

Comparative Usage of Two Similar Airframes

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ABSTRACT

In-service data from two Bombardier business jets, a Global 5000 and a Global Express XRS, have been compared. Flight data has been analyzed from both airframes with comparable number of ground-air-ground cycles. Individual flight phase have been examined and compared between the two airframes. Primary emphasis has been placed on airframe usage. The influence of primary mission on ground-air-ground cycles has been highlighted in the form of ground and flight loads, as well as dynamics of the flights. It is demonstrated that safe-life maintenance approach may have to be adjusted to account for the airframe usage.

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INTRODUCTION

Since 1990's a number of in-flight catastrophic airframe failures highlighted the necessity of accounting for specific aircraft usage in maintenance procedures. The most visible case was that of Aloha flight 243 that encountered an upper fuselage skin failure, on a flight from Hilo to Honolulu.[1] The crew managed to land the aircraft, a Boeing 737-200, on the island of Maui. The National Transportation Safety Board (NTSB) attributed the cause of the accident to the failure of the airline to detect the effects of fatigue damage on the fuselage, instigated by the specific usage of that airframe.[2]

In 2002, two aircraft being used as heavy air tankers in service for the United States Forest Service (USFS) crashed following in-flight failure of their wing structures.[3, 4] Following these accidents, NTSB issued Recommendation A-04-29[5] urging the UAFS to "Develop maintenance and inspection programs for aircraft that are used in firefighting operations that take into account and are based on... the magnitude of maneuver loading and the level of turbulence in the firefighting environment and the effect of these factors on remaining operational life."

Since then, there has been a number of other in-flight structural failures, although not all catastrophic, that have pointed out the necessity of maintenance procedures driven in part by the specific aircraft usage. In fact, the Federal Aviation Administration (FAA) established programs in Operational Loads Monitoring (OLM) to collect in-service data from a number of aircraft in civilian aviation. Under this program, data was acquired from a large number of airframes[7, 8, 9, 10, 11, 12, 13] that allowed the examination of the in-service loads and airframe usage. The ultimate goal was the better understanding of the factors that influence the fatigue life of these aircraft that could be driven by the airframe loads and usage and possible differences between the design standards and the operational environment. This type of information was deemed valuable for three

groups of constituents. Comparison with design standards could help the manufacturers, the operators, and the regulating agencies to tailor their design and maintenance standards for the specific applications.

As the result of the above program, considerable information has been collected on aircraft certified for airline operation. However, not as much data is available on business jets certified under FAR23 or FAR25. Some of the results obtained from smaller airliners can be relevant to business jets, but large variations in size and the nature of their usage necessitates their specific examination.

In the present article, the authors examine the results obtained from two similar business jets, flown in very different missions. In-service flight data, recorded by Digital Flight Data Recorders (DFDRs) is used to arrive at statistical results pertaining to airframe usage and some loads. The comparison of the results from the two airframes highlights the differences in their missions and their usage, which may necessitate different maintenance schedules.

AIRCRAFT AND DATA DESCRIPTION

Aircraft Description

The airframes used for this investigation were both of the Global Express family, manufactured by Bombardier Aerospace Co. One aircraft, the Global 5000, was used in support of the FAA. This aircraft was flown as a business jet, but was also used for various other missions including verification of airspace procedures. Average flight distance for this aircraft was approximately 500 nautical miles. In the latter role, the aircraft was often used for successive touch-and-goes and other relatively low-altitude flights. The second aircraft, the Global Express XRS, was used exclusively as a business jet and was flown over distances that averaged approximately 1,200 nautical miles, with simple Ground-Air-Ground (GAG) cycles. This aircraft is a slightly stretched version of the Global

5000 for added range. From this point on, the two aircraft will be referred to as “the XRS” and “the 5000,” respectively. The missions flown in the 5000 subjected this airframe to almost twice as many GAG cycles per hour, relative to the XRS. Both aircraft were certified for flight up to 51,000 ft and could reach Mach 0.89 in cruise. Some features of the two designs are shown in [Table 1](#).

Table 1. Comparison of the two aircraft [14].

Parameter	Global 5000	Global Express XRS
Performance		
Range at M = 0.85 (nm)	5,200	6,000
Maximum Speed (Mach, KTAS)	0.89 (513)	0.89 (513)
Typical Cruise Speed (Mach, KTAS)	0.85 (488)	0.85 (488)
Maximum Operating Altitude (ft)	51,000	51,000
Geometry		
Length (ft)	96.8	99.4
Height (ft)	25.5	25.5
Wing Span (ft)	94.0	94.0
Wing Area (ft ²)	1,022.0	1,022.0
Weights		
Maximum Takeoff Weight (pounds)	92,500	99,500
Typical Basic Operating Weight (pounds)	50,840	52,230

Recorded Data

Quick Access Recorders (QARs), [15] which are independent recording systems, were installed on both aircraft. These devices record information similar to that of a DFDR, but can store up to 128 channels of data for 1,500 hours of data, as opposed to approximately 25 hours for the latter.

