profile discrepancies create minor lift variations for the same track. If we assume that one blade of a four bladed rotor is producing less lift than the others, I'm sure that you will agree that the helicopter will tend to roll and pitch at 1R. As we sit close to the roll axis our bodies hardly detect the roll element. However, the pilot sits well ahead of the rotor's pitching axis and perceives the pitching as vertical bounce. Here again we tune into the 1R vertical vibration, measure the amount and phase angle of the out-of-balance on a vertical accelerometer in the cockpit. Having identified the blade producing insufficient lift, we correct the inequality by a calibrated increase in the angle of attack, using the pitch link. The effect on the track is very small - almost imperceptible with the strobe. This explains why some helicopters fly best with one blade out of track. The secret is to know which blade to adjust and by what amount. Provided that a disciplined approach is taken to Helituning and perfection is achieved in each element of the sequence, this final adjustment locks all the others together. We have smooth rotors, a much improved ride, and more importantly we have laid the enemy to rest. Unless prompted, we quickly forget that the helicopter was bedevilled with seemingly unrelated problems. It flys on and on and really becomes an effective machine, spending its time on task, not in the hangar.

RECONNAISSANCE

18. Now that the battle has been joined and won, we need evidence of the result. A second set of vibration signatures is taken to show the new levels after the Helituning. These become the start point for the rest of the helicopter's life. They can be Xeroxed onto viewfoils which in turn can be used as comparators. The new card can be held under the viewfoil, revealing deterioration of a particular component. Thus trends can be established easily.

HEALTH MONITORING

19. The vibration signature analyser can be used at set intervals to monitor an aircraft fleet. Average or normal values emerge quickly. INSIPIENT PROBLEMS CAN BE DETECTED EVEN BEFORE THEY ARE REPORTED BY THE PILOT. Modern helicopters have powered controls, auto-stabilisation equipment and automatic flight control systems which prevent all but the most severe vibrations reaching the pilot. BY THE TIME HE FEELS IT, THE DAMAGE HAS BEEN DONE. Once detected and quantified, the vibratory source can either be adjusted immediately, the component can be changed (leading to a minor repair) or the maintenance action can be delayed to a planned servicing with more frequent monitoring as necessary. I believe that vibration signature analysis is becoming a very powerful Non-Destructive Testing tool, along with X-rays and ultrasonics. Moreover, its adoption leads to preventive maintenance and brings on-condition maintenance one step nearer reality. You will see marked reductions in problems caused by cyclic stress because your helicopters will be in tune.

THE FUTURE

20. We will see great strides in vibration analysis and dynamic balancing once the technique becomes adopted universally. It saves time, money and down-time. Increasing use will be made of micro-processors to analyse the vibration spectra. We will take simultaneous measurements in three or more axes and process the out-of-balance forces. The Helituner will list instructions to adjust the rotative components to tune the helicopter more accurately and more quickly. Time - in our business, as in all others - is money. The aircraft under test can be compared with a data bank and levels assessed as serviceable, approaching reject or reject level. The technology exists. All we have to do is to package the product, built to serve your needs.

CONCLUSION

21. Vibration is the constant enemy of the helicopter. In the past, because we lacked suitable measuring equipment, we used very crude tools and settled for shaky helicopters and money absorbing maintenance methods. Today we have the tools to obtain accurate vibration signatures to pin-point problems with confidence. We also possess the means of observing out-of-track and out-of-balance conditions and can eliminate the vibrations at source. The future will see micro-processors used to interpret the data more rapidly and give instructions for speedy Helituning.

22. Smooth rotors and effective vibration health monitoring leads to less maintenance, longer times between overhauls, less premature component rejections, a reduction in "no fault found" cases. Perhaps more importantly the direct operating costs are reduced, profitability and availability are increased. Lastly, the crews and passengers enjoy a pleasant and less tiring ride. What more could we want?

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