THE NASA DIGITAL VGH PROGRAM--EARLY RESULTS

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SUMMARY

NASA has recently revived the "VGH" measurement program for airline transports to fulfill a need within the airline industry for realistic data describing flight operations of airline transports. These data will be used by transport designers to make better estimates of fatigue life consumption of current aircraft and to update design criteria for future aircraft. This program, using digital data recorded on magnetic tape was started in 1977. Several examples of the statistical outputs are reviewed to illustrate the types of analyses and results becoming available.

INTRODUCTION

NASA has recently revived the "VGH" measurement program for airline transports to fulfill a need within the airline industry for realistic data describing flight operations of airline transports. Data needed include operating altitude, airspeed, weight, loads, and control usage. These data will be used by transport designers to make better estimates of fatigue life consumption of current aircraft and to update design criteria for future aircraft.

NACA/NASA has historically provided such data, starting in the 1930's with the NASA "VG" program which gave velocity and load factor from operating aircraft for direct comparison with the designer's VG diagrams. Later, starting in the 1950's, a new dimension of altitude was added in the NACA/NASA-supplied film recorder, which provided time histories of velocity, load factor, and height which were read up and analyzed principally by manual processes. These analogue recorder programs for airline transports ceased in 1971, due to changing priorities within NASA.

In 1977, NASA revived the program for airline transports with some changes (ref. 1). It was decided to determine if data from digital recorders already existing on many wide-body aircraft for accident investigation purposes could be utilized to fulfill the Digital VGH Program objectives. More parameters would be attempted, since they are readily available. The present report gives several examples of the statistical outputs evolved for a Lockheed L-1011 aircraft using data obtained in routine flight operations in 1973, and compares them with results from 1978 operations. In addition, the report discusses several interesting operational effects obtained from an inspection of the time histories.

The service areas for the two data sets discussed are given in figure 1. The oldest data set was obtained for flights flown in February through May 1973 along the east coast with Chicago and San Juan added. This set consists of 83 flights, about 200 hours of flight time, and about 169 000 km (91 000 nautical miles). The data tapes for this 1973 data set were obtained in 1977 and were used to develop the analysis techniques, computer programs, and output formats. The newest set covers March 1978 through July 1979 and is for much the same routing, but with the addition of Mexico City, Acapulco, Seattle, and Portland, for 918 flights, about 1600 hours, and 1 300 000 km (700 000 nautical miles). For each data set, the data are for the same airplane obtained continuously, or as nearly as possible.

DISCUSSION

The data are recorded on existing Digital Flight Data Recorders on a 25-hour loop-tape on airliners in routine airline service (figure 2). The airline company reads out the data once or twice a week, transcribes the selected parameters into an IBM compatible format, and sends it and the support data (weights and trip length from flight logs) to NASA. NASA plots these data and edits them both manually and automatically and processes them into two basic statistical outputs--loads statistics and flight profile statistics--as described in reference 1 and illustrated in figures 3 and 4. The matrix of statistical data types output for this first program phase is shown in figure 4. Not all these data types will be discussed in this paper. Instead, this paper will show typical statistical outputs for altitude, weight, airspeed, and acceleration, as shown by the numbers 1, 2, 3, and 4 on figure 4. Complete statistical results for the L-1011, B-727, and B-747 airplanes are expected to be published within the next year, in separate reports.

Maximum Altitude Per Flight

The 83 flights of the 1973 operations, figure 5, show the maximum altitude per flight was about equally divided between 8892-10516 and 10516-12040 meters (30-35 000 and 35-40 000 feet). For the larger sample of 918 flights starting in 1978 over a broader route structure, the 10516-12040 m (35-40 000 feet) altitude was by far the most popular and two flights actually went to 12800 m (41 000 feet). At the 10516-12040 m (35-40 000 feet) maximum altitude level, the 2-2.5-hour trip was most prevalent for both sets of data. About 17 percent of all trips had peak altitudes less than 5944 m (19 500 feet) in 1978-1979.

Landing Fuel

Landing fuel mass is given for the L-1011 operation in figure 6 for the 83 flights, February to May 1973, and for 918 flights, 1978-1979 operations.

