Fleet Usage Impact on Crack Growth Life

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AFGROW Users Workshop 2024

Fleet Usage

Aircraft utilization directly affects key operational parameters which are essential to ensuring structural integrity:

- Aircraft Utilization can affect many parameters such as:
    - Duration of flight
    - Gross Weight and Fuel Weight
    - Payload
    - Airspeed
    - Altitude
- Impact to Operational Parameters can have significant effects on:
    - Aircraft External Loads
    - Operational Loads Encountered
    - Dynamic Responses

Fleet Usage

- For commercial aircraft, during the design process, the planned operational flights are determined and used for the certification effort.
- As a result, every effort is made to make conservative assumptions of the planned utilization and flights are usually categorized simply as: Short, Medium and Long missions.
- There is no commercial regulatory requirement to perform structural integrity updates based on actual utilization data for individual operators.
- Due to the recent escalation in passenger travel requirements, airlines have significantly changed operational utilization to meet demand.

Examples of Recent Changes

- Narrowbody aircraft are becoming more popular for long-haul flights due to technology advances, efficiency and cost savings.
    - Up to 30% Fuel Savings
    - Increased flight frequency due to reduced turn around time

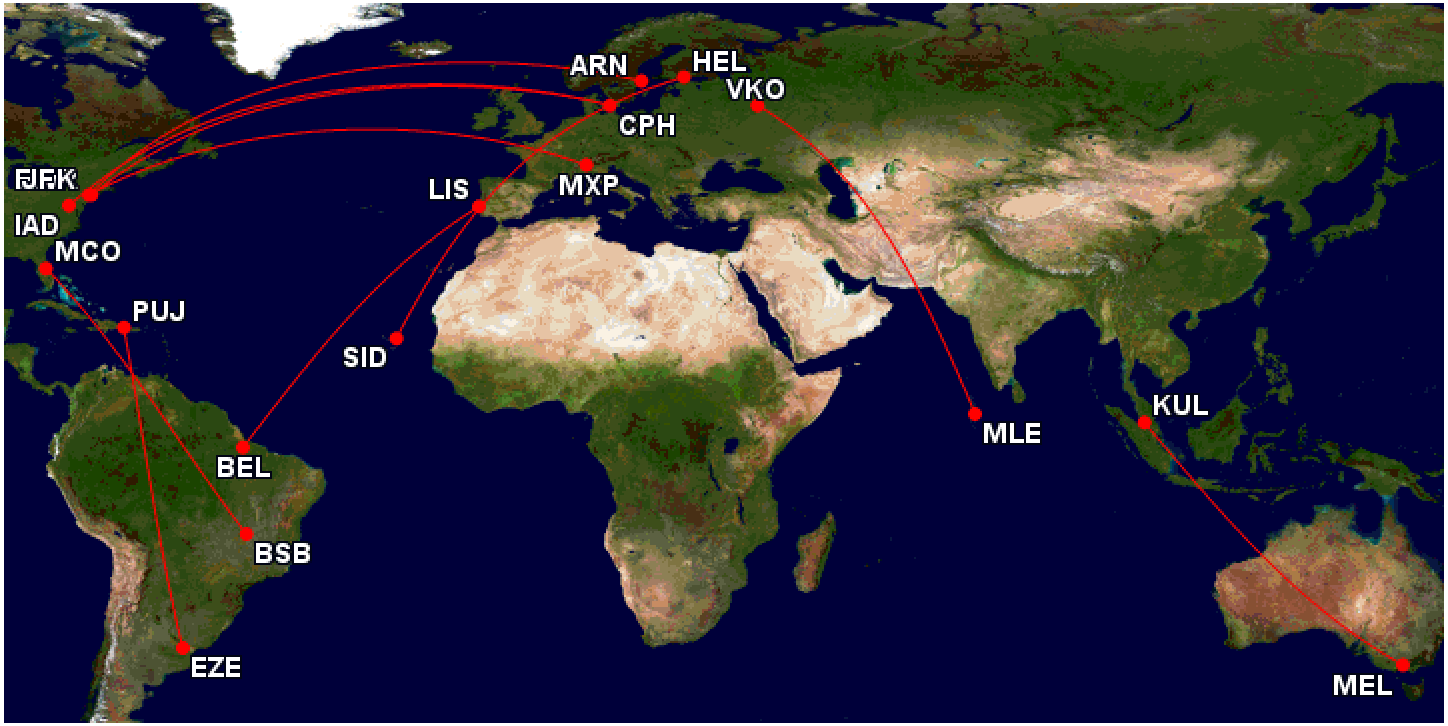
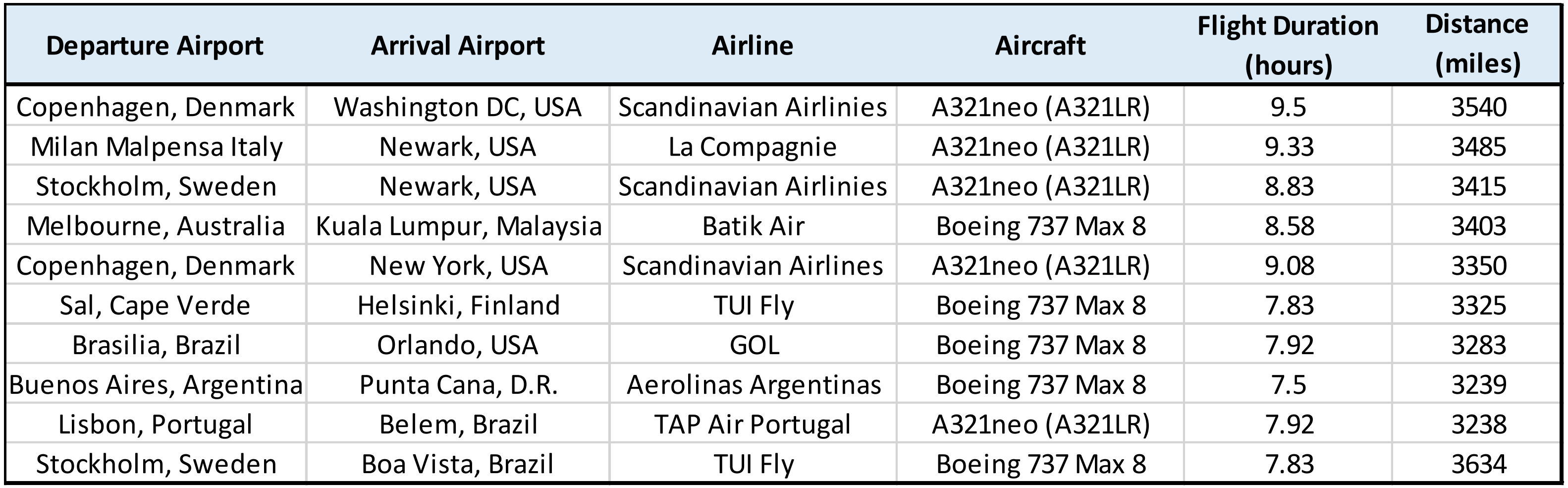


Fig. 1 Narrowbody (A321 and 737Max) Lond Distance Flights

Ref. https://samchui.com/2023/02/25/the-10-longest-narrow-body-flights-in-the-world/

Examples of Recent Changes

- Long routes for narrowbody aircraft will have a significant impact on operational loads due to the duration of the flight.



Departure Airport	Arrival Airport	Airline	Aircraft	Flight Duration (hours)	Distance (miles)
Copenhagen, Denmark	Washington DC, USA	Scandinavian Airlinies	A321neo (A321LR)	9.5	3540
Milan Malpensa Italy	Newark, USA	La Compagnie	A321neo (A321LR)	9.33	3485
Stockholm, Sweden	Newark, USA	Scandinavian Airlinies	A321neo (A321LR)	8.83	3415
Melbourne, Australia	Kuala Lumpur, Malaysia	Batik Air	Boeing 737 Max 8	8.58	3403
Copenhagen, Denmark	New York, USA	Scandinavian Airlines	A321neo (A321LR)	9.08	3350
Sal, Cape Verde	Helsinki, Finland	TUI Fly	Boeing 737 Max 8	7.83	3325
Brasilia, Brazil	Orlando, USA	GOL	Boeing 737 Max 8	7.92	3283
Buenos Aires, Argentina	Punta Cana, D.R.	Aerolinas Argentinas	Boeing 737 Max 8	7.5	3239
Lisbon, Portugal	Belem, Brazil	TAP Air Portugal	A321neo (A321LR)	7.92	3238
Stockholm, Sweden	Boa Vista, Brazil	TUI Fly	Boeing 737 Max 8	7.83	3634

Fig. 2 Narrowbody Longest Routes

- Very long flights for narrowbody aircraft will expose the airframe to higher gross weights and also longer exposure to loads such as the gust environment.
- Such changes can have a significant impact on the continued airworthiness of the airframe.

Examples of Recent Changes

- Long routes on narrow bodies are not isolated cases. In fact, they are standard routes.
  - Example: Airline: La Compagnie, France
    Route: Milan, Italy to New York
    Duration: 9:05 hours
    Aircraft Model : A321-251NX
    Aircraft: Serial Number 09131, Registry F-HNCO

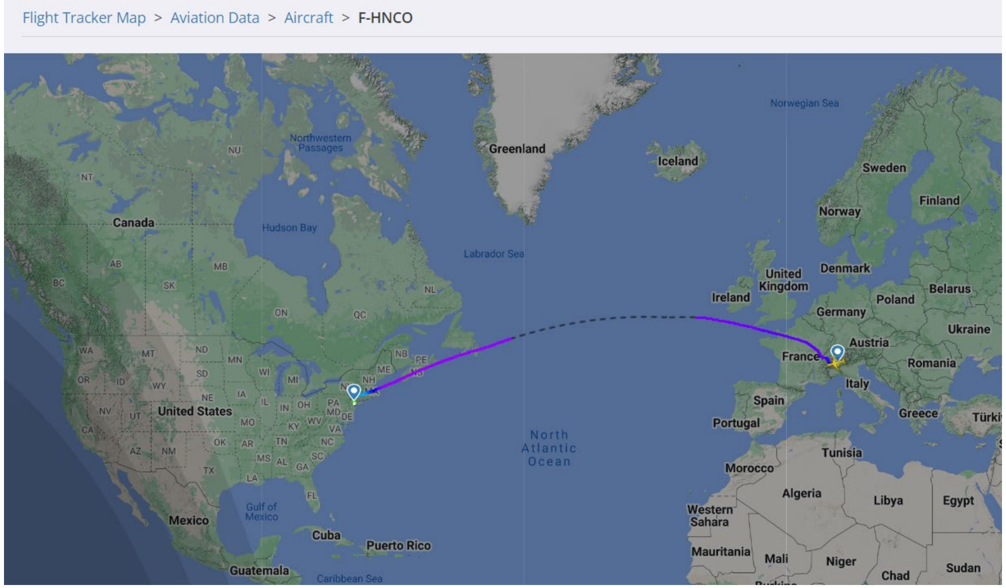


Fig. 3 A321 9 Hour Transatlantic Flight

Source: FlightRadar 24
Aircraft: A321-251 SN09131
Time Period: 8-8-23 to 8-7-24
Total # of Flights: 718 flights
Total # of Hours: 5148 flight hours
Average Flight Time: 7.2 hours

Note: current commercial software and apps do provide basic information but do not provide details such as ground versus flight time, gross weight, payload, etc. and only go back a couple of years.

Usage Approaches

Aircraft Utilization has a direct impact on structural integrity and is therefore addressed for both commercial and military aircraft but in a different manner.

- Commercial aviation must conservatively predict usage during the design phase
- Military aviation employs an ASIP approach which includes fleet monitoring

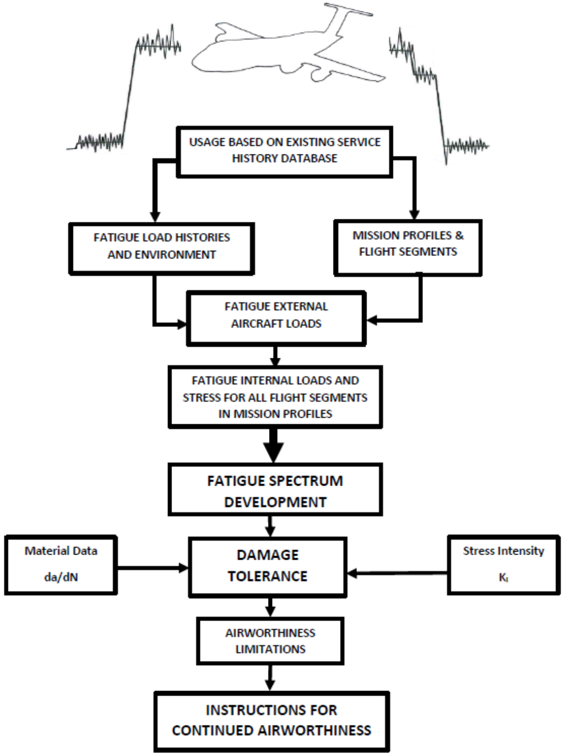


Fig. 4 Commercial Approach

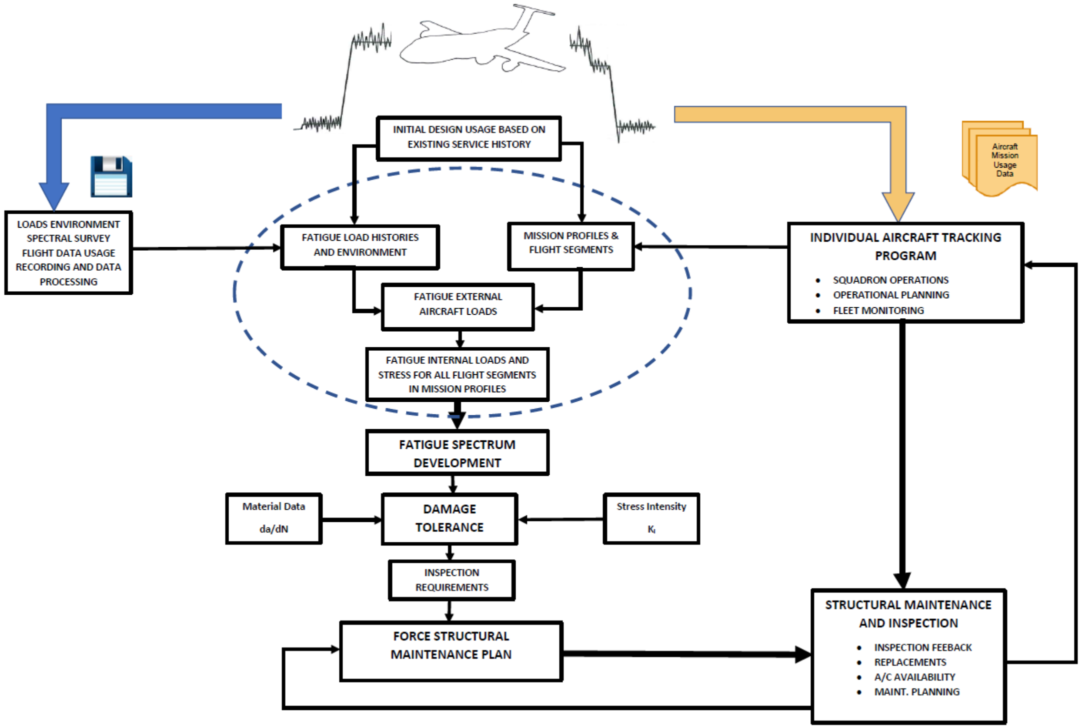


Fig. 5 Military ASIP Approach

Available Usage Data

Commercial regulations do not specifically mandate updates to continued airworthiness. Only in extreme restricted category operations is this required. However, operational usage is monitored and available to the public.

