Experimental Analysis of Steady-State Maneuvering Effects on Transmission Vibration Patterns Recorded in an AH-1 Cobra Helicopter

Edward M. Huff
NASA Ames Research Center

Mark Dzwonczyk
California Signal Processing Associates, Inc

Summary:

A significant body of research exists on the vibration patterns of rotorcraft drive trains from test stand data, yet there is a dearth of similar results from data gathered *in situ*. While it would be desirable to apply engineering knowledge or test stand results directly to the flight situation, vehicle state, environmental conditions, and maneuvering forces can be expected to have important, yet poorly understood, effects on observed vibration patterns. Furthermore, many structural sources of vibration, which are present in flight, such as the engine, main rotor, and tail rotor, make vibration recordings more difficult to analyze and interpret than those collected from isolated test rigs.

Accordingly, a series of flight studies is currently being conducted at the NASA's Ames Research Center to measure the extent of these effects. This paper reports on the analysis of vibration data collected from a two-phase flight experiment that was completed in May 1999 on the Flying Laboratory for Integrated Test and Evaluation (FLITE), a Cobra AH-1 rotorcraft maintained by the US Army at Ames (Fig.1). Although results thus far are preliminary, important findings have already been discovered regarding the power, spectral distribution, and stationarity of transmission vibration patterns as a function of maneuvering effects. The acquired data are also being used to study multi-axis vibration response characteristics, maintenance effects, and so forth.

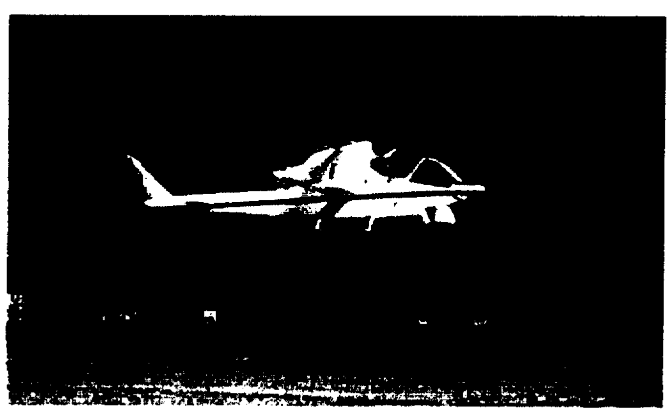

Fig.1. Ames' Flying Laboratory for Integrated Test and Evaluation (FLITE)

Study Objective:

The flight experiment was designed primarily to determine the extent to which steady-state maneuvers influence characteristic vibration patterns measured at the input pinion and output annulus gear locations of the main transmission. If results were to indicate that maneuvers systematically influence vibration patterns, more extensive studies would be planned to explore the response surface. It was also designed to collect baseline data for comparison with experimental data to be recorded at a later date from test stands at Glenn Research Center. Finally, because this was the first vibration flight study on the Cobra aircraft, considerable energy was invested in developing an in-flight recording apparatus, as well as exploring acceleration mounting methods, and generally learning about the overall vibratory characteristics of the aircraft itself.

Method:

The Cobra was instrumented as shown in Fig. 2. A PC-based data acquisition system (*HealthWatch*), designed specifically for this application and located in the tail boom, recorded eight-channels of analog time-varying signals. Two three-axis accelerometers positioned on special mounting nuts at the input pinion and output epicyclic locations were monitored, taking up six channels. One channel was used for sampling a tachometer (once per rev interrupter pickup) signal on the main rotor shaft, and the remaining channel was used to sample engine torque. Taking into consideration the resonant frequency of the mounting bracket for accelerometers, which was estimated at 23kHz, appropriate order anti-aliasing filters were used in combination with sampling rate of 50kHz to satisfy the Nyquist sampling conditions. In addition to analog data, correlated aircraft attitude data were also obtained from a 1553 data bus.

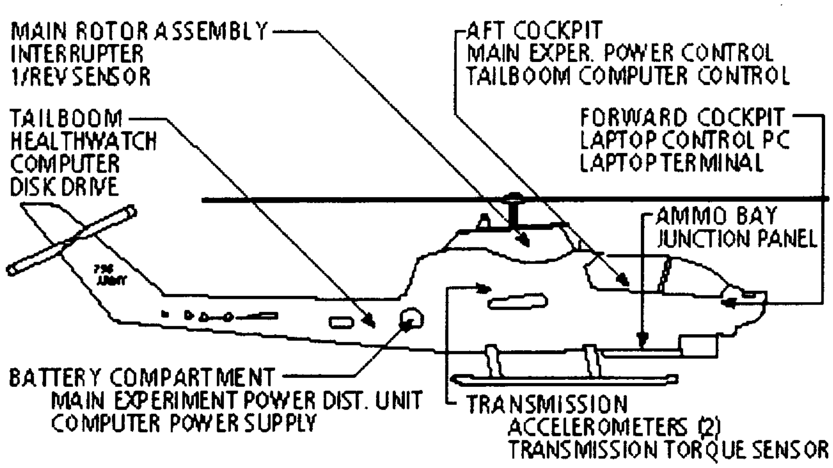

Fig. 2 Aircraft Instrumentation

The experiment was conducted in two phases, each of which was composed of four flights on separate days. Phase 1 was completed in August 1998, and Phase 2 in May 1999. In each phase, the same pilots flew the aircraft in 14 different steady-state maneuvers (Table 1), according to a pre-determined Latin Square matrix schedule designed to counterbalance random wind conditions, ambient temperature, and fuel depletion. Maneuvers were scheduled to last at least 34 seconds, in order to allow sufficient revolutions of the main rotor and planetary gears to apply known diagnostic techniques. In each Phase of the experiment, therefore, 168 raw data records were obtained of 34 sec. each: 14 flight maneuvers, flown by two pilots, on six separate occasions.