In 1973, the most popular trip of 2-2.5-hours duration almost always landed with 13 608-22 680 kg (30-50 000 lbs) of fuel. In 1978-1979, the most popular landing fuel mass by a factor of 2 was 4536-13 608 kg (10-30 000 lbs) for the same 2.5 hour trip length. However, the 1.0-1.5-hour trip landed with more fuel, 13 608-22 680 kg (30-50 000 lbs), twice as often as it did with the minimum 4536-13 608 kg (10-30 000 lbs). The 13 608-22 680 kg (30-50 000 lbs) landing fuel mass was still the most probable mass for all trip lengths. The distributions of trip duration for all fuel masses in 1978-1979 show more shorter trips than in 1973. The differences in trip duration distributions for the 83 flights and the 918 flights in 1978-1979, shown in figures 5 and 6, can be attributed to the effects of sample size and possibly other factors such as changes in fuel cost and availability.

Landing Flap Usage

The time spent at various airspeed intervals in each flap detent is given in figure 7 for 83 landings of the L-1011-1 aircraft in 1973 operations; flap placard speeds are also noted. These data are actual flap surface position indications collected into standard "bins" or detents of 5 to 8 degrees. It can be seen that flap deployment above the placard speed is minimal, the general trend is for broad speed distributions in small detents, and narrow distributions close to the placard speeds in the landing detents.

Loads

The measure of load on the aircraft is the body-axis normal acceleration at the center of gravity. As explained in reference 1, the basic counting technique employed is the "level crossing method" as opposed to the "peak count method" of the previous NACA/NASA VGH Program. Sample results for the L-1011-1 operation are given in figure 8 and compared with previous wide-body data extracted from the data set reported in reference 2.

The previous wide-body results are within a factor of 2 of the present results at a given load increment. However, at a given counting rate, the loads are within 10 to 15 percent. However, since they were not derived exactly the same way as the present results, the comparison must be made cautiously. The previous wide-body results are total peak counts per hour obtained by adding separately determined maneuver counts and gust counts to get the total counts; the present results are total level crossing counts per hour obtained directly from the trace of total normal accelerations. Results in reference 3 indicate the level crossing technique can sometimes give up to twice the crossing rate of the peak count method.

The present results, figure 8, provide data all the way to zero load. At these low levels, the counts are considerably higher than at the 0.2-g level previously available, as would be expected.

Examination of many power spectra of center-of-gravity normal acceleration showed the presence of sharply peaked responses just below 1 hz, whereas, the aircraft short period response (or gust response frequency) is characteristically 0.2 to 0.5 hz for the L-1011 with stick fixed. From the flight conditions, it was surmised that autopilot operation was involved; however, the 1973 data set did not include autopilot status. When the 1978 data set was obtained with autopilot status, it was possible to clearly see that the high frequency response was occurring with autopilot on, as in figure 9.

Figure 9 shows power spectra of L-1011 c.g. normal acceleration plotted after the manner of reference 4, to show the relative power under each peak. Thus, the vertical scale is linear with power spectral density times frequency versus log frequency horizontally. The measured data are for autopilot off and on under similar operating conditions. For autopilot off, the peak response is at about 0.3 hz, which is the aircraft stick-fixed short period frequency. For autopilot on, the peak is at about 0.8 hz, which was surmised to be the short period response with autopilot on. Subsequent calculations by the manufacturer and NASA confirmed this frequency shift.

There are at least two effects of this shift to be noted. First, the higher frequency motion is considered to be less disturbing to the passengers according to reference 5, which indicates 0.2 to 0.7 hz as the critical motion sickness region. Secondly, the average zero crossing rate of interest to fatigue analysis is increased 10 to 20 percent when the response is integrated across all frequencies.

Autopilot Operation

To assess the importance of these effects of autopilot operation, statistics on autopilot usage were compiled from 400+ hours of the 1978-1979 data set. The results are given in figure 10 and indicate for the L-1011 that the most frequently used altitude band for autopilot turn-on is ∿2896 to 4420 m (10-15 000 ft) in the departure, but the most popular turn-off altitude is in the last 1372 m (5000 ft) in descent. In about 5 percent of the cases, it was on at touchdown; in about 8 percent of the flights, it was not on at all. Thus, the L-1011 autopilot was used approximately 75 percent of the time it was operating.