- FAA has sponsored operational loads monitoring and published dozens of aircraft model specific operational loads reports (see DOT/FAA series documents)
- The Department of Transportation has also monitored and recorded the operational usage of over 400 aircraft types for the following:
- All commercial flights within the USA
- All international flights originating from the USA to a foreign country or arriving to a USA airport from a foreign country
- The DOT has organized this into a database of usage which goes back to 1990
- The DOT database catalogues by month and year each and every flight with details on the type of aircraft, number of passengers, gross weight, payload, ground and flight duration.

Available Usage Data

Large Transport

One source of flight duration type usage data for US and Foreign air carries is available thru the Bureau of Transportation Statistics. The Bureau manages a database of all air carrier flights from 1990 to present. Data from December 2005 to present is available directly from the website. The website can be accessed at:

https://www.bts.gov/airline-data-downloads

The database provides a listing of all routes flown daily by each carrier with the type of aircraft and number of passengers carried. In order to use the database, the codes for each parameter are necessary but these can be obtained from the website. Data provided includes:

- **Airline**
- **Point of Departure & Arrival**
- **Payload**
- **Ramp Time**
- **Flight Time**
- **Distance Flown**
- **# of Passengers Carried**
- **Weight of Freight Carried**
- **Aircraft Type**

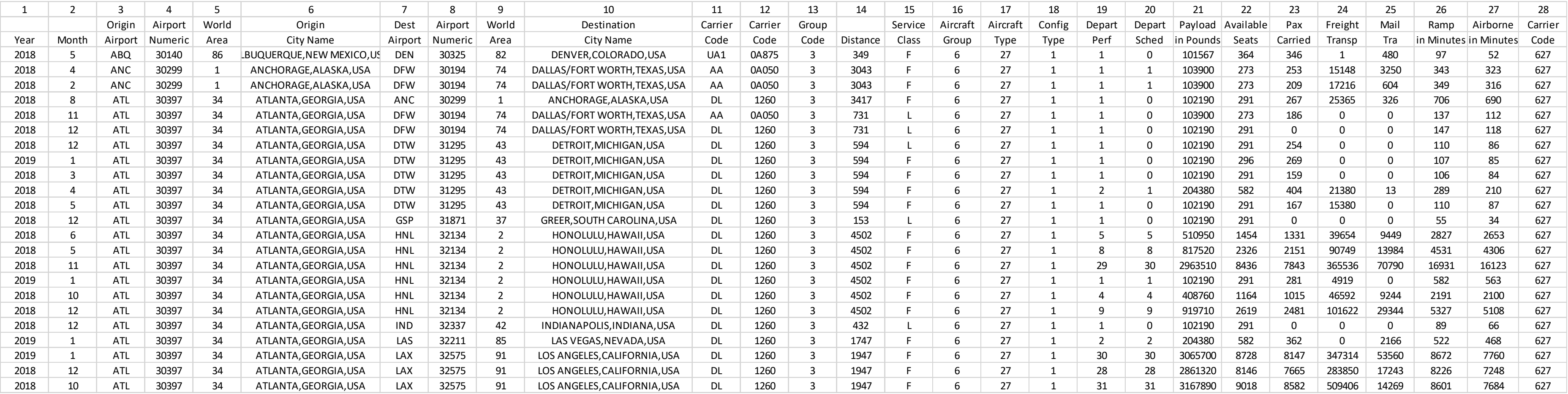
Major benefit of database is that is provides a source for establishing usage data in terms of types of missions flown and flight lengths. Since the usage data spans over 30 years, it provides a very comprehensive look at the operational usage of each aircraft type which includes over 400 types.

Available Usage Data

Large Transport

The following is an example of a portion of the record for the year 2018. Note that the information is recorded by year, month and day and organized by departure location and destination. The data includes the air carrier's identity, aircraft model, payload, number of passengers and flight duration.

This type of data can readily be used to identify over a length of time the most common flight durations flown by a given aircraft type.



1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
		Origin	Airport	World	Origin	Dest	Airport	World	Destination	Carrier	Carrier	Group		Service	Aircraft	Aircraft	Config	Depart	Depart	Payload	Available	Pax	Freight	Mail	Ramp	Airborne	Carrier
Year	Month	Airport	Numeric	Area	City Name	Airport	Numeric	Area	City Name	Code	Code	Code	Distance	Class	Group	Type	Type	Perf	Sched	in Pounds	Seats	Carried	Transp	Tra	in Minutes	in Minutes	Code
2018	5	ABQ	30140	86	LBUQUERQUE,NEW MEXICO,US	DEN	30325	82	DENVER,COLORADO,USA	UA1	0A875	3	349	F	6	27	1	1	0	101567	364	346	1	480	97	52	627
2018	4	ANC	30299	1	ANCHORAGE,ALASKA,USA	DFW	30194	74	DALLAS/FORT WORTH,TEXAS,USA	AA	0A050	3	3043	F	6	27	1	1	1	103900	273	253	15148	3250	343	323	627
2018	2	ANC	30299	1	ANCHORAGE,ALASKA,USA	DFW	30194	74	DALLAS/FORT WORTH,TEXAS,USA	AA	0A050	3	3043	F	6	27	1	1	1	103900	273	209	17216	604	349	316	627
2018	8	ATL	30397	34	ATLANTA,GEORGIA,USA	ANC	30299	1	ANCHORAGE,ALASKA,USA	DL	1260	3	3417	F	6	27	1	1	0	102190	291	267	25365	326	706	690	627
2018	11	ATL	30397	34	ATLANTA,GEORGIA,USA	DFW	30194	74	DALLAS/FORT WORTH,TEXAS,USA	AA	0A050	3	731	L	6	27	1	1	0	103900	273	186	0	0	137	112	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	DFW	30194	74	DALLAS/FORT WORTH,TEXAS,USA	DL	1260	3	731	L	6	27	1	1	0	102190	291	0	0	0	147	118	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	DTW	31295	43	DETROIT,MICHIGAN,USA	DL	1260	3	594	L	6	27	1	1	0	102190	291	254	0	0	110	86	627
2019	1	ATL	30397	34	ATLANTA,GEORGIA,USA	DTW	31295	43	DETROIT,MICHIGAN,USA	DL	1260	3	594	F	6	27	1	1	0	102190	296	269	0	0	107	85	627
2018	3	ATL	30397	34	ATLANTA,GEORGIA,USA	DTW	31295	43	DETROIT,MICHIGAN,USA	DL	1260	3	594	F	6	27	1	1	0	102190	291	159	0	0	106	84	627
2018	4	ATL	30397	34	ATLANTA,GEORGIA,USA	DTW	31295	43	DETROIT,MICHIGAN,USA	DL	1260	3	594	F	6	27	1	2	1	204380	582	404	21380	13	289	210	627
2018	5	ATL	30397	34	ATLANTA,GEORGIA,USA	DTW	31295	43	DETROIT,MICHIGAN,USA	DL	1260	3	594	F	6	27	1	1	0	102190	291	167	15380	0	110	87	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	GSP	31871	37	GREER,SOUTH CAROLINA,USA	DL	1260	3	153	L	6	27	1	1	0	102190	291	0	0	0	55	34	627
2018	6	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	5	5	510950	1454	1331	39654	9449	2827	2653	627
2018	5	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	8	8	817520	2326	2151	90749	13984	4531	4306	627
2018	11	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	29	30	2963510	8436	7843	365536	70790	16931	16123	627
2019	1	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	1	1	102190	291	281	4919	0	582	563	627
2018	10	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	4	4	408760	1164	1015	46592	9244	2191	2100	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	HNL	32134	2	HONOLULU,HAWAII,USA	DL	1260	3	4502	F	6	27	1	9	9	919710	2619	2481	101622	29344	5327	5108	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	IND	32337	42	INDIANAPOLIS,INDIANA,USA	DL	1260	3	432	L	6	27	1	1	0	102190	291	0	0	0	89	66	627
2019	1	ATL	30397	34	ATLANTA,GEORGIA,USA	LAS	32211	85	LAS VEGAS,NEVADA,USA	DL	1260	3	1747	F	6	27	1	2	2	204380	582	362	0	2166	522	468	627
2019	1	ATL	30397	34	ATLANTA,GEORGIA,USA	LAX	32575	91	LOS ANGELES,CALIFORNIA,USA	DL	1260	3	1947	F	6	27	1	30	30	3065700	8728	8147	347314	53560	8672	7760	627
2018	12	ATL	30397	34	ATLANTA,GEORGIA,USA	LAX	32575	91	LOS ANGELES,CALIFORNIA,USA	DL	1260	3	1947	F	6	27	1	28	28	2861320	8146	7665	283850	17243	8226	7248	627
2018	10	ATL	30397	34	ATLANTA,GEORGIA,USA	LAX	32575	91	LOS ANGELES,CALIFORNIA,USA	DL	1260	3	1947	F	6	27	1	31	31	3167890	9018	8582	509406	14269	8601	7684	627

Fig. 6 DOT Airline Usage Sample

Available Usage Data

Large Transport

By focusing on some of the more relevant data items, it is easier to see the usefulness of the database. The following shows an abbreviated subset of the data focusing on flight distance, payload, passengers and ramp time and flight time.

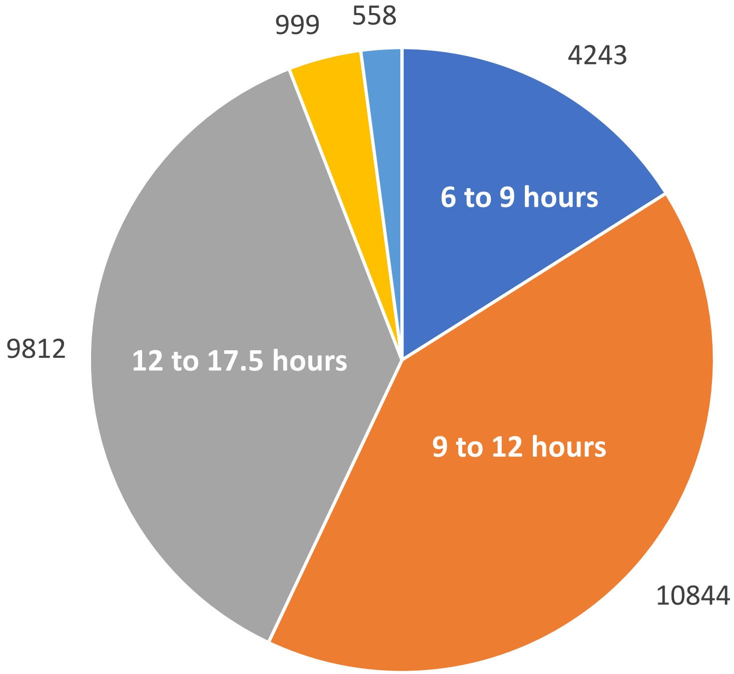
1	6	7	10	14	17	21	22	23	24	26	27
	Origin	Dest	Destination		Aircraft	Payload	Available	Pax	Freight	Ramp	Airborne
Year	City Name	Airport	City Name	Distance	Type	in Pounds	Seats	Carried	Transp	in Minutes	in Minutes
2018	ALBUQUERQUE,NEW MEXICO,USA	DEN	DENVER,COLORADO,USA	349	27	101567	364	346	1	97	52
2018	ANCHORAGE,ALASKA,USA	DFW	DALLAS/FORT WORTH,TEXAS,USA	3043	27	103900	273	253	15148	343	323
2018	ANCHORAGE,ALASKA,USA	DFW	DALLAS/FORT WORTH,TEXAS,USA	3043	27	103900	273	209	17216	349	316
2018	ATLANTA,GEORGIA,USA	ANC	ANCHORAGE,ALASKA,USA	3417	27	102190	291	267	25365	706	690
2018	ATLANTA,GEORGIA,USA	DFW	DALLAS/FORT WORTH,TEXAS,USA	731	27	103900	273	186	0	137	112
2018	ATLANTA,GEORGIA,USA	DFW	DALLAS/FORT WORTH,TEXAS,USA	731	27	102190	291	0	0	147	118
2018	ATLANTA,GEORGIA,USA	DTW	DETROIT,MICHIGAN,USA	594	27	102190	291	254	0	110	86
2019	ATLANTA,GEORGIA,USA	DTW	DETROIT,MICHIGAN,USA	594	27	102190	296	269	0	107	85
2018	ATLANTA,GEORGIA,USA	DTW	DETROIT,MICHIGAN,USA	594	27	102190	291	159	0	106	84
2018	ATLANTA,GEORGIA,USA	DTW	DETROIT,MICHIGAN,USA	594	27	204380	582	404	21380	289	210
2018	ATLANTA,GEORGIA,USA	DTW	DETROIT,MICHIGAN,USA	594	27	102190	291	167	15380	110	87
2018	ATLANTA,GEORGIA,USA	GSP	GREER,SOUTH CAROLINA,USA	153	27	102190	291	0	0	55	34

Fig. 7 DOT Usage Details

Available Usage Data

Large Transport

The following is an example of mission length utilization rates based on the airline usage data from the International Flight Database. This is for the 777 for a period of 12 months from 2022 to 2023.



Mission Type	# of Flts	Description	% Usage
Very Long	4243	Very Long 12 to 17.5 hours	16%
Long	10844	Long 9 to 12 Hours	41%
Medium-Long	9812	Medium to Long 6 to 9 Hours	37%
Short-Medium	999	Short to Medium 3 to 6 Hours	4%
Short	558	Short 1 to 3 Hours	2%
Total flights =	26456		

Max flight time = 1054
Max in hours = 17.57

Min flight time = 57
Min in hours = 1.0

Fig. 8 Operational Usage Data for 777 International Fleet over 12 Months 2022 to 2023

Usage Impact Methods

Current commercial industry trend does not account for changes in usage as there is no regulatory requirement to do so. Typical industry approaches attempt to use simplified GAG (ground-air-ground) or SEC (single equivalent cycle) methods to account for how aircraft is flown and utilized.

The following presentation details and compares a DTA evaluation using the FAA Service Load Histories versus that of a pseudo equivalent single cycle (SEC) per flight to evaluate the impact of usage.

