

Operational Loads Monitoring of a Fleet of Beech 1900D Aircraft

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ABSTRACT

Presented here are analyses and statistical summaries of data collected from 11,299 flight operations recorded on 6 BE-1900D aircraft during routine commuter service over a period of three years. Basic flight parameters such as airspeed, altitude, flight duration, etc. are shown in a form that allows easy comparison with the manufacturer's design criteria. Lateral ground loads are presented for ground operations. Primary emphasis is placed on aircraft usage and flight loads. Maneuver and gust loads are presented for different flight phases and for different altitude bands. In addition, derived gust velocities and various coincident flight events are shown and compared with published operational limits. The data presented in this form should allow an objective comparison of the existing certification and design criteria with actual usage data, thereby affording aircraft manufacturer and operators a better understanding and control of those factors that influence the structural integrity of commuter aircraft.

INTRODUCTION

BACKGROUND

As part of its continuing efforts to understand the issues involved in the aging of aircraft, Federal Aviation Administration (FAA) undertook an effort to study the operational aspects of a fleet of commuter aircraft. This project entailed the collection, processing, and statistical evaluation of the flight and ground loads collected from a fleet of BE-1900D aircraft in commuter service. The objectives of this program were to acquire, evaluate, and utilize typical operational in-service data to; 1) compare with the data used in the design and qualification testing of civil transport aircraft, and 2) provide a basis to improve the structural criteria and methods of design, evaluation, and substantiation of future airplanes.

Operational data was collected from Digital Flight Data Recorders (DFDR) installed on a fleet of 6 BE-1900D commuter aircraft. The data consisted of 11,299 flights files from a single operator. A summary of these flight files is shown in Table 1.

This article's emphasis is on data related to aircraft usage and some of the statistical loads derived from recorded data that were obtained over a course of approximately three years. The reduced data presented here should allow an objective comparison of the existing certification and design criteria with actual usage data, thereby affording aircraft manufacturer and operators a better understanding and control of those factors that influence the structural integrity of commuter aircraft.

AIRCRAFT AND FLIGHT INFORMATION

Some of the operational specifications of the BE-1900D aircraft equipped with DFDR are shown in Table 2. The data collection and editing system consisted of; (1) the data collection system installed on board the aircraft, and (2) the ground data editing station. The airline performed the collection and pre-processing of the BE-1900D recorded data and then provided it to Wichita State University (WSU) on disks. The parameters recorded by the DFDR are shown in Table 3.

Table 1: Flight data files used for the analysis

Fleet	Good Data	Bad Data
Aircraft 1	82	0
Aircraft 2	567	1,770
Aircraft 3	2,251	1
Aircraft 4	2,893	0
Aircraft 5	560	0
Aircraft 6	3,175	0
Totals for 6 Aircraft	9,528	1,771

Table 2: BE-1900D aircraft characteristics

Parameter	Value
Maximum Taxi Weight	17,060 lb
Maximum Takeoff Weight	16,950 lb
Maximum Landing Weight	16,600 lb
Zero-Fuel Weight	15,000 lb
Operating Empty Weight	10,350 lb
Fuel Capacity	668 U.S. gallons
Two P&W PT6A-67D Turboprops	1,279 shp each
Wing Span	57 ft 11.25 in
Wing Reference Area	310 ft ²
Wing MAC	5.32 ft
Length	57 ft 10 in
Height	15 ft 6 in
Tread	17 ft 2 in
Wheel Base	23 ft 9.5 in

Table 3: Recorded flight parameters and frequency

Parameter (Units)	Sample Rate
Vertical Acceleration (g)	8 Hz
Longitudinal Acceleration (g)	4 Hz
Lateral Acceleration (g)	4 Hz
Flap Position (discrete)	1 Hz
Heading (deg)	1 Hz
Pitch Angle (deg)	1 Hz
Roll Angle (deg)	1 Hz
Indicated Airspeed (knots)	1 Hz
Altitude (ft)	1 Hz
GPS - Lat. & Long. (degrees & minutes)	1 Hz
Gyros (deg/sec)	1 Hz
Weight on Wheel (discrete)	1 Hz

METHOD OF ANALYSIS

Not all of the parameters of interest were recorded. Therefore, some had to be extracted from the recorded information. Also, in some cases, the raw data contained too much noise for accurate determination of other parameters. An example was calculating the rate of climb from the recorded pressure altitude, where the latter had to be filtered using a 10-second running average.