Detailed examination of the normal acceleration trace showed the occasional presence of a low-amplitude low-frequency oscillation. This "limit cycle" phenomenon is illustrated in figure 11. Peak-to-peak amplitudes averaged about .07 g's. This low-amplitude low-frequency motion, associated with the altitude hold mode according to the theoretical studies, is below the region associated with passenger discomfort (reference 5) and is not considered a factor in fatigue life consumption. Similar effects were noted on the 727 and 747 aircraft, figure 12, with the smaller shorter-range aircraft experiencing it more than 20 percent of the time, and the large long-range type less than 10 percent of the time the autopilot is on. It is estimated the effect of this limit cycle is to increase the fuel consumption a few tenths of 1 percent.

CONCLUDING REMARKS

Data from airline digital flight data recorders can provide relevant statistical data for estimating fatigue life consumption of the current airliner fleet and for design criteria updating for future designs. In addition, the data have indicated real operating effects due to the autopilot, i.e., gust response frequency peak increase by 2 or 3 times, and the existence of the low-frequency low-amplitude limit cycle motion in altitude hold. Extension of the program to more data types for ground operations is planned, along with acquisition of DC-10 data. Finally, on-board processing of simple data types is being considered. Throughout the program, industry feedback is sought and received.

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4. Houbolt, John C.: Design Manual for Vertical Gusts Based on Power Spectral Techniques. AFFDL-TR-70-106, pp. 11 and 12, December 1970.

5. Aeromedical Aspects of Vibration and Noise. AGARDOGRAPH No. 151, Chap. 5, November 1972.

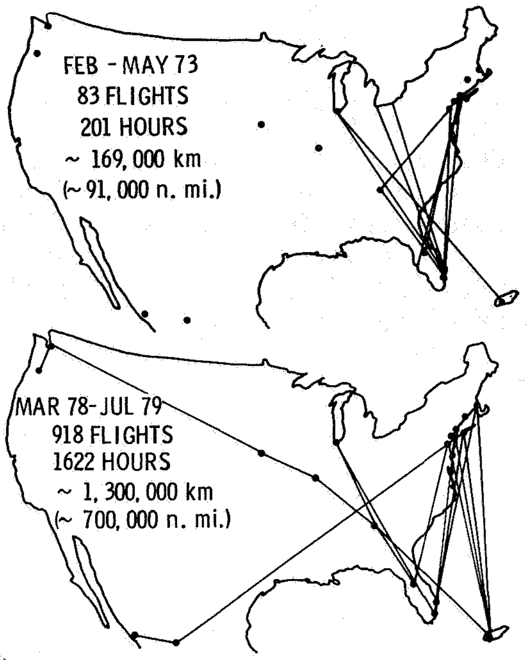


Figure 1.- Location of service areas for L-1011 operations.

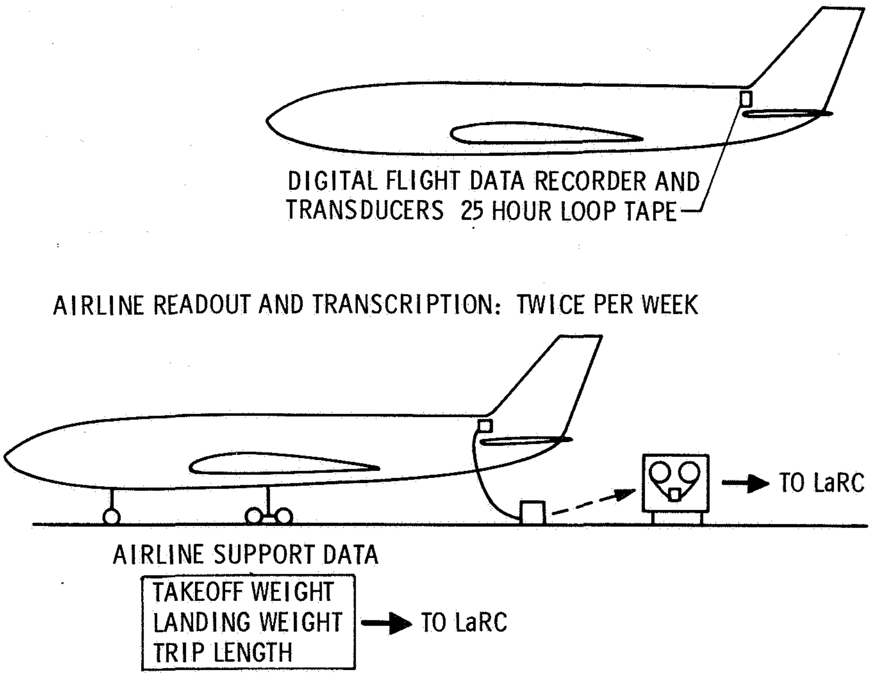


Figure 2.- Digital VGH program data source.