Flight by Flight Method (FBF):

- FAA Recorded Load Histories in a Flight by Flight Sequenced Program utilizing the 777-200 data contained in DOT/FAA/AR-06/11

Single Equivalent Cycle (SEC) based on Material Data Only assuming 1 cycle/flight or hour and does not account for aircraft configuration or usage:

- TC-12/17 Development and Assessment of Simplified Stress Sequences

Usage Impact Example - Widebody

Aft Upper Crown at Stringer 1 for a 122” Fuselage Radius

2024-T3 Clad 0.07” Sheet Skin with 7075-T6 Sheet Stringers

Geometry Consists of a 3 Frame Bay x 2 Stringer Bay Doubler

Example 1: 6 inch wide 0.07” sheet with 0.188” centered countersunk hole

DTA: single 0.05” corner crack from 0.188” countersunk hole no load transfer

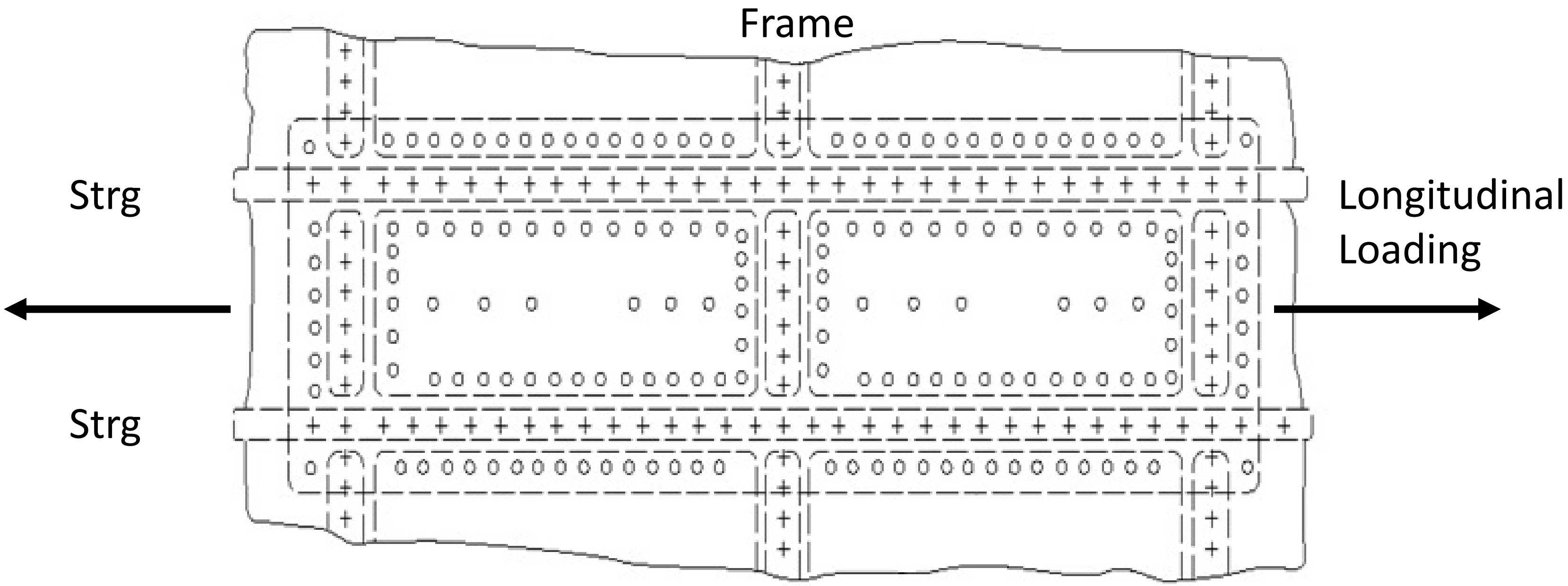


Fig. 9 Example 1 – 777 Fuselage Crown (Ref. FAA AC 120-104 Fig. 5-13)

Usage Impact Example - Widebody

Comparison of compliance for FBF spectrum method versus the SEC method:

FBF Method (using Aeronautica's Aspec Software):
- Utilizes mission profiles, usage and flight segment definition
- Accounts for effective load sources such as gust, maneuver, landing, taxi, etc.
- Accounts for dynamic effects due to gust, landing and taxi
- Utilizes FAA developed recorded statistical typical load histories
- Incorporates fuselage pressure as well as aero pressures
- Supports WFD/LOV Evaluation per FAR 25.571 and FAR 26

SEC Method:
- Utilizes only Static Strength Material Ftu properties
- Assumes OEM based MS = 0 on Ftu and ignores Combined Panel Ftu allowable based MS
- Assumes 2.5g Maneuver is only critical condition
- Ignores Touchdown/Landing Impact could be critical from which PR/2t cannot be subtracted
- Assumes an R ratio of 0 and an alternating load of +/- 0.3g
- Does not account for dynamic effects
- Does not account for any mission usage, weights, or specific load sources
- Unlikely to support any WFD/LOV Evaluations per FAR 25.571 and FAR 26

Usage Impact Example - Widebody

FBF Spectrum Process begins with Mission Profile definition and flight segment description:

- FAA and Industry Data is Utilized to Establish Missions and Flight Segments (DOT/FAA/AR-06/11 for the 777-200, Bureau of Transportation Usage Statistics, FAA SDR database)
- 777 Usage obtained from review of DOT Monthly Utilization Data:

https://www.bts.gov/airline-data-downloads

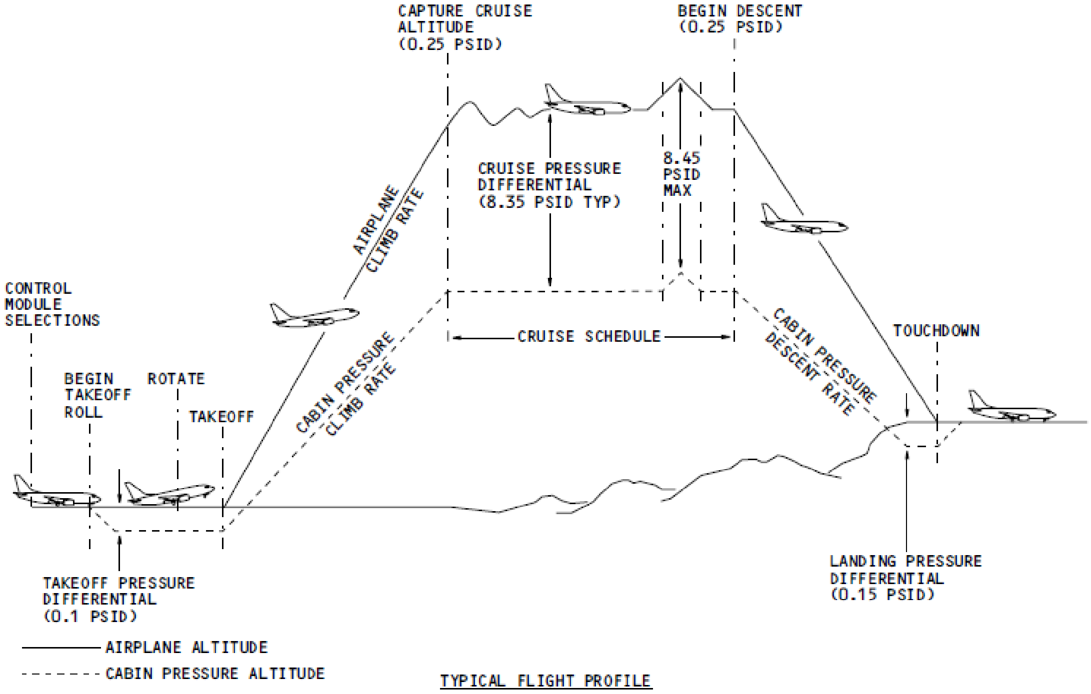
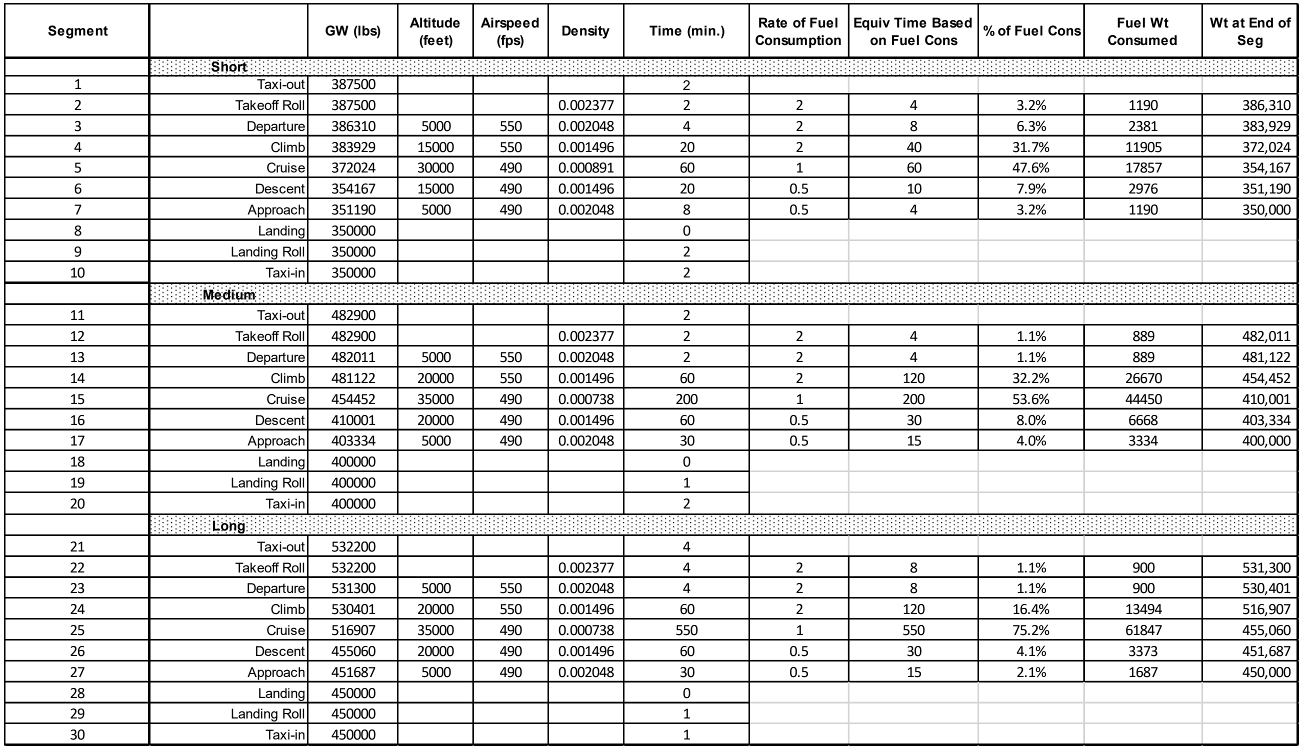


Fig. 10 Mission Profile

Usage Impact Example - Widebody

Based on the mission profile flight length and utilization, performance and take off and landing weights, each of the flight segments can be defined as follows:



Segment		GW (lbs)	Altitude (feet)	Airspeed (fps)	Density	Time (min.)	Rate of Fuel Consumption	Equiv Time Based on Fuel Cons	% of Fuel Cons	Fuel Wt Consumed	Wt at End of Seg
	Short										
1	Taxi-out	387500				2					
2	Takeoff Roll	387500			0.002377	2	2	4	3.2%	1190	386,310
3	Departure	386310	5000	550	0.002048	4	2	8	6.3%	2381	383,929
4	Climb	383929	15000	550	0.001496	20	2	40	31.7%	11905	372,024
5	Cruise	372024	30000	490	0.000891	60	1	60	47.6%	17857	354,167
6	Descent	354167	15000	490	0.001496	20	0.5	10	7.9%	2976	351,190
7	Approach	351190	5000	490	0.002048	8	0.5	4	3.2%	1190	350,000
8	Landing	350000				0					
9	Landing Roll	350000				2					
10	Taxi-in	350000				2					
	Medium										
11	Taxi-out	482900				2					
12	Takeoff Roll	482900			0.002377	2	2	4	1.1%	889	482,011
13	Departure	482011	5000	550	0.002048	2	2	4	1.1%	889	481,122
14	Climb	481122	20000	550	0.001496	60	2	120	32.2%	26670	454,452
15	Cruise	454452	35000	490	0.000738	200	1	200	53.6%	44450	410,001
16	Descent	410001	20000	490	0.001496	60	0.5	30	8.0%	6668	403,334
17	Approach	403334	5000	490	0.002048	30	0.5	15	4.0%	3334	400,000
18	Landing	400000				0					
19	Landing Roll	400000				1					
20	Taxi-in	400000				2					
	Long										
21	Taxi-out	532200				4					
22	Takeoff Roll	532200			0.002377	4	2	8	1.1%	900	531,300
23	Departure	531300	5000	550	0.002048	4	2	8	1.1%	900	530,401
24	Climb	530401	20000	550	0.001496	60	2	120	16.4%	13494	516,907
25	Cruise	516907	35000	490	0.000738	550	1	550	75.2%	61847	455,060
26	Descent	455060	20000	490	0.001496	60	0.5	30	4.1%	3373	451,687
27	Approach	451687	5000	490	0.002048	30	0.5	15	2.1%	1687	450,000
28	Landing	450000				0					
29	Landing Roll	450000				1					
30	Taxi-in	450000				1					

Fig. 11 777-200 Mission Profile Flight Segment Fatigue Load Condition Definitions

Usage Impact Example - Widebody

Recorded Statistical Fatigue Loads are Obtained for each relevant flight segment from FAA/Industry Data:

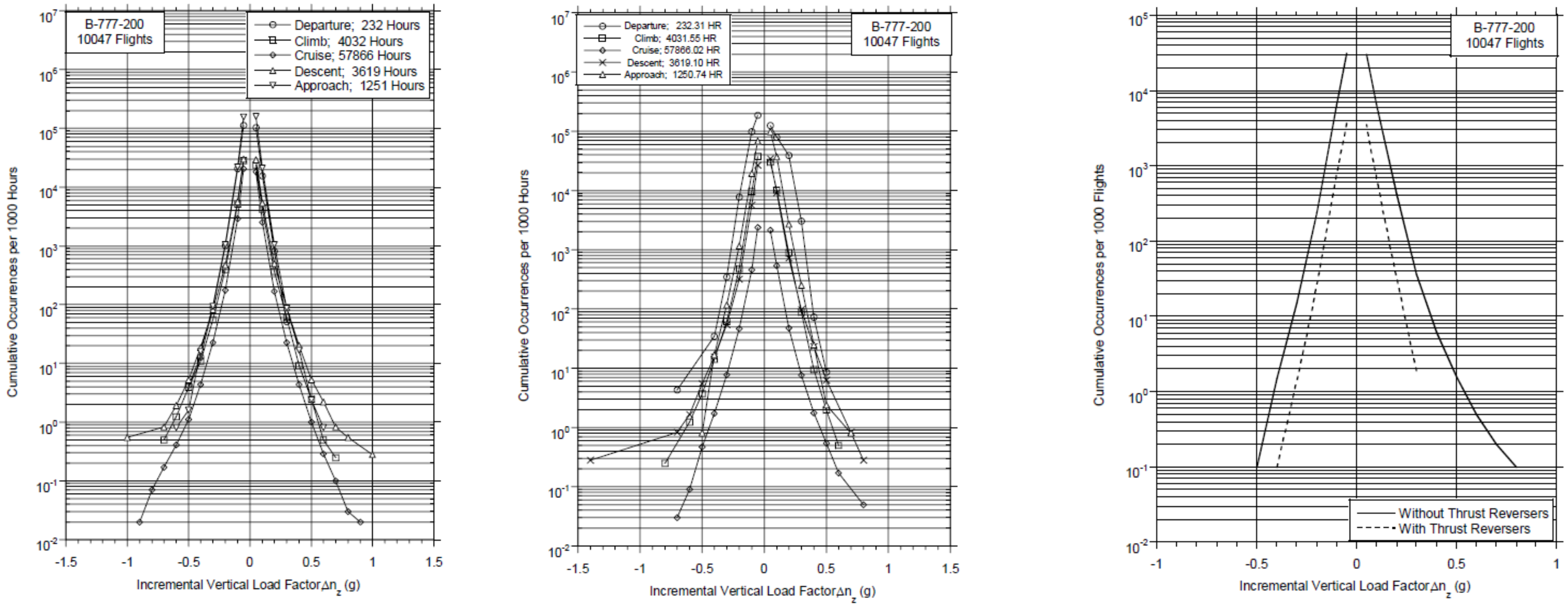


Figure C-41. Cumulative Occurrences of Incremental Vertical Gust Load Factor per 1000 Hours by Flight Phase