In those cases where aircraft parameters had to be derived (e.g. aircraft lift-curve slope), for consistency, the values used were those of Reference 1. In addition, since the recorded data contained no information about the aircraft inertial properties, a weight of 16,500 lbs was used throughout. The details pertaining to specific calculations and the derivations of the required

parameters are described in Reference 2, with a brief summary given here.

FLIGHT DISTANCE

Flight distance was determined using three different methods; 1) integration of the true airspeed, 2) integration of the distance from GPS data, and 3) great circle distance from takeoff to landing.

Obviously, the first method included all errors due to wind speed. The second method was based on the techniques outlined in Reference 3. A database of airport identifiers and their coordinates was obtained from Reference 4. The GPS coordinates of the aircraft before takeoff and after landing were compared with this data to determine the most likely departure and arrival airports.

DESIGN LOAD FACTOR ESTIMATION

The 2-second rule outlined in Reference 5 was used to separate load factors into gusts and maneuvers. Originally, the gust and maneuver load spectra were specified in AFS-120-73-2 (Reference 6). However, this report was superseded by AC23-13A (Reference 7). The load spectra in this report are expressed in terms of a load factor ratio A_N/A_{NLLF} . AFS-120-73-2 defines this ratio as the incremental load factor at operating weight divided by the incremental design limit load factor at maximum gross weight. The design limit load factor for both gust and maneuver were those estimated in Reference 1. These limit load factors do not necessarily reflect the true design values.

For the gust spectra comparison the incremental *gust* design limit load factor is specified in AC23-13A as follows:

$$A_{NLLF} = \frac{30KV_m}{498W/S} \quad (1)$$

$$K = \begin{cases} \frac{1}{2} \left(\frac{W}{S} \right)^{1/4} & \text{for } W/S < 16 \text{ psf} \\ 1.33 - \frac{2.67}{(W/S)^{3/4}} & \text{for } W/S > 16 \text{ psf} \end{cases} \quad (2)$$

AC23-13A does not specify the method for determining the incremental *maneuver* design limit load factor. Therefore, this load factor was calculated in accordance with the approach specified in FAR 23.337 using the takeoff gross weight of 16,500 lbs.

For the positive incremental load factor:

$$A_{NLLF} = 2.1 + [24,000/(W + 10,000)] - 1 \quad (3)$$

For the negative incremental load factor:

$$A_{NLLF} = -0.4 \{ 2.1 + [24,000/(W + 10,000)] \} - 1 \quad (4)$$

DERIVED GUST VELOCITY

Derived gust velocities were calculated from measured normal accelerations, only for vertical gusts. Derived gust velocity was computed from the peak values of gust incremental normal acceleration as

$$U_{de} = \frac{\Delta n_z}{\bar{C}} \quad (5)$$

where the aircraft response factor, $\bar{C}$, was calculated from

$$\bar{C} = \frac{\rho_0 V_e C_{L_{\alpha}} S}{2W} K_g \quad (6)$$

Aircraft lift-curve slope, $C_{L_{\alpha}}$, was determined by raising the wing lift-curve slope, $C_{l_{\alpha}}$, given by the following equation by 10%:

$$C_{l_{\alpha}} = \frac{2\pi A_r}{2 + \left[4 + A_r^2 \beta^2 \left(1 + \frac{\tan^2 \Lambda}{\beta^2} \right) \right]} \quad (7)$$