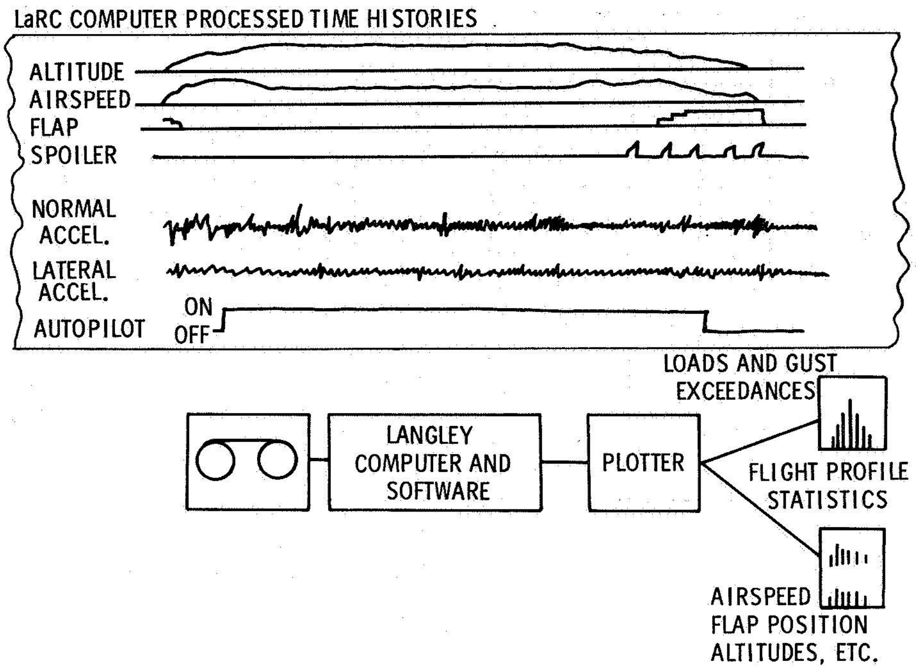


Figure 3.- Data processing and analysis.

		COUNTS/hr	PERCENT OF TIME	PERCENT OF FLIGHTS
FLAPS UP OR DOWN	ACCELS AND GUST VELOC.	FOR ALTITUDE INTERVALS ④	—	MAX ACCELS AND GUST VEL. FOR ALT INTERVALS
	WEIGHTS	—	FOR CLIMB, LEV. FLT AND DESC. VS ALT.	FOR TAKE-OFF AND LANDING VS DURATION ②
	AIRSPEEDS	—	TOTAL, CLIMB, LEV. FLT AND DESC. VS ALT.	—
	ALTITUDE	—	SEE WEIGHTS AND AIRSPEED	MAX ALTITUDE VS DURATION ①

FLAPS > 2^0	FLAP DETENTS	—	FOR TAKE-OFF AND LANDING	TIME OF FLAP CHANGE FROM TAKE-OFF AND LANDING
	WEIGHTS	—	FOR EACH DETENT ③	—
	ALT. ABOVE GROUND	—		—
	AIRSPEED	—		EQUIV. AIRSPEED AT FLAP DETENT CHANGE
	ACCELS	FOR TAKE-OFF AND LANDING FOR EACH DETENT	—	—
		MAX NORMAL ACCEL EACH DETENT VS AIRSPEED		

NUMBERS 1, 2, 3, AND 4 REFER TO TOPICS DISCUSSED IN TEXT

Figure 4.- Statistical data outputs.