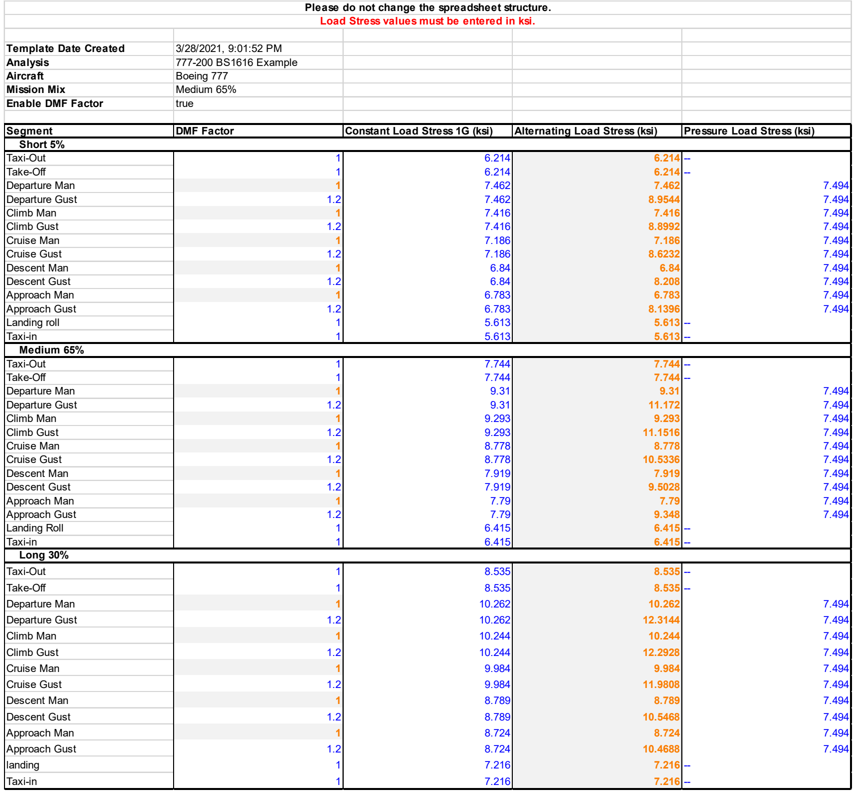
Figure C-69. Cumulative Occurrences of Incremental Vertical Maneuver Load Factor per 1000 Hours by Flight Phase

Figure C-35. Cumulative Frequency of Incremental Vertical Load Factor During Landing Roll

Fig. 12 777-200 Selected Load Histories for Discretization

Usage Impact Example - Widebody

The next step involves entering this data along with the load histories, mission definitions and usage into the Aspec flight by flight spectrum program. Note, example uses the s DMF of 1.2 and accounts for the internal PR/2t pressure stress of 7.494 ksi.



Please do not change the spreadsheet structure.

Load Stress values must be entered in ksi.

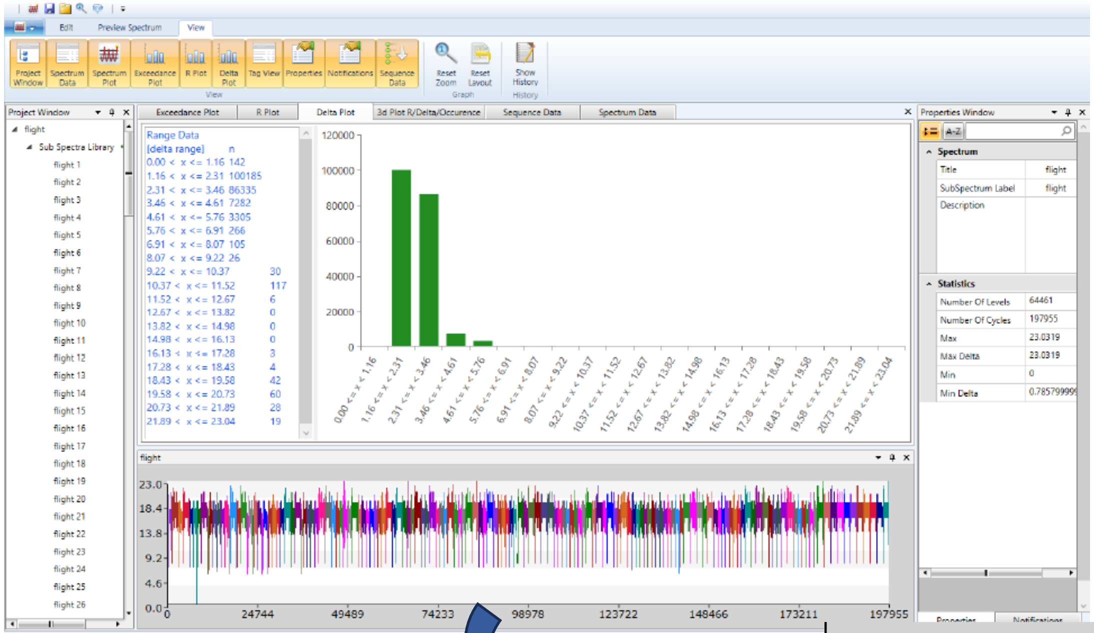
Template Date Created	3/28/2021, 9:01:52 PM
Analysis	777-200 BS1616 Example
Aircraft	Boeing 777
Mission Mix	Medium 65%
Enable DMF Factor	true

Segment	**DMF Factor**	**Constant Load Stress 1G (ksi)**	**Alternating Load Stress (ksi)**	**Pressure Load Stress (ksi)**
Short 5%				
Taxi-Out	1	6.214	6.214	--
Take-Off	1	6.214	6.214	--
Departure Man	1	7.462	7.462	7.494
Departure Gust	1.2	7.462	8.9544	7.494
Climb Man	1	7.416	7.416	7.494
Climb Gust	1.2	7.416	8.8992	7.494
Cruise Man	1	7.186	7.186	7.494
Cruise Gust	1.2	7.186	8.6232	7.494
Descent Man	1	6.84	6.84	7.494
Descent Gust	1.2	6.84	8.208	7.494
Approach Man	1	6.783	6.783	7.494
Approach Gust	1.2	6.783	8.1396	7.494
Landing roll	1	5.613	5.613	--
Taxi-in	1	5.613	5.613	--
Medium 65%				
Taxi-Out	1	7.744	7.744	--
Take-Off	1	7.744	7.744	--
Departure Man	1	9.31	9.31	7.494
Departure Gust	1.2	9.31	11.172	7.494
Climb Man	1	9.293	9.293	7.494
Climb Gust	1.2	9.293	11.1516	7.494
Cruise Man	1	8.778	8.778	7.494
Cruise Gust	1.2	8.778	10.5336	7.494
Descent Man	1	7.919	7.919	7.494
Descent Gust	1.2	7.919	9.5028	7.494
Approach Man	1	7.79	7.79	7.494
Approach Gust	1.2	7.79	9.348	7.494
Landing Roll	1	6.415	6.415	--
Taxi-in	1	6.415	6.415	--
Long 30%				
Taxi-Out	1	8.535	8.535	--
Take-Off	1	8.535	8.535	--
Departure Man	1	10.262	10.262	7.494
Departure Gust	1.2	10.262	12.3144	7.494
Climb Man	1	10.244	10.244	7.494
Climb Gust	1.2	10.244	12.2928	7.494
Cruise Man	1	9.984	9.984	7.494
Cruise Gust	1.2	9.984	11.9808	7.494
Descent Man	1	8.789	8.789	7.494
Descent Gust	1.2	8.789	10.5468	7.494
Approach Man	1	8.724	8.724	7.494
Approach Gust	1.2	8.724	10.4688	7.494
landing	1	7.216	7.216	--
Taxi-in	1	7.216	7.216	--

Fig. 13 Example 1g, Alternating and Pressure Stress in Crown Example

Usage Impact Example - Widebody

Based on the data entered for the aft upper fuselage crown, a spectrum consisting of 1183 flight hours representing 156 flights was developed. A plot of the Aspec generated flight with the maximum stress is shown below using Afgrow's Spectrum Manager:



Range Data

[delta range]	n
0.00 < x <= 1.16	142
1.16 < x <= 2.31	100185
2.31 < x <= 3.46	86335
3.46 < x <= 4.61	7282
4.61 < x <= 5.76	3305
5.76 < x <= 6.91	266
6.91 < x <= 8.07	105
8.07 < x <= 9.22	26
9.22 < x <= 10.37	30
10.37 < x <= 11.52	117
11.52 < x <= 12.67	6
12.67 < x <= 13.82	0
13.82 < x <= 14.98	0
14.98 < x <= 16.13	0
16.13 < x <= 17.28	3
17.28 < x <= 18.43	4
18.43 < x <= 19.58	42
19.58 < x <= 20.73	60
20.73 < x <= 21.89	28
21.89 < x <= 23.04	19

Spectrum

Title	flight
SubSpectrum Label	flight
Description	

Statistics

Number Of Levels	64461
Number Of Cycles	197955
Max	23.0319
Max Delta	23.0319
Min	0
Min Delta	0.78579999

Widebody Mission Mix:

Total Flights = 156 Flights

Total Time = 1183 Hours

Max Stress = 23.032 ksi

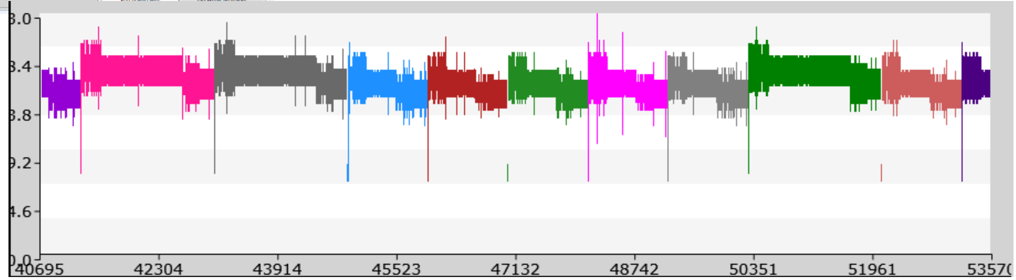


Fig. 14 Sample Flight 44 from Example Widebody Spectrum

Usage Impact Example - Widebody

The UDRI method simply utilizes the material Ftu, the fuselage radius and skin thickness and internal fuselage pressure. Then, it assumes that 2.5g Maneuver is the critical condition:

777-200:

Fuselage Radius= 122”

Fuselage Skin = 0.070”

Fuselage Pressure = 8.6 psi

2024-T3 Ftu (B-basis) = 61 ksi

Ckd = 0.88 knockdown factor (no source – unsubstantiat

1g Longitudinal Fatigue Stress = 10.934 ksi

PR/2t pressure stress = 7.494 ksi

Once per Flight Delta Nz = 0.3

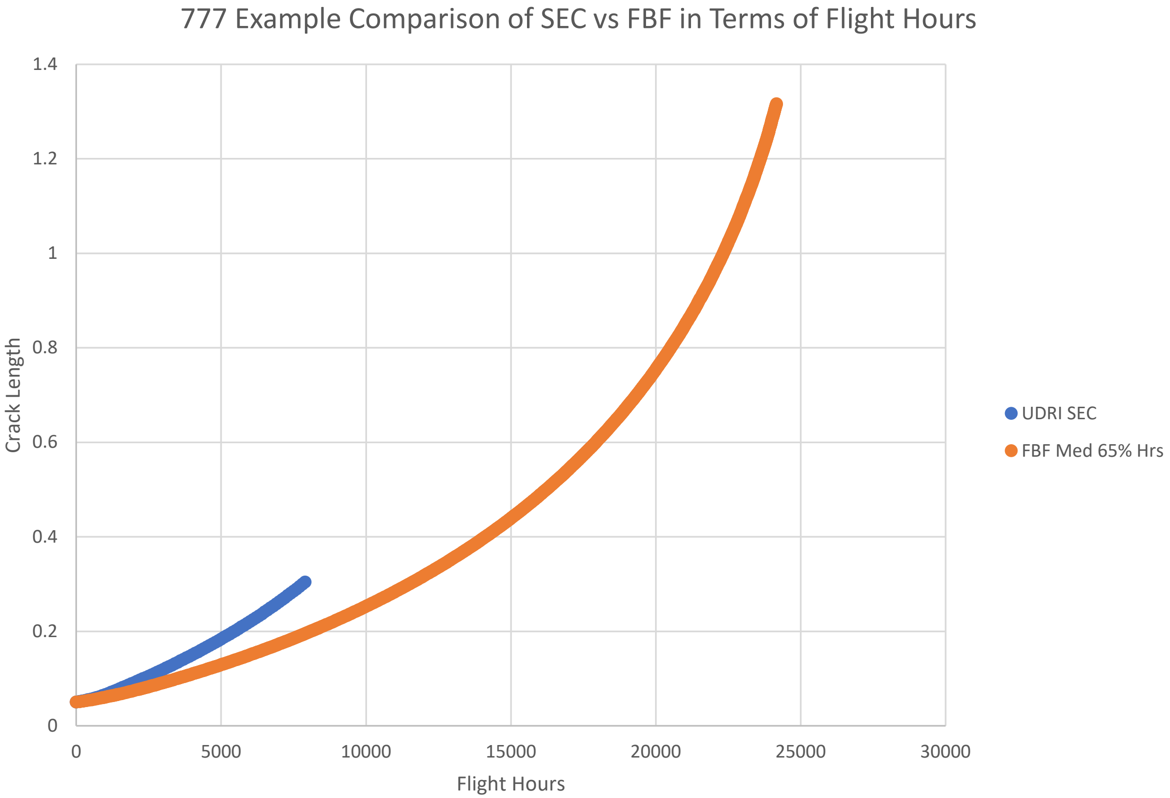
$$\sigma_{1g} = \frac{C_{kd}\left(\frac{F_{tu}}{1.5}\right) - \frac{(\Delta P + 1.1)r}{2t}}{2.5}$$

Once Per Flight SEC = (1g stress + 0.3g*1g stress)+ PR/2t = 10.934*1.3 + 7.494 = 21.708 ksi

Assumes an R ratio of 0, so SEC cycle is +21.708 and -0, once per flight or hour

Usage Impact Example - Widebody

Crack growth comparison using Afgrow is made for a 6” wide 2024-T3 plate 0.07” thick with a centered 3/16” diameter countersunk fastener hole with no load transfer and a single 0.05” corner.