During Phase 1, the two three-axis accelerometers were mounted near the input pinion and the planetary ring gears respectively. During Phase 2, the accelerometer previously at the input pinion was moved to a second location near the annulus gear. In all other respects, Phases 1 and 2 were the same.

Table 1: List of Maneuvers

Maneuver	Name	Symbol	Description
A	Forward Flight, Low Speed	FFLS	Fly straight, level, & forward at ~ 20 kts.
B	Forward Flight, High Speed	FFHS	Fly straight, level, & forward at ~ 60 kts.
C	Sideward Flight Left	SL	Fly straight, level, & sideward left.
D	Sideward Flight Right	SR	Fly straight, level, & sideward right.
E	Forward Climb, Low Power	FCLP	Fly forward, straight, & climbing at 40 psi.
F	Forward Descent, Low Power	FDLP	Fly forward, straight, & descending at 10 psi.
G	Flat Pitch on Ground	G	Vehicle on ground skids.
H	Hover	H	Stationary hover.
I	Hover Turn Left	HTL	Level hover, turning left.
J	Hover Turn Right	HTR	Level hover, turning right.
K	Coordinated Turn Left	CTL	Fly level, forward, & turning left.
L	Coordinated Turn Right	CTR	Fly level, forward, & turning right.
M	Forward Climb, High Power	FCHP	Fly forward, straight, & climbing at 50 psi.
N	Forward Descent, High Power	FDHP	Fly forward, straight, & descendingat 50 psi.

Results:

Several avenues of analysis are being pursued and will be completed in time for final preparation of the conference paper. These analyses include: (1) consistency in maintaining aircraft attitudes during recording intervals; (2) statistical stationarity during the various flight maneuvers; (3) vibration pattern differences attributable to flight maneuvers; and (4) planetary analysis methods using single- and double-accelerometer arrays.

An important example of the findings include an early analysis that was required after the first flights were completed in Nov. 1998 to address very high peak-to-peak g-levels that were observed at both the pinion (±500g) and planetary

(±250g) locations. Unfortunately, such high levels exceed the dynamic range of the accelerometers and signal clipping occurred. Since the literature was ambiguous with regard to anticipated RMS levels, there was some concern initially that the observations were due to a recording artifact.

As can be seen in Tables 1 and 2, the effect of moving the lower tri-axial accelerometer (i.e., channels 4-6) to a new location at some distance from the original mesh contact point reduced the RMS signal value somewhat and allowed the accelerometers to be used within their dynamic range.

Table 1: Signal amplitudes (g-level) measured as root mean square (RMS)

Channel	Test Flight	Flight 1-15	Flight 3-08	Flight 3-21
1	27.86 g	34.57 g	33.84 g	32.77 g
2	20.03 g	20.98 g	22.10 g	22.80 g
3	12.55 g	15.39 g	14.57 g	14.61 g
4	64.74 g	86.52 g	74.87 g	76.94 g
5	198.73 g	128.01 g	123.69 g	127.63 g
6	23.37 g	21.59 g	19.97 g	19.70 g

(various flights for maneuver F)

Channel	Test Flight	Flight 2-25	Flight 2-31	Flight 3-21
1	41.59 g	43.72 g	43.76 g	44.49 g
2	33.94 g	34.84 g	34.98 g	35.73 g
3	16.70 g	15.04 g	15.01 g	15.51 g
4	95.79 g	94.18 g	87.72 g	96.37 g
5	148.82 g	86.21 g	88.24 g	93.21 g
6	31.36 g	15.90 g	16.33 g	16.69 g

(various flights for maneuver N)

The conclusion that such high g-levels are an inherent aspect of the Cobra transmission, and not an anomaly due to the data recording system, was further corroborated by a shake-table test. The highly consistent output of each accelerometer channel is shown for a known peak amplitude of 30 g (Table 3). In general, all channels were highly linear up to the shake-table maximum of 30g, and there was no reason to believe they would account for the observed signal amplitudes.

Channel	RMS	RMS $\times\sqrt{2}$	Peak
1	21.72 g	30.72 g	31.13 g
2	21.91 g	30.99 g	31.74 g
3	22.08 g	31.23 g	31.37 g
4	22.38 g	31.65 g	33.20 g
5	21.75 g	30.76 g	31.25 g
6	21.96 g	31.06 g	31.74 g

Table 3: Shake table results.

Conclusions:

During the course of this study, the need for controlled, experimental flight data has been amply demonstrated, as well as the need to compare flight and test-rig data systematically. In several respects, the existing literature was found to provide ambiguous, and, in a few instances misleading, expectations about in-flight vibration measurement. Based on these findings, an OH-58c helicopter is currently being instrumented at Ames with the HealthWatch system, and baseline comparison data are being collected from the OH-58 test-rig at NASA's Glenn Research Center.