1973 OPS - 83 FLIGHTS

FLIGHT DURATION, hr	-152–1372 m -.5–4.5 × 10^3 ft	1372–2896 m 4.5–9.5	2896–4420 m 9.5–14.5	4420–5944 m 14.5–19.5	5944–7488 m 19.5–24.5	7488–8992 m 24.5–29.5	8992–10516 m 29.5–34.5	10516–12040 m 34.5–39.5	12040–13564 m 39.5–44.5	TOTALS ALL ALTITUDES
5–6										
4.5–5										
4–4.5							2.4	1.2		3.6
3.5–4						1.2	2.4	1.2		4.8
3–3.5						2.4	13.2	7.2		22.8
2.5–3						1.2	9.6	1.2		12.0
2–2.5						4.8	8.4	22.8		36.0
1.5–2						2.4		1.2		3.6
1–1.5						2.4	4.8			7.2
0.5–1		2.4		2.4		1.2	1.2			7.2
0–0.5	1.2	1.2								2.4
TOTALS	1.2	3.6		2.4		15.6	42.0	34.8		99.6

ALTITUDE, m

ALTITUDE, ft

(a) 1973 operations, 83 flights.

1978 -79 OPS - 918 FLIGHTS

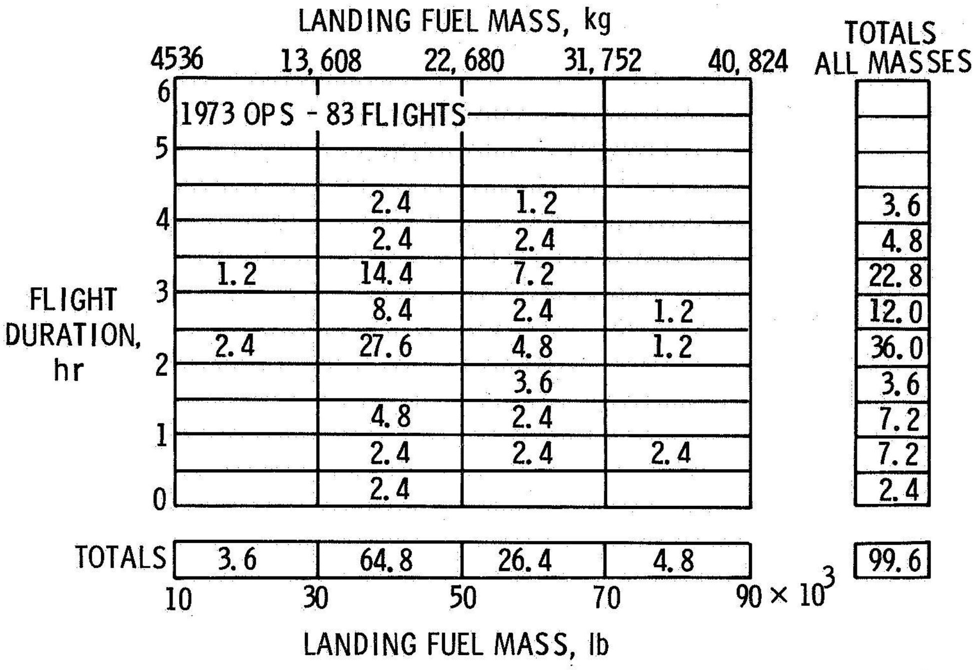
FLIGHT DURATION, hr	-152–1372 m -.5–4.5 × 10^3 ft	1372–2896 m 4.5–9.5	2896–4420 m 9.5–14.5	4420–5944 m 14.5–19.5	5944–7488 m 19.5–24.5	7488–8992 m 24.5–29.5	8992–10516 m 29.5–34.5	10516–12040 m 34.5–39.5	12040–13564 m 39.5–44.5	TOTALS
5.5–6								.1		.1
5–5.5								.1		.1
4.5–5								1.0		1.0
4–4.5							.1	2.2		2.3
3.5–4							.7	4.0		4.7
3–3.5							1.5	8.5		10.0
2.5–3					.1	.1	1.9	5.9		8.0
2–2.5				.1		.2	1.7	14.6	.2	16.8
1.5–2						.2	2.0	9.5	.1	11.8
1–1.5		.1			.1	.8	3.8	9.6		14.4
0.5–1	.1		.3	3.2	6.6	1.4	3.9	1.7		17.2
0–0.5	.1	3.2	4.0	5.2	.3					13.3
TOTALS	.2	3.3	4.3	8.5	7.6	2.7	15.6	57.2	.3	99.7

