What can the FALLSTAFF Spectrum Do For You?

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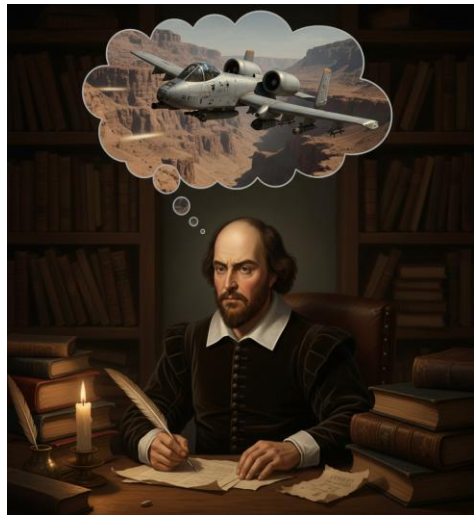
A-10 ASIP

What is FALSTAFF?

- **Definition & Origin**
  - FALSTAFF: **F**ighter **A**ircraft **L**oading **STA**ndard **F**or **F**atigue Evaluation
  - Developed in 1975 via a European aerospace consortium (NLR, LBF, IABG, F+W)
  - Represents a standardized, flight-by-