The QAR is an independent recording system that records the same information as does the Flight Data Recorder (FDR). The XRS was equipped with a 128-channel recorder, while 256 channels were recorded on the 5000. The data common between the two recorders that was used for the present investigation and their recording rates are shown in [Table 2](#).

Data Extraction and Processing

In order to extract the pertinent information, a certain degree of preprocessing was required. As indicated in [Table 2](#), various channels were recorded at different rates, but to simplify the analysis, all sample rates were converted to 8 Hz through interpolation. Rate of climb was not a recorded parameter, so it had to be extracted from the time history of altitude. In order to dampen excessive noise in this parameter, altitude recordings were filtered using a two-second running average. Also, accelerometer readings were normalized relative to their initial readings before start of taxi-out.

Indications of Weight On Wheel (WOW) were used to identify takeoff and landing points. Liftoff was marked as the point when WOW signal from *all* three gears showed the aircraft being airborne. Touchdown was when any of the three signals indicated contact with the ground. Therefore, there were periods when not all three WOW signals showed the aircraft being on the ground or being airborne. On takeoff, these were included in the rotation phase, while on landing they were included in the landing roll.

Outside static pressure and temperature were not recorded. Therefore, these were obtained from the recorded altitude, assuming standard atmosphere. Knowing these parameters, true and equivalent airspeeds could be estimated from the indicated airspeed using [Equation \(1\)](#).

Table 2. Some recorded parameters and their recording frequencies.

Parameter	Units	Sample Rate (Hz)
Time	Seconds	8
Indicated Airspeed	Knots	0.5
Pressure Altitude	Feet	1
Total Temperature	Celsius	0.5
Vertical Acceleration	g	8
Longitudinal Acceleration	g	4
Lateral Acceleration	g	4
Heading	degrees	1
Pitch	degrees	4
Roll	degrees	2
GPS Latitude	degrees	1
GPS Longitude	degrees	1
Left Angle of Attack	degrees	1
Right Angle of Attack	degrees	1
Flap	Integer	1
Slat	Integer	1
Weight on Wheel – left	Ground/Air	4
Weight on Wheel – nose	Ground/Air	4
Weight on Wheel – right	Ground/Air	4
Right Engine Fan Speed	Percentage	1
Right Engine Core Speed	Percentage	1
Left Engine Fan Speed	Percentage	1
Left Engine Core Speed	Percentage	1

$$V_i^2 = \frac{2(\gamma RT)}{\gamma - 1} \left\{ \left[\frac{1}{2} \frac{\rho_0 V_i^2}{P} + 1 \right]^{\frac{\gamma-1}{\gamma}} - 1 \right\} \quad (1)$$

Theoretically, it was possible to use the combination of the indicated airspeed and total temperature to serve the same purpose. However, in practice and in light of the inherent characteristics of the recorded parameters, this approach did not result in reliable values of true and equivalent airspeeds.

Flight distance was determined by integrating true airspeed between takeoff and landing

$$D = \sum_{t_{start}}^{t_{end}} V_i \Delta t$$



Flight Phase Identification

Missions were separated into airborne and ground operations. The airborne parts were further separated into seven phases, while six phases were used for the latter parts. The criteria concerning phase recognition and separation are shown in Table 3. These phases are shown schematically in Figure 1. Figure 2 shows the time history of the altitude for a typical flight from the 5000.

Table 3. Conditions for flight phase separation.

Flight Phase	Start Time (t_1) Identification	Stop Time (t_2) Identification
Taxi-Out	Heading change > 20 deg, on ground	(t_1 of Roll) minus 5 sec.
Takeoff Roll	$n_x > 0.15g$, on ground	Pitch change > 3 deg.
Rotation	t_2 of Roll	Pitch > 15 deg or pitch change > 10 deg
Departure	t_2 of Rotation	Flaps retracted
Climb	RC > 750 fpm for 20 sec. and flaps up	RC < 750 fpm for 20 sec. and flaps up
Cruise	$ RC < 200$ fpm for 20 sec. and flaps up	$ \Delta h > 250$ ft and flaps up
Descent	RC < -750 fpm for 20 sec. and flaps up	Flaps are in transit or set to first detent
Initial Approach	Flaps in first detent and RC ≤ 0, in air	Flaps in second or third detent, in air
Mid Approach	Flaps in second detent and RC ≤ 0, in air	Flaps in third detent, in air
Final Approach	Flaps in third detent, in air	Touchdown minus 3 seconds
Landing Roll	t_2 of final approach	Heading change > 5 deg
Runway Turn-Off	t_2 of landing roll	Heading change < 2 deg for 5 sec.
Taxi-In	t_2 of runway turn-off	Engine core < 11% minus 38 sec.

For each flight, aircraft usage and flight loads were examined for the entire flight, as well as for individual phases. In the case of the XRS, more detailed information than given here can be found in Reference 16. The present article contains the highlights plus comparable information about the 5000, with the emphasis placed on comparison of the usage of the two airframes.

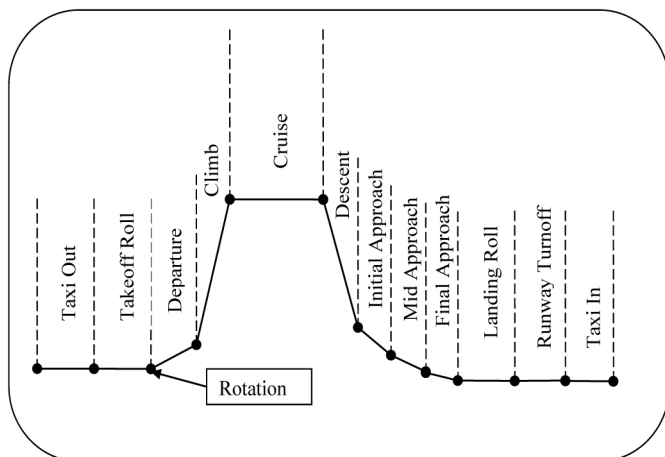


Figure 1. Schematic of various flight phases.

RESULTS AND DISCUSSION

Although the analysis yielded phase-specific results, in the interest of brevity, most of the results discussed below will be limited to the

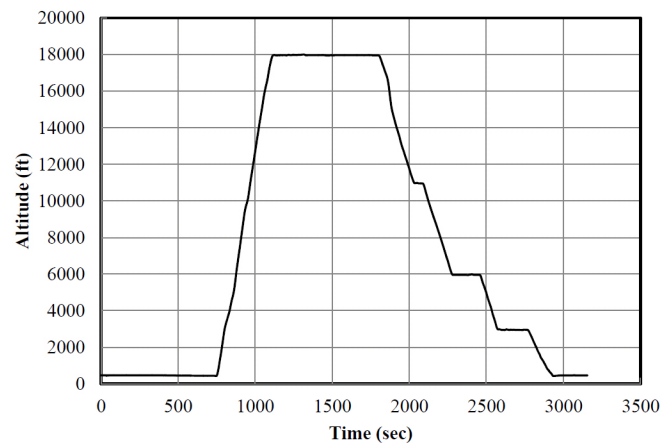


Figure 2. Altitude time history of one flight.

GAG cycles. Some phase-specific results will be examined here, where necessary.

Distance, Duration, and Airspeed

Recorded data constituted 242 files from the 5000 and 544 files from the XRS. The 5000 was used for multiple touch-and-goes and numerous short flights, while the XRS was not. After separating individual flights and removing the data files that did not contain useful information, data from 382 distinct flights from the 5000 and 409 flights from the XRS remained. Collectively, they amounted to 582 hours (193,932 nm) and 1,137 hours (492,162 nm) of flight time from the 5000 and the XRS, respectively. Therefore the 5000 was subjected to almost as many GAG cycles as was the XRS, but in half as much time. This is also evident in Figure 3 that shows almost two-thirds of the flights in the 5000 were shorter than 500 nautical miles and the average distance flown was less than half of that of the XRS. The summary of the available data is shown in Table 4. It is obvious that each of the GAG cycles involved cycling of the flaps and the landing gear, in addition to cyclic fuselage pressurization.

Figures 4 and 5 show the maximum altitudes and duration with coincident distance. As indicated in Figure 4, most of the flights longer than 500 nautical miles were flown at altitudes between 36,000 and 48,000 feet. These aircraft are certified for flights up to 51,000 feet, but no such flight was detected in the available data. Generally, flights lasting shorter than one hour were flown at altitudes of 30,000 or less. Furthermore, a clear correlation between the maximum distance and duration flown in the XRS can be observed in Figure 5. This was purely due to the fact that this airframe was used only for transportation, with little variation in its missions, whereas the 5000 was used for a variety of purposes.