ALTITUDE, m

ALTITUDE, ft

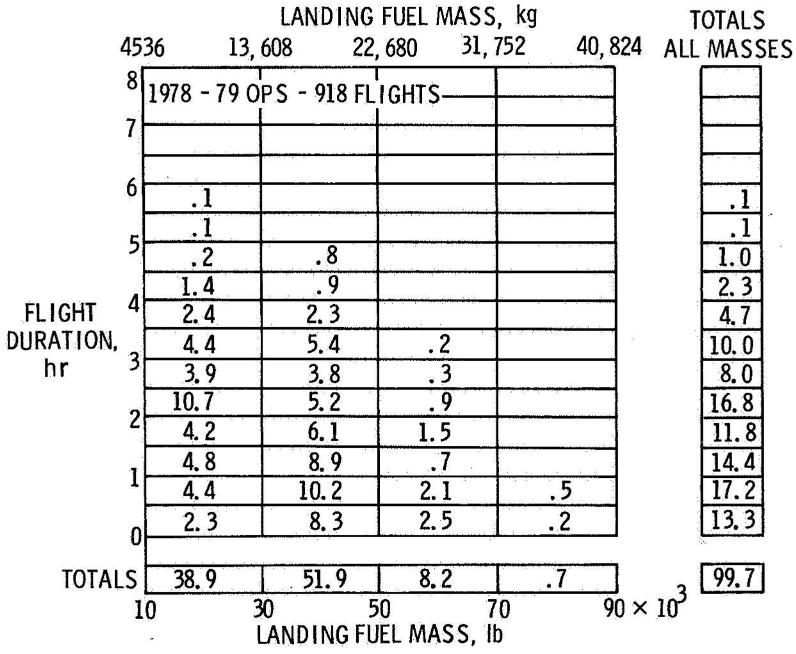
(b) 1978-1979 operations, 918 flights.

Figure 5.- Percent of flights to maximum altitude per flight versus flight duration.



		2.4	1.2		3.6
		2.4	2.4		4.8
	1.2	14.4	7.2		22.8
		8.4	2.4	1.2	12.0
	2.4	27.6	4.8	1.2	36.0
			3.6		3.6
		4.8	2.4		7.2
		2.4	2.4	2.4	7.2
		2.4			2.4
TOTALS	3.6	64.8	26.4	4.8	99.6

(a) 1973 operations, 83 flights.



	.1				.1
	.1				.1
	.2	.8			1.0
	1.4	.9			2.3
	2.4	2.3			4.7
	4.4	5.4	.2		10.0
	3.9	3.8	.3		8.0
	10.7	5.2	.9		16.8
	4.2	6.1	1.5		11.8
	4.8	8.9	.7		14.4
	4.4	10.2	2.1	.5	17.2
	2.3	8.3	2.5	.2	13.3
TOTALS	38.9	51.9	8.2	.7	99.7

(b) 1978-1979 operations, 918 flights.

Figure 6.- Landing fuel mass versus flight duration.

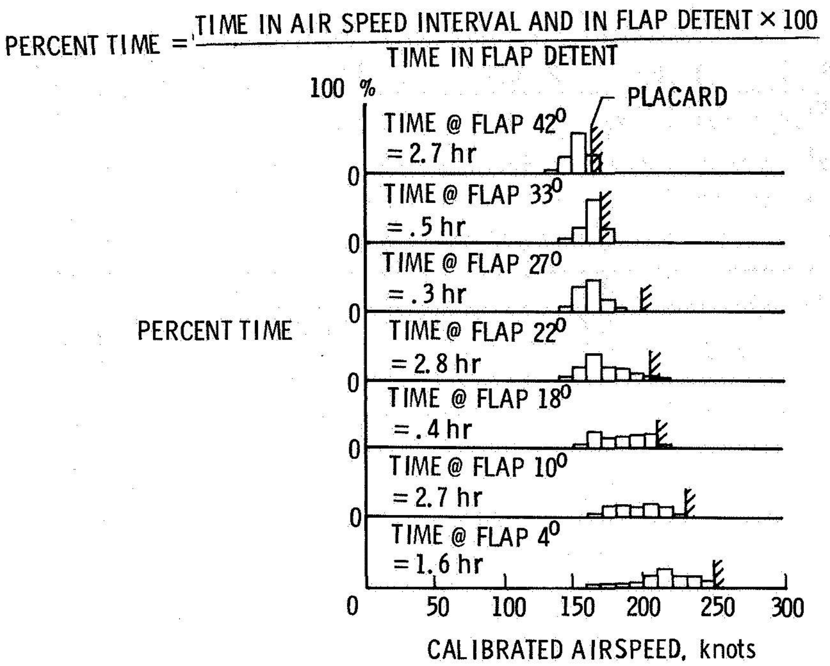


Figure 7.- L-1011 flap position versus airspeed during landing.