FLIGHT PHASE DEFINITION

Each flight was divided into twelve (12) phases, although not all were used in the subsequent analysis. These phases consisted of:

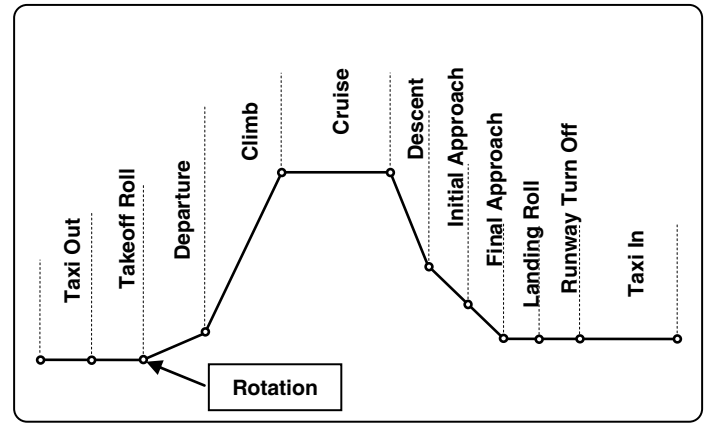
- Ground operations:
 - Taxi out
 - Takeoff roll
 - Landing roll
 - Runway turn off
 - Taxi in
- Airborne phases:
 - Takeoff rotation (not used)
 - Departure (initial climb with flaps deflected)
 - Climb (flaps retracted)
 - Cruise
 - Descent (flaps retracted)
 - Initial approach (flaps in the first detent)
 - Final approach (flaps in the second detent)

These phases are shown schematically in Figure 1(a), with a typical flight time history presented in Figure 1(b) for comparison.

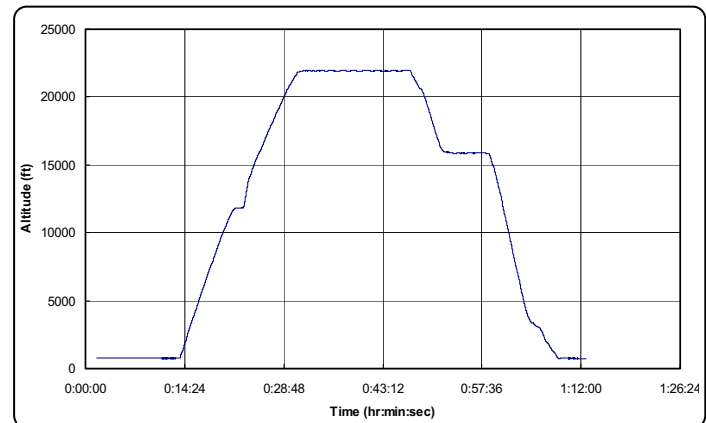
Table 4 lists the conditions for determining the start and the end of each flight phase. It should be noted that an airborne phase could occur several times per flight (e.g. multiple cruise phases for one flight).

NORMAL LOAD FREQUENCY

In order to determine the cumulative occurrences of loads and derived gust velocities, the peak-between-means method of Reference 8 was employed.



(a) Schematic of various flight phases



(b) Typical flight time history

Figure 1: Definition of flight phases

This method is consistent with past practices and pertains to all accelerations, whether due to gusts or due to maneuvers. In this method, only one peak or valley is counted between two successive crossings of the mean. A threshold zone (dead band) was used in the data reduction to ignore irrelevant load variations around the mean. This is shown schematically in Figure 2. A peak was assumed only when the data crossed into or through the dead band. The same dead band limits were used for gusts and maneuvers.

The incremental acceleration measured at the center of gravity could be the result of either maneuvers or gusts. In order to derive the contribution of each, the maneuver induced accelerations had to be separated from those due to gusts. Reference 5 reported the results of a study to evaluate methods of separating maneuver and gust load factors from measured acceleration time histories. As a result of this study it was recommended and accepted by the FAA that a cycle duration of 2.0 seconds be used to separate gusts and maneuvers.