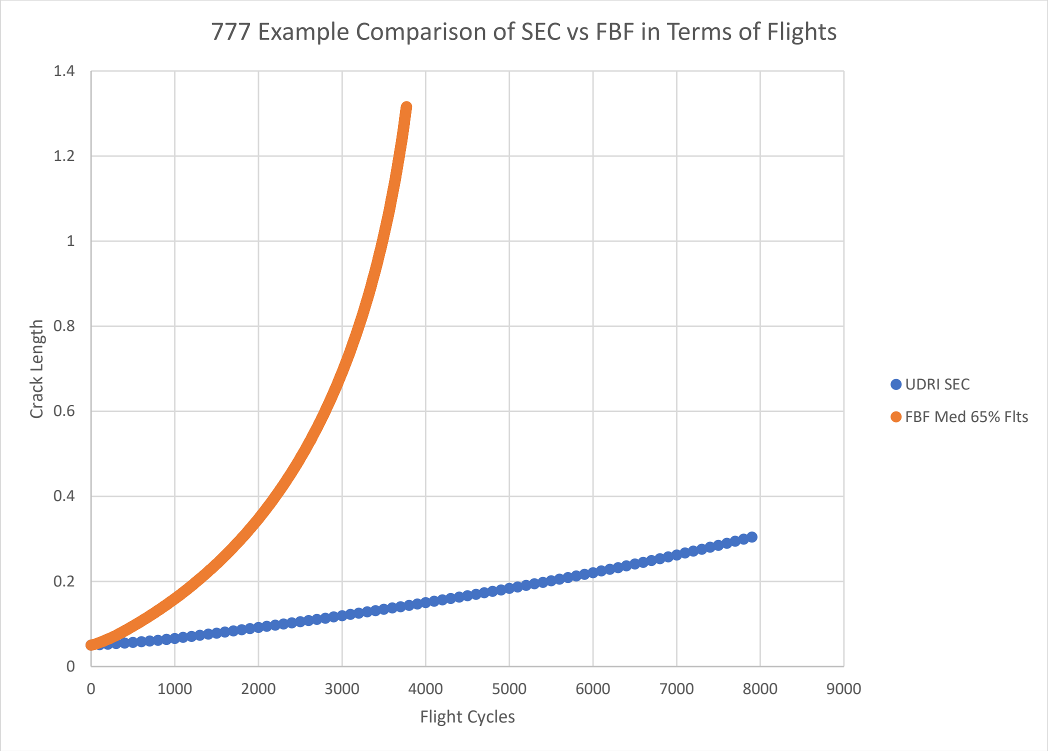
<u>Aspec FBF:</u>
N = 24164 Hours
Ccrit = 1.316”

<u>UDRI SEC:</u>
N = 7900 Hours
Ccrit = 0.30”

Fig. 15 Comparison of Crack Growth Life in terms of Flight Hours

Usage Impact Example - Widebody

Converting the crack growth results into flight cycles instead of the flight hours, the following comparison is also made. Note that the SEC method produces a longer life than the Aspec FBF. This is predominantly due to the fact that the SEC assumes that the GAG fatigue loads is the most damaging source.



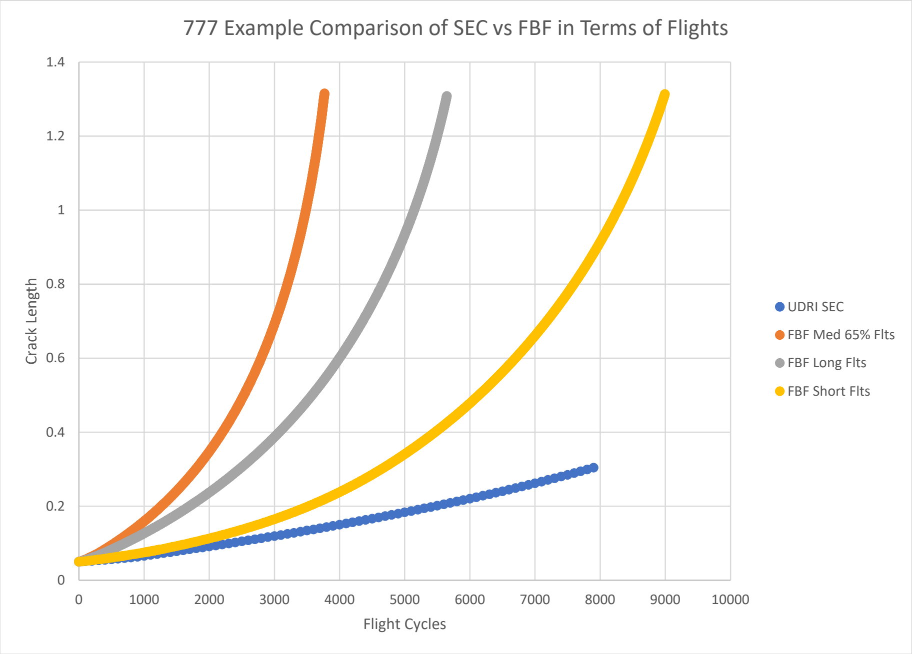
<u>Aspec FBF:</u>
N = 3770 Flights
Ccrit = 1.316”

<u>UDRI SEC:</u>
N = 7900 Flights
Ccrit = 0.30”

Fig. 16 Comparison of Crack Growth Life in terms of Flight Cycles

Usage Impact Example - Widebody

As an added comparison, the same analysis was repeated for 100% of the flights being Long Mission and 100% of the flights being Short Mission. Notice for the 100% Mission, the comparison to the SEC is much closer. This illustrates that the SEC method assumes that all crack growth damage comes from the GAG cycle only. Note the 100% Short Mission is approximately a 2 hour mission and so produces slightly higher life than the SEC flight..



<u>Aspec 100% Short FBF:</u>
N = 8994 Flights
Ccrit = 1.3”

<u>UDRI SEC 100% GAG:</u>
N = 7900 Flights
Ccrit = 0.30”

As seen previously, Short Flights only account for <u>2% of all 777 flights</u>

Fig. 17 Comparison of Crack Growth Life in terms of Flight Cycles

Usage Impact Example - Widebody

Looking at the damage source results from the Afgrow runs, it is seen that for the Aspec FBF spectrum, the most damaging sources are maneuver and gust. This is due to the average flight of the 777-200 in service being over 9 hours. Therefore, for a long-haul transport, flight cycles are not as significant as the amount of time spent in the flight environment.

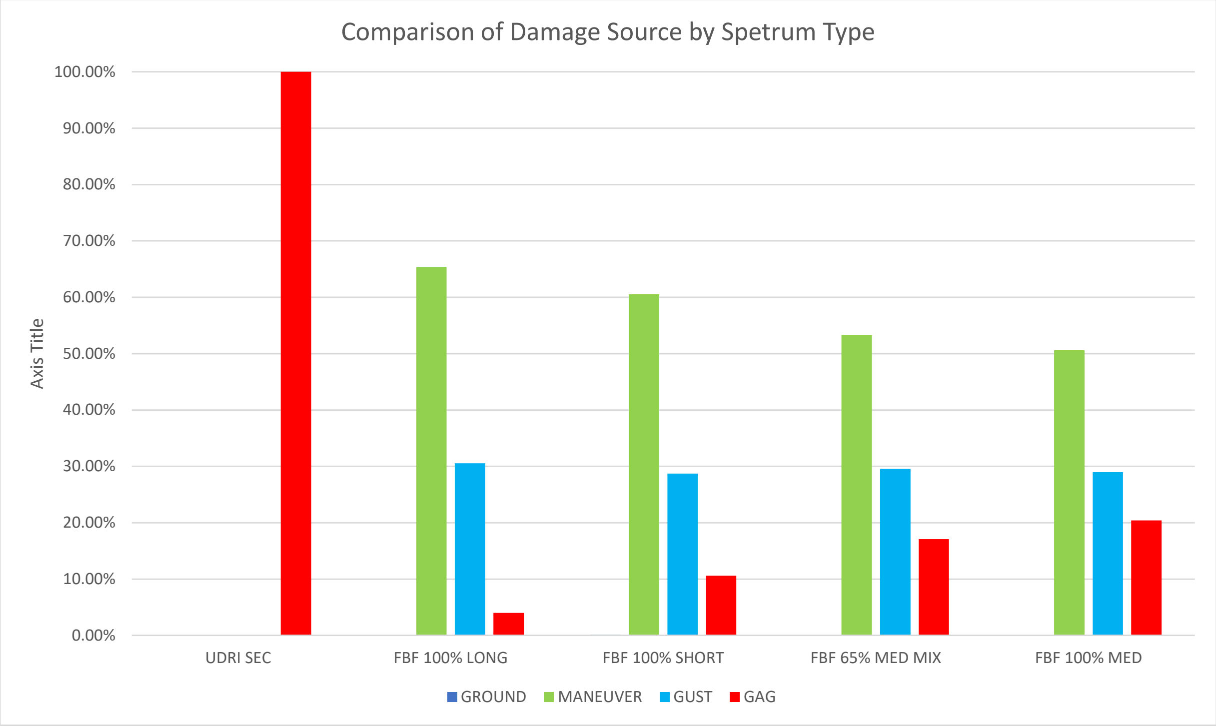
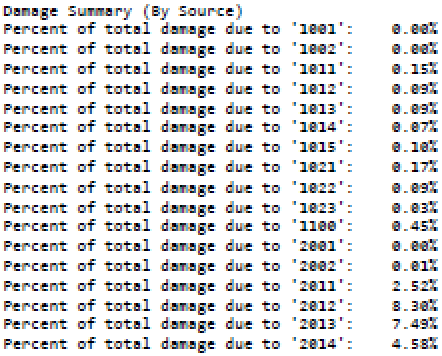


Fig. 18 Comparison of Crack Growth Life in terms of Flight Cycles

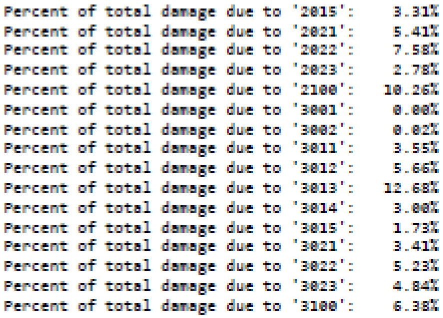
Usage Impact Example - Widebody

FAA FAR 25.571 clearly requires that the utilization of the aircraft be accounted for. As previously shown, this cannot be accomplished with a Single Equivalent Cycle for all aircraft. In particular, aircraft usage which includes longer flights will have their crack growth damage source from several portions of the flight segment depending on the mission profile. Below is an Afgrow output summary for the damage source from the previous example:

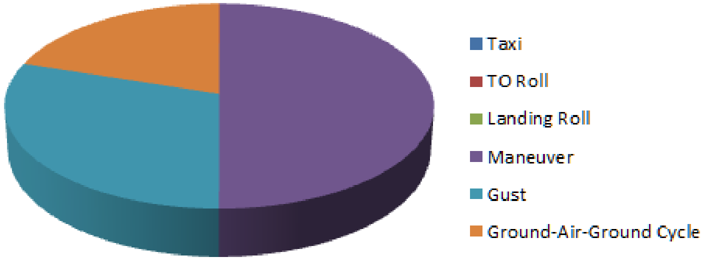
1st Digit	Mission #	ie 1 = Mission type 1
2nd Digit	GAG Type	ie 1 = Max-min
3rd digit	Load Source	ie 23 = Gust Cruise



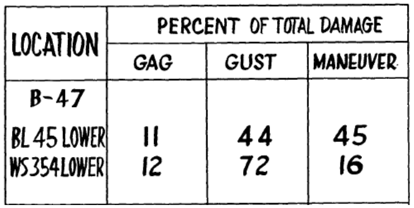
```
Damage Summary (By Source)
Percent of total damage due to '1001':     0.00%
Percent of total damage due to '1002':     0.00%
Percent of total damage due to '1011':     0.15%
Percent of total damage due to '1012':     0.09%
Percent of total damage due to '1013':     0.09%
Percent of total damage due to '1014':     0.07%
Percent of total damage due to '1015':     0.10%
Percent of total damage due to '1021':     0.17%
Percent of total damage due to '1022':     0.09%
Percent of total damage due to '1023':     0.03%
Percent of total damage due to '1100':     0.45%
Percent of total damage due to '2001':     0.00%
Percent of total damage due to '2002':     0.01%
Percent of total damage due to '2011':     2.52%
Percent of total damage due to '2012':     8.30%
Percent of total damage due to '2013':     7.49%
Percent of total damage due to '2014':     4.58%
```



```
Percent of total damage due to '2015':     3.31%
Percent of total damage due to '2021':     5.41%
Percent of total damage due to '2022':     7.58%
Percent of total damage due to '2023':     2.78%
Percent of total damage due to '2100':    10.26%
Percent of total damage due to '3001':     0.00%
Percent of total damage due to '3002':     0.02%
Percent of total damage due to '3011':     3.55%
Percent of total damage due to '3012':     5.66%
Percent of total damage due to '3013':    12.68%
Percent of total damage due to '3014':     3.00%
Percent of total damage due to '3015':     1.73%
Percent of total damage due to '3021':     3.41%
Percent of total damage due to '3022':     5.23%
Percent of total damage due to '3023':     4.84%
Percent of total damage due to '3100':     6.38%
```



Note: Military aircraft can likewise be affected:



LOCATION	PERCENT OF TOTAL DAMAGE		
	GAG	GUST	MANEUVER
B-47			
BL 45 LOWER	11	44	45
WS354LOWER	12	72	16

Fig. 19 Benefit of Damage Source Summary – Determination of Hours versus Cycles Criticality

Usage Impact Example - Narrowbody

A321 Aft Upper Crown for a 78” Fuselage Radius

2024-T3 Clad 0.063” Sheet Skin with 0.063” 2024-T3 Sheet Stringers

Stringer Pitch ~ 9.6”, Stringer width ~2.4”

Geometry Consists of a 3 Frame Bay x 2 Stringer Bay Doubler

Example 2: 0.063” sheet 2.4 inches wide with 0.156” diameter centered hole

DTA: single 0.05” corner crack from 0.156” hole No load transfer

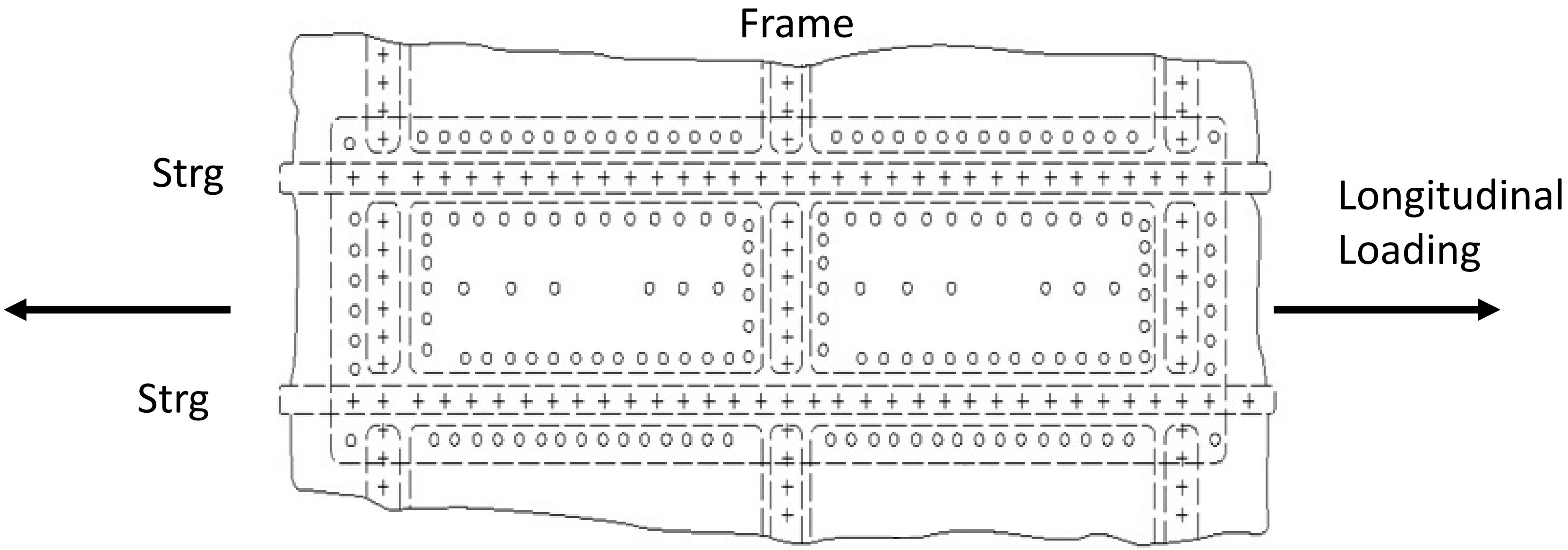
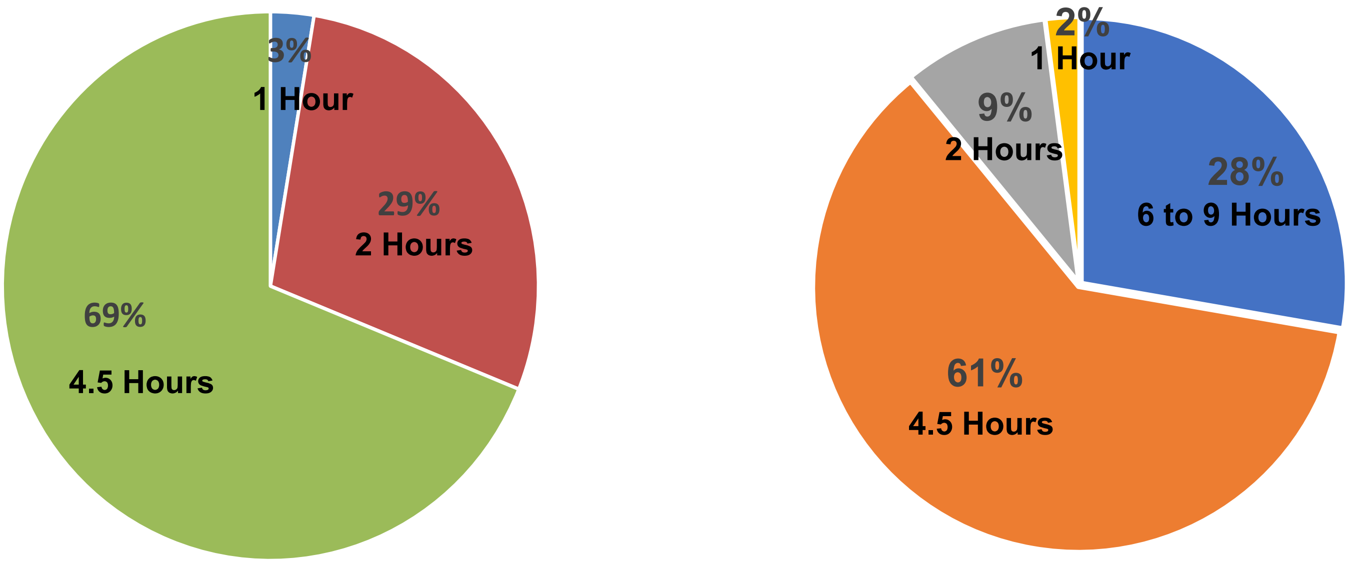


Fig. 20 Example 2 – A321 Fuselage Crown

Usage Impact Example - Narrowbody

Narrowbody usage has changed over the past 5 years. In particular, there is a distinct difference between Domestic and International Flight Usage.

- Example: Domestic Utilization versus a 9 Hour Flight versus a 1 Hour Flight



Domestic Flights

International Flights

Fig. 21 A321 Distribution of Flight Lengths, Distances and Weights per Flight

Usage Impact Example - Narrowbody

As with Example 1, the recorded statistical fatigue loads are obtained for each relevant flight segment from DOT/FAA/AR-02/35. These are for the A320 but are applicable to the A321 as well.

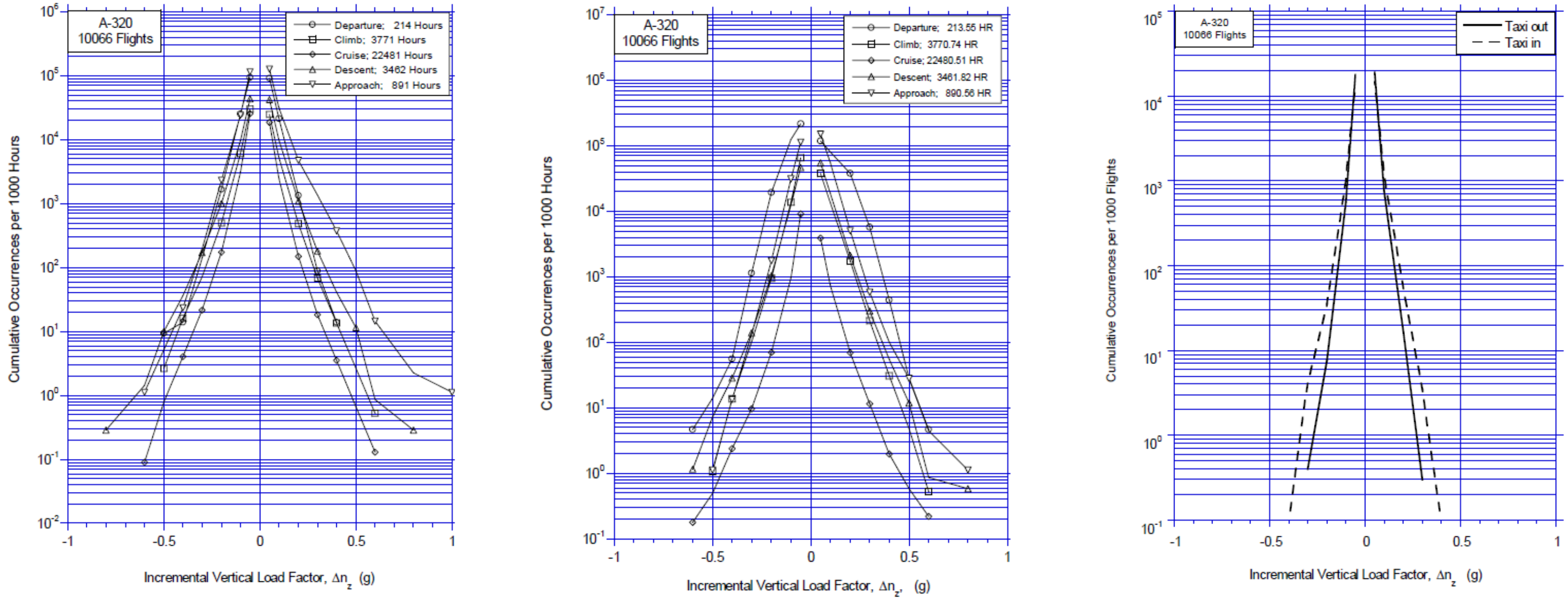


FIGURE A-50. CUMULATIVE OCCURRENCES OF INCREMENTAL VERTICAL GUST LOAD FACTOR PER 1000 HOURS BY FLIGHT PHASE

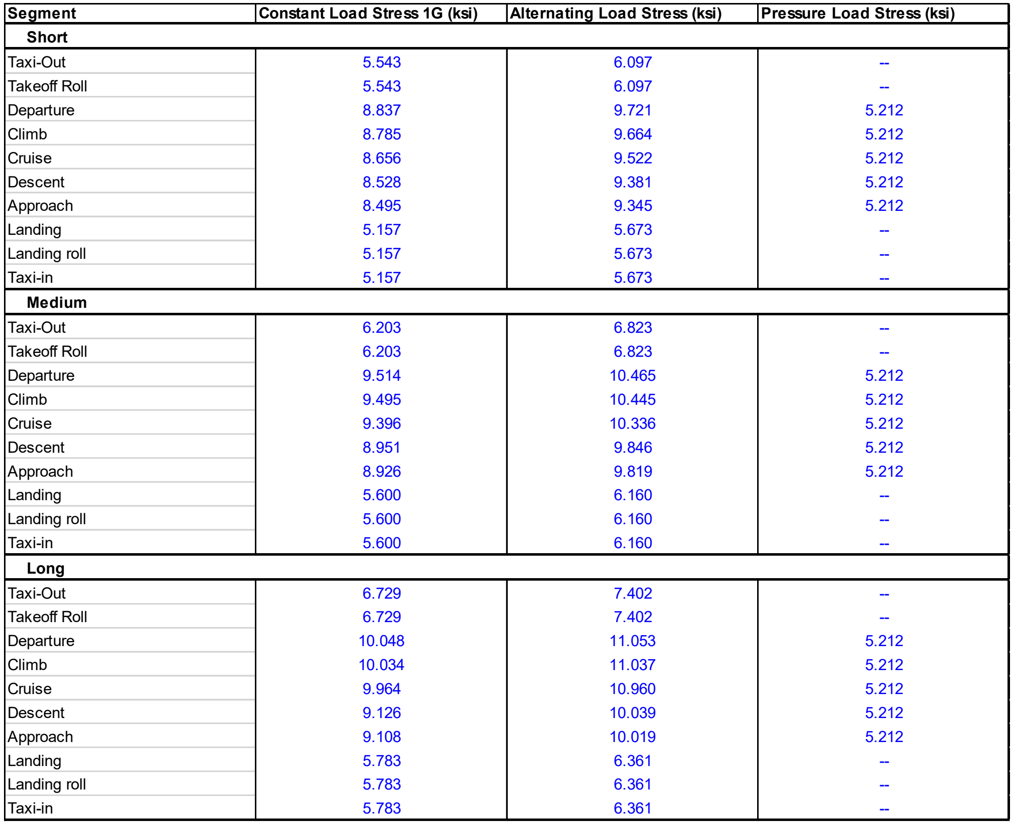
FIGURE A-79. CUMULATIVE OCCURRENCES OF INCREMENTAL VERTICAL MANEUVER LOAD FACTOR PER 1000 HOURS BY FLIGHT PHASE

FIGURE A-33. CUMULATIVE FREQUENCY OF INCREMENTAL VERTICAL LOAD FACTOR DURING TAXI OPERATIONS

Fig. 22 A321 Selected Load Histories for Discretization

Usage Impact Example - Narrowbody

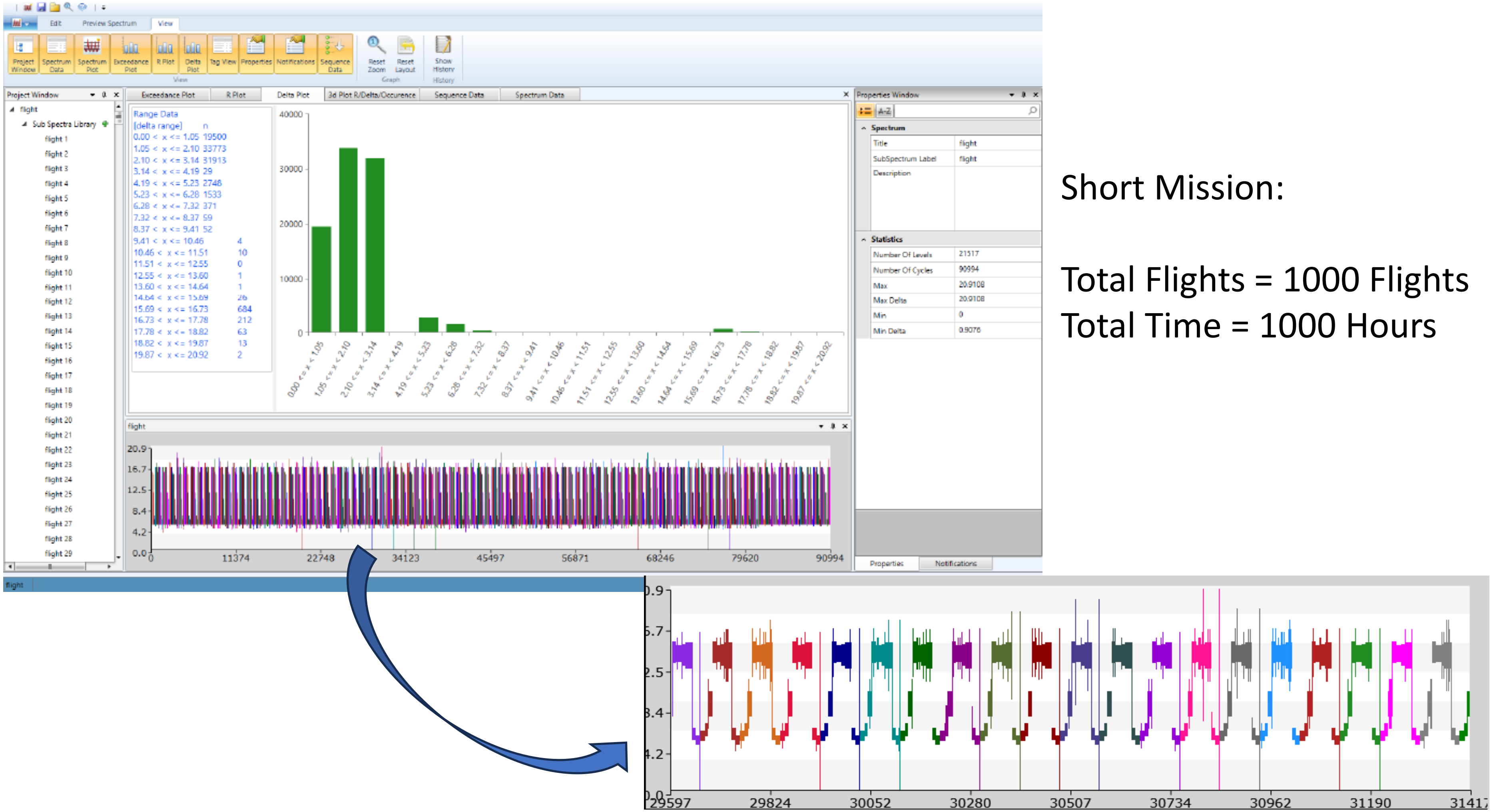
Fatigue loads and stresses for each segment are obtained in the same manner as the previous example. The next step then involves entering this data along with the load histories, mission definitions and usage into the Aspec flight by flight spectrum program.