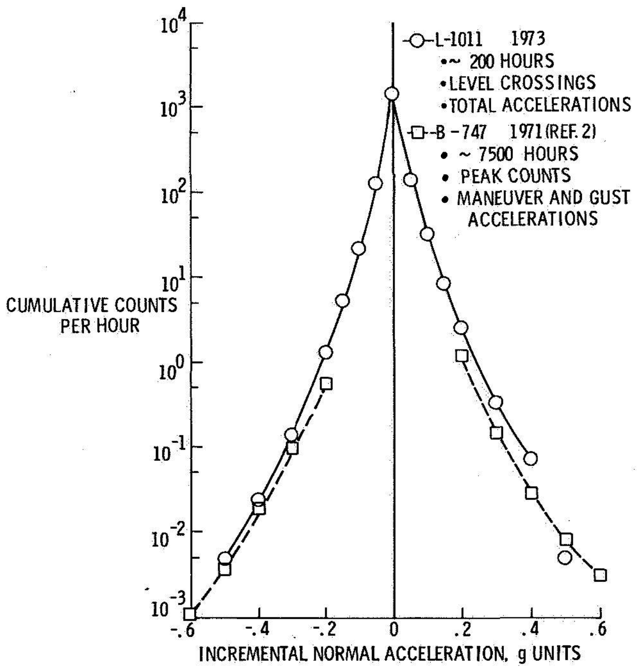


Figure 8.- Loads exceedances.

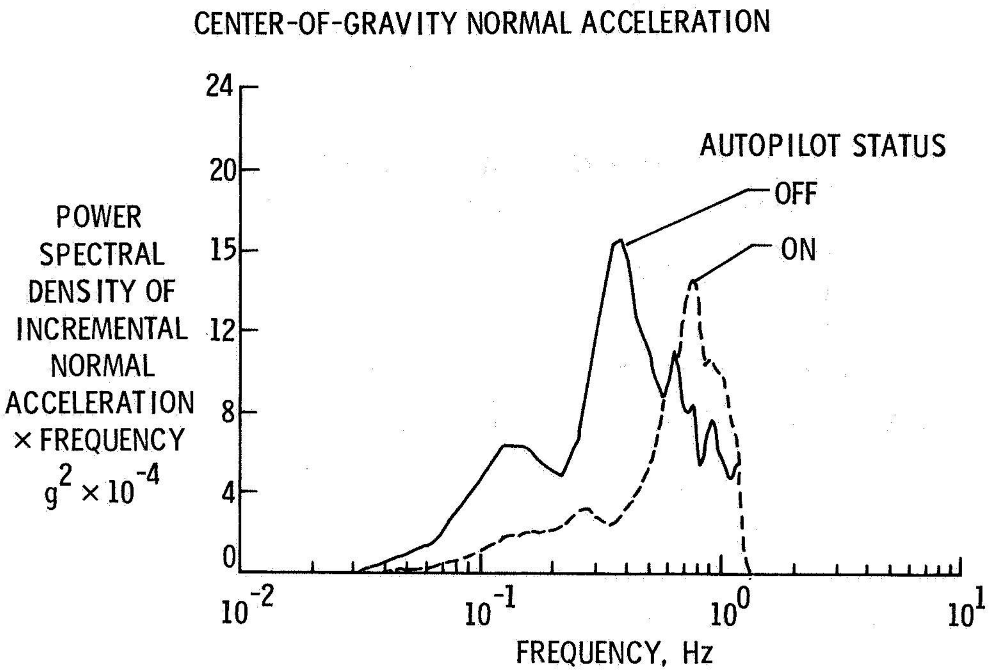
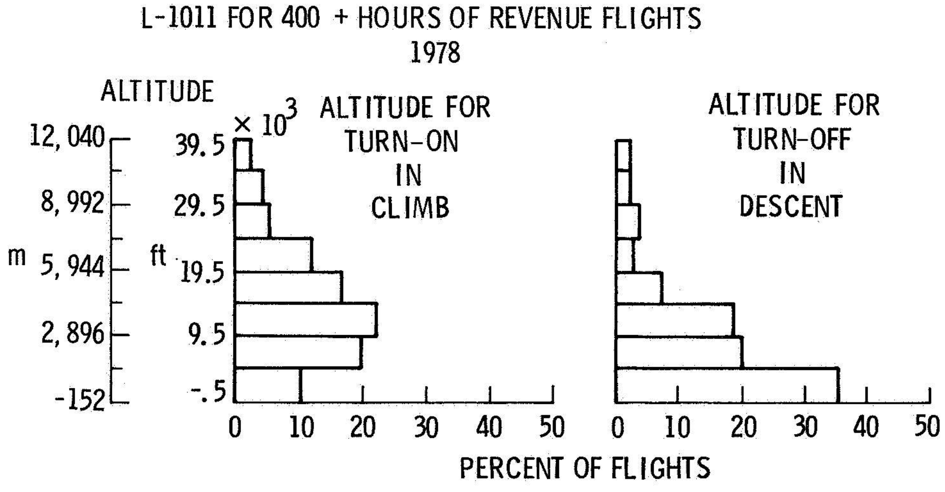


Figure 9.- Effects of autopilot on L-1011 measured power spectra.



SUMMARY

- AUTOPILOT WAS "ON" ABOUT 75% OF THE TIME
- AUTOPILOT WAS "ON" AT TOUCHDOWN FOR 5% OF THE FLIGHTS
- AUTOPILOT WAS NOT USED ON 8% OF THE FLIGHTS

Figure 10.- Autopilot on-off statistics.

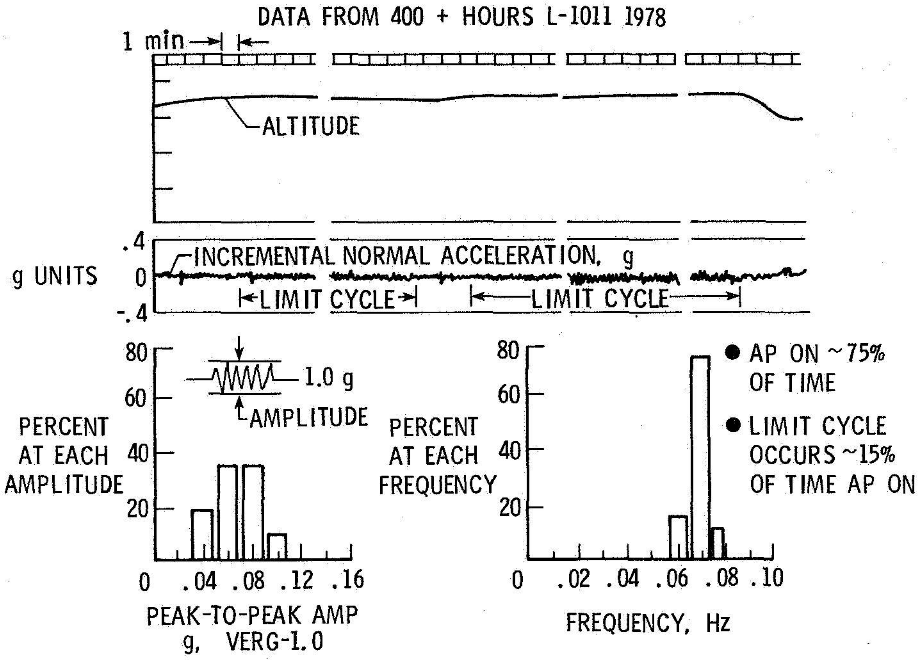


Figure 11.- Autopilot "limit cycle" experience.

AIRPLANE	% TIME AUTOPILOT ON	% TIME AUTOPILOT ON WHICH HAVE LIMIT CYCLE	DOMINANT FREQ. Hz	PEAK-TO-PEAK LOAD, g
B-727	56.42	23.69	.06	.068
L-1011	75.14	15.14	.07	.07
B-747	92.12	7.48	.066	.074

Figure 12.- Summary of autopilot-on and limit cycle times.