Segment	Constant Load Stress 1G (ksi)	Alternating Load Stress (ksi)	Pressure Load Stress (ksi)
Short			
Taxi-Out	5.543	6.097	--
Takeoff Roll	5.543	6.097	--
Departure	8.837	9.721	5.212
Climb	8.785	9.664	5.212
Cruise	8.656	9.522	5.212
Descent	8.528	9.381	5.212
Approach	8.495	9.345	5.212
Landing	5.157	5.673	--
Landing roll	5.157	5.673	--
Taxi-in	5.157	5.673	--
Medium			
Taxi-Out	6.203	6.823	--
Takeoff Roll	6.203	6.823	--
Departure	9.514	10.465	5.212
Climb	9.495	10.445	5.212
Cruise	9.396	10.336	5.212
Descent	8.951	9.846	5.212
Approach	8.926	9.819	5.212
Landing	5.600	6.160	--
Landing roll	5.600	6.160	--
Taxi-in	5.600	6.160	--
Long			
Taxi-Out	6.729	7.402	--
Takeoff Roll	6.729	7.402	--
Departure	10.048	11.053	5.212
Climb	10.034	11.037	5.212
Cruise	9.964	10.960	5.212
Descent	9.126	10.039	5.212
Approach	9.108	10.019	5.212
Landing	5.783	6.361	--
Landing roll	5.783	6.361	--
Taxi-in	5.783	6.361	--

Fig. 23 Example 1g, Alternating and Pressure Stress in Crown Example

Usage Impact Example - Narrowbody



Range Data

[delta range]	n
0.00 < x <= 1.05	19500
1.05 < x <= 2.10	33773
2.10 < x <= 3.14	31913
3.14 < x <= 4.19	29
4.19 < x <= 5.23	2748
5.23 < x <= 6.28	1533
6.28 < x <= 7.32	371
7.32 < x <= 8.37	59
8.37 < x <= 9.41	52
9.41 < x <= 10.46	4
10.46 < x <= 11.51	10
11.51 < x <= 12.55	0
12.55 < x <= 13.60	1
13.60 < x <= 14.64	1
14.64 < x <= 15.69	26
15.69 < x <= 16.73	684
16.73 < x <= 17.78	212
17.78 < x <= 18.82	63
18.82 < x <= 19.87	13
19.87 < x <= 20.92	2

Spectrum

Title	flight
SubSpectrum Label	flight
Description	

Statistics

Number Of Levels	21517
Number Of Cycles	90994
Max	20.9108
Max Delta	20.9108
Min	0
Min Delta	0.9076

Short Mission:

Total Flights = 1000 Flights

Total Time = 1000 Hours

Fig. 24 Example Short Flight Spectrum

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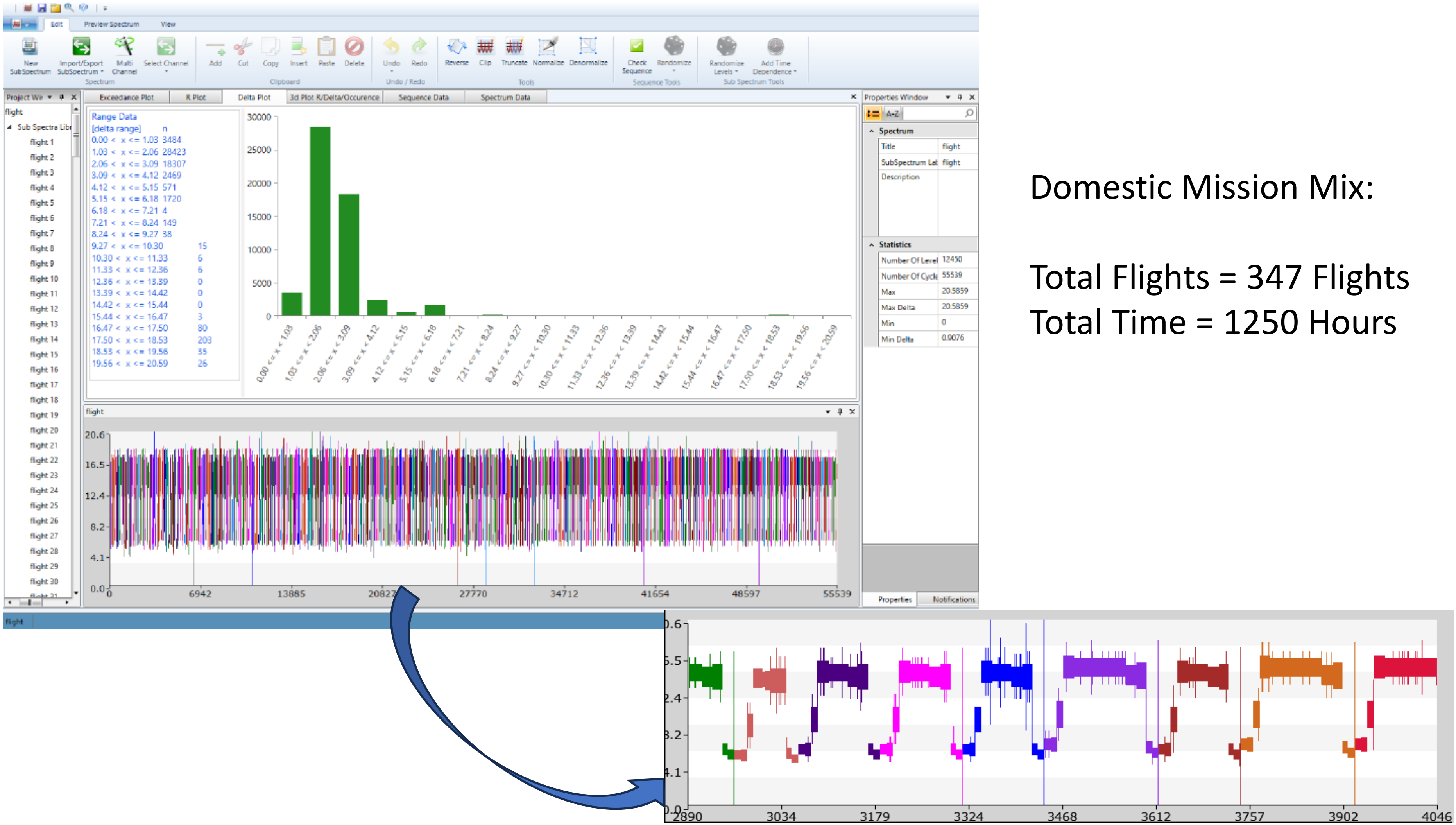
Usage Impact Example - Narrowbody



```
Range Data
[delta range]        n
0.00 <  x <= 1.03  3484
1.03 <  x <= 2.06  28423
2.06 <  x <= 3.09  18307
3.09 <  x <= 4.12  2469
4.12 <  x <= 5.15  571
5.15 <  x <= 6.18  1720
6.18 <  x <= 7.21  4
7.21 <  x <= 8.24  149
8.24 <  x <= 9.27  38
9.27 <  x <= 10.30          15
10.30 <  x <= 11.33         6
11.33 <  x <= 12.36         6
12.36 <  x <= 13.39         0
13.39 <  x <= 14.42         0
14.42 <  x <= 15.44         0
15.44 <  x <= 16.47         3
16.47 <  x <= 17.50         80
17.50 <  x <= 18.53         203
18.53 <  x <= 19.56         35
19.56 <  x <= 20.59         26
```

Spectrum

Title	flight
SubSpectrum Lal	flight
Description	

Statistics

Number Of Level	12450
Number Of Cycle	55539
Max	20.5859
Max Delta	20.5859
Min	0
Min Delta	0.9076

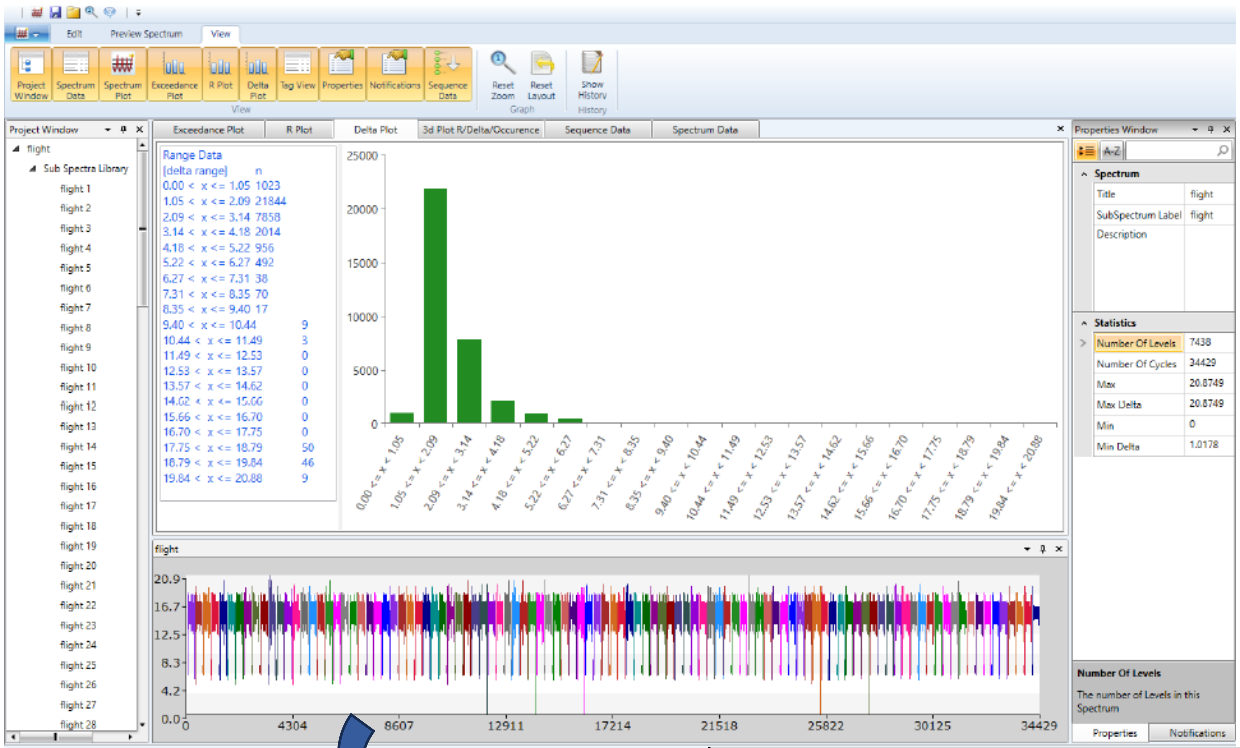
Domestic Mission Mix:

Total Flights = 347 Flights

Total Time = 1250 Hours

Fig. 24 Example Domestic Mission Mix Flight Spectrum

Usage Impact Example - Narrowbody



Range Data

[delta range]	n
0.00 < x <= 1.05	1023
1.05 < x <= 2.09	21844
2.09 < x <= 3.14	7858
3.14 < x <= 4.18	2014
4.18 < x <= 5.22	956
5.22 < x <= 6.27	492
6.27 < x <= 7.31	38
7.31 < x <= 8.35	70
8.35 < x <= 9.40	17
9.40 < x <= 10.44	9
10.44 < x <= 11.49	3
11.49 < x <= 12.53	0
12.53 < x <= 13.57	0
13.57 < x <= 14.62	0
14.62 < x <= 15.66	0
15.66 < x <= 16.70	0
16.70 < x <= 17.75	0
17.75 < x <= 18.79	50
18.79 < x <= 19.84	46
19.84 < x <= 20.88	9

Spectrum

Title	flight
SubSpectrum Label	flight
Description	

Statistics

Number Of Levels	7438
Number Of Cycles	34429
Max	20.8749
Max Delta	20.8749
Min	0
Min Delta	1.0178

Number Of Levels

The number of Levels in this Spectrum

Very Long Mission:

Total Flights = 105 Flights

Total Time = 1000 Hours

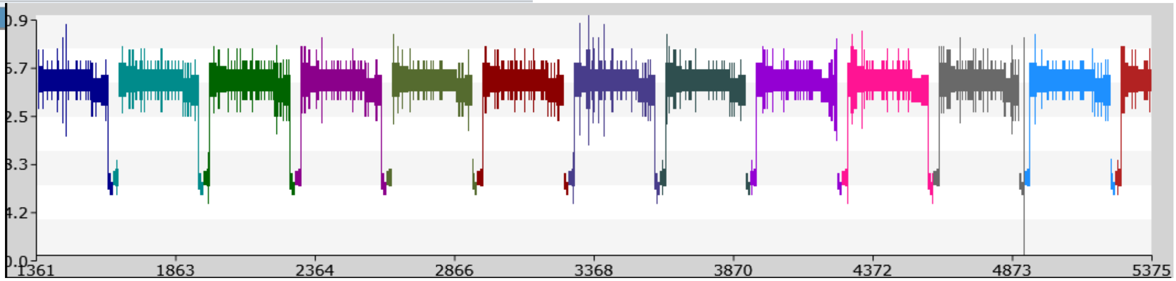


Fig. 24 Example Long International Flight Spectrum

Usage Impact Example - Narrowbody

Crack growth comparison is made for a 2.4” wide 2024-T3 plate 0.063” thick with a centered 5/32” diameter countersunk fastener hole with no load transfer and a single 0.05” corner. The plot below is in Flight Hours.

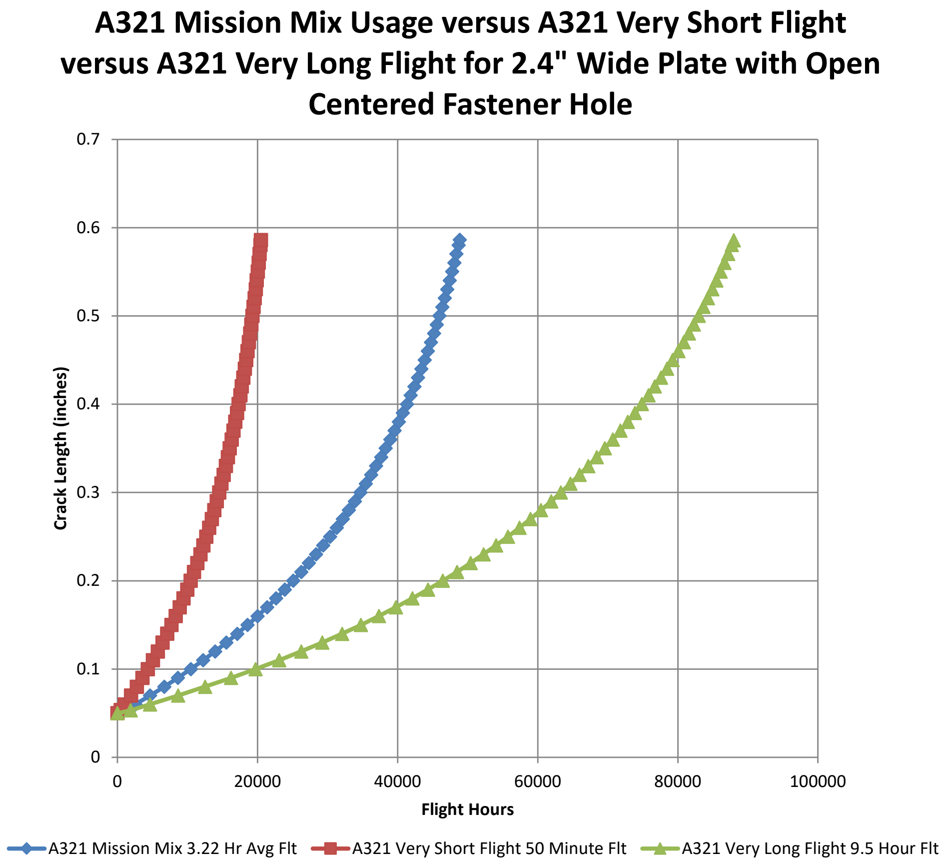


Fig. 25 Comparison of Short, Domestic Mission Mix and Very Long International Flight

Usage Impact Example - Narrowbody

The following plot shows the same results but in flight cycles. Note that most maintenance is performed in terms of flight cycles, not flight hours.

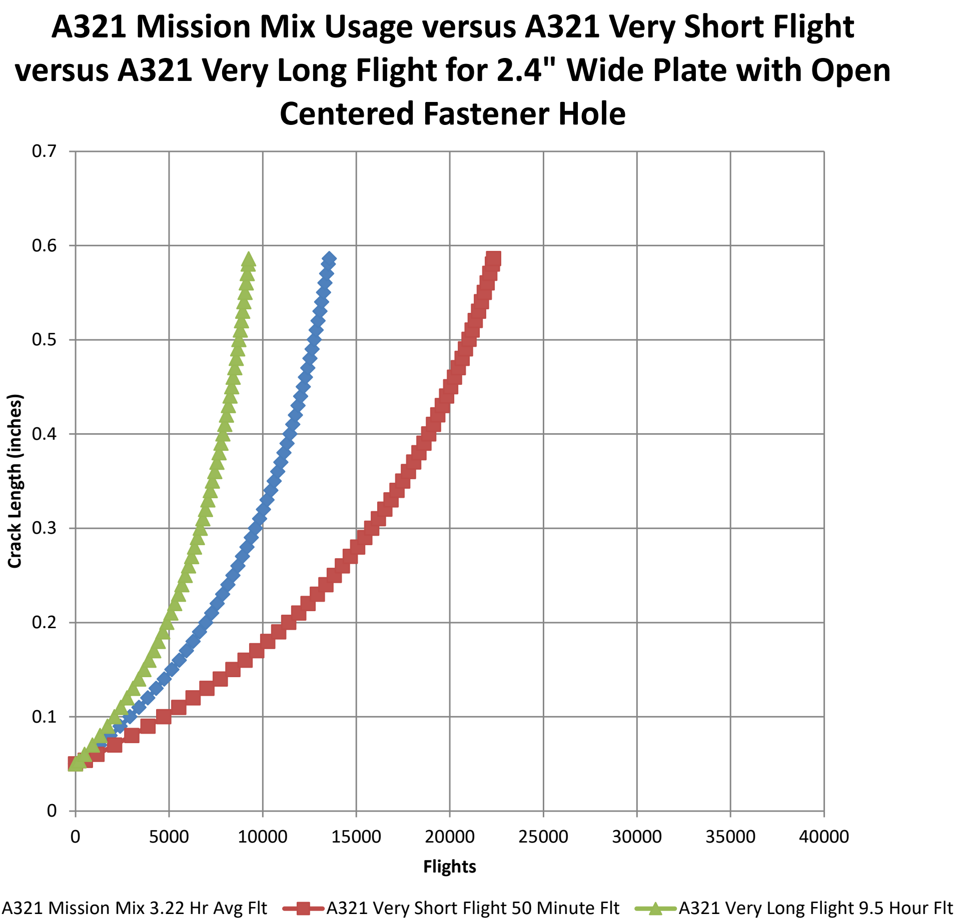


Fig. 26 Comparison of Short, Domestic Mission Mix and Very Long International Flight

Usage Impact Example - Narrowbody

- This A321 example demonstrates that with the use of narrowbodies for longer flights, the same general trend is observed as for the previous 777 widebody example.
- The impact to the actual instructions for continued airworthiness can be significant. Using the A321 example, the following impacts could be felt:
  - Domestic Mission Mix Usage: N life = 13555 flights
  - Short Flight: N life = 22345 flights
  - Very Long Flight: N life = 9261 flights
- Assuming N threshold = N life / 2:
  - Domestic Mission Mix Usage: N threshold = 6778 flights
  - Short Flight: N threshold = 11173 flights
  - Very Long Flight: N threshold = 4631 flights
- This shows that if the aircraft is being operated on very long flights, evaluations using either a simple single Short Flight or a Domestic Route Mission Mix, the resulting thresholds could be from around 45% to 140% unconservative.

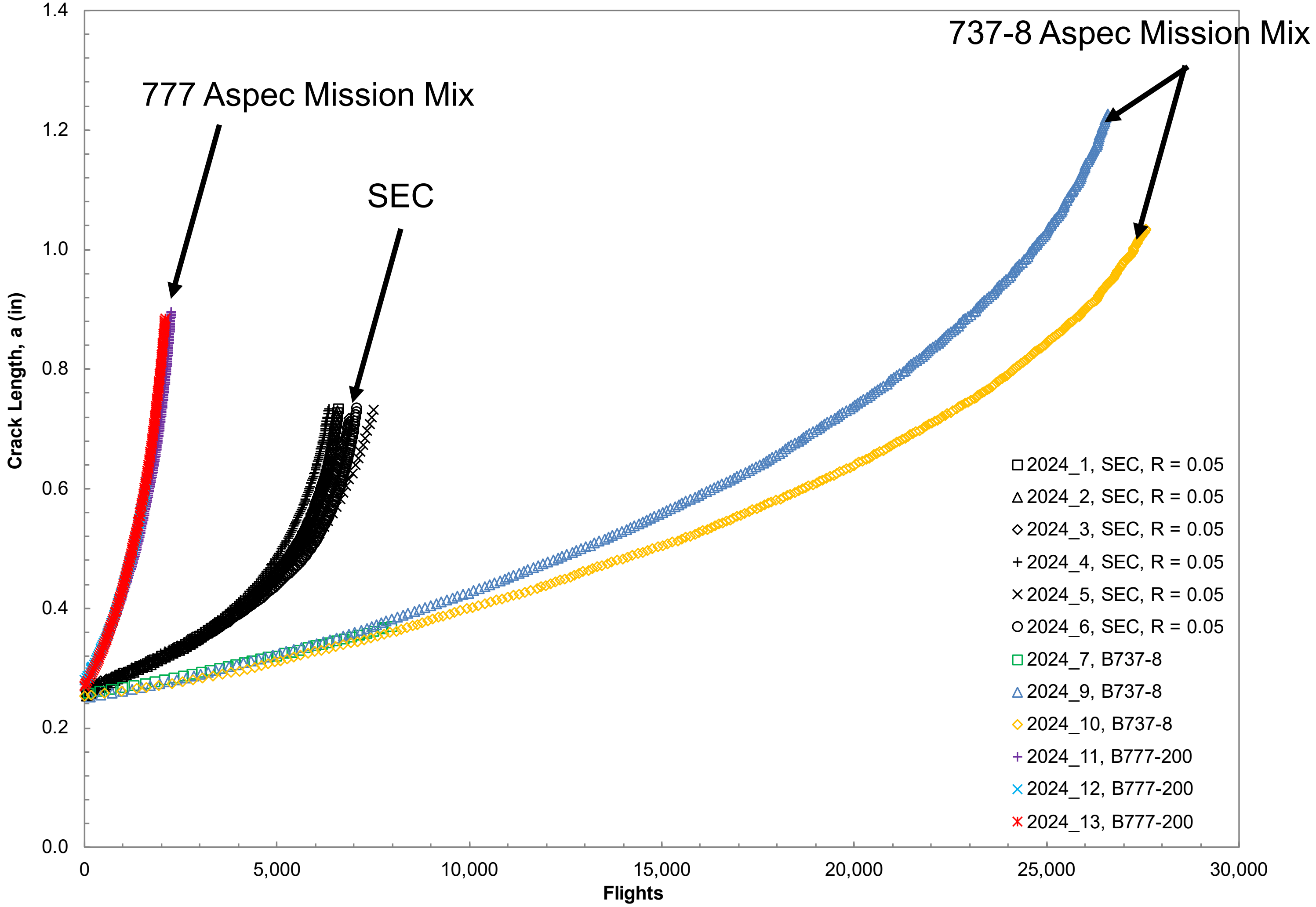
Usage Impact Example - Test

- Test Program – ASTM E647
- Material: 2024-T3, LT Bare
- Geometry:
  - Thickness: 0.063”
  - Width: 4.0”
  - Gage Length: 8.0”
  - Pre-crack Length: 0.24”
- Maximum spectrum stress

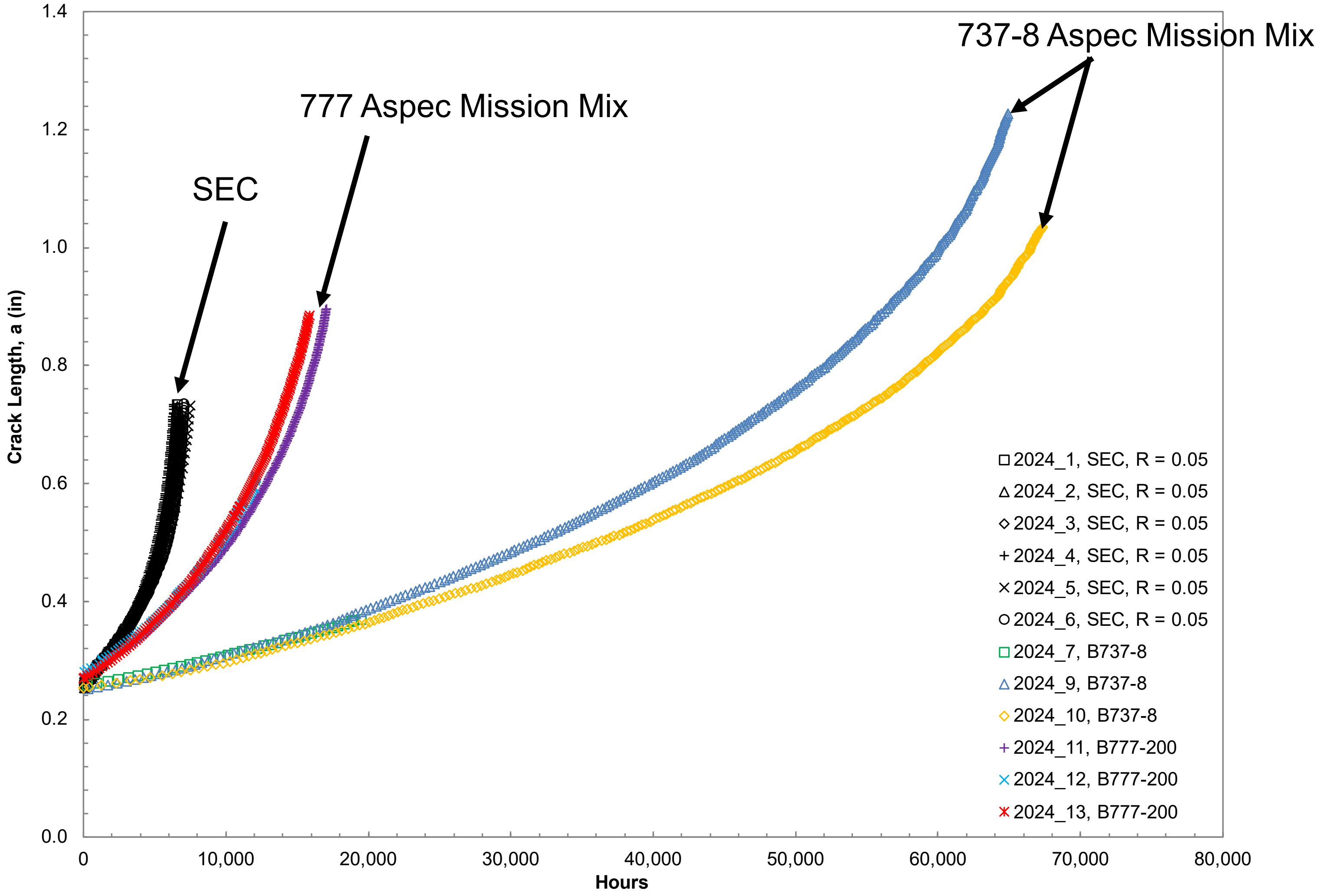
  737-8
  - SEC UDRI Single Cycle: 22.084 ksi Max stress for every flight and hour
  - Aspec FbF Mission Mix (Domestic Only): 14.549 ksi Max stress in entire spectrum

  777-200
  - SEC UDRI Single Cycle: 22.318 ksi Max stress for every flight and hour
  - Aspec FbF Mission Mix: 23.032 ksi Max stress in entire spectrum

Usage Impact Example - Test



Usage Impact Example - Test



Summary

- Initial Usage Assumptions for Continued Airworthiness Should be Regularly Re-evaluated for Impact
- Spectra Simplification can only occur once the damage sources have been fully determined
- Fully representative spectra such as Flight by Flight should be always used in initial evaluations.
- Complex or multi channel loading can further complicate the damage source determination
- Significant Changes in Utilization May Require:
  - Additional flight data recording
  - Re-evaluation of fatigue loads
  - Revision to fatigue spectra
  - Update to DTA and ICA
- Fleet Usage Monitoring and Evaluation is Imperative to Producing Representative Continued Airworthiness

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ABOUT THE COURSE

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About the Instructors

James Burd
FAA DER STRUCTURES AND DAMAGE TOLERANCE President, Aeronautica LLC

James Burd has over 30 years of experience in the aircraft industry as a structures, stress, and damage tolerance engineer. He graduated from North Carolina State University in 1987 with a degree in Aerospace Engineering.

James started his career in the USAF where he served as the C-5 Aircraft Structural Integrity Program (ASIP) Manager. Upon leaving the USAF, James worked on several DOD related programs at L-3 Systems and Northrop Grumman including the full scale fatigue test of the USN E-6A Milstar radome and the E-8C JStars ASIP program.

Subsequently, James worked at Gulfstream Aerospace for several years in the fatigue and damage tolerance group and later worked at Lockheed Martin on the L-1011 aging aircraft program. From 1998 until 2004, James also served as a participating member on the Aviation Rulemaking Advisory Committee (ARAC) for Widespread Fatigue Damage (WFD) and the Aging Airplane Safety rule.

In 1998, James became an FAA Designated Engineering Representative (DER) for Structures and Fatigue/ Damage Tolerance. He presently retains delegations for Part 23, Part 25, Part 26, Part 27 and Part 29 regulations and has supported certification efforts on a large number of platforms. James currently supports engineering and certification projects for numerous civil and government projects with his team at Aeronautica.

In particular, they support fatigue, damage tolerance and continuing airworthiness evaluations.

About the Instructors

Dr Scott Fawaz
FAA RS-DER STRUCTURES AND DAMAGE TOLERANCE

Dr. Scott Fawaz graduated from the United States Air Force Academy in 1987 having obtained an Engineering Mechanics degree.

In 1988, he received his Master of Aeronautical Engineering from the Air Force Institute of Technology. In 1997, he received his doctorate in Aerospace Engineering from the Technical University Delft, The Netherlands.

He served 23 years in the United States Air Force working in aircraft structural integrity of new and aging aircraft. He had assignments at the San Antonio Air Logistics Center, Air Force Research Laboratory, and United States Air Force Academy (USAFA).

At USAFA he was on the teaching faculty and directed the Center for Aircraft Structural Life Extension (CAStLE) from 2003 – 2010.

After leaving the USAF, he led the fatigue and damage tolerance group for the Gulfstream G650. With several government and commercial contract awards for SAFE in 2011, Dr. Fawaz focused all his efforts at SAFE.

From 2011 to 2022 he supported civil and military aviation basic and applied research; advanced technology development, demonstration and validation; and engineering and manufacturing development.

Since retiring in 2022, he has shifted focus to teaching short courses. Dr. Fawaz is a FAA Designated Engineering Representative (DER) for Structures and Damage Tolerance with Repair Specification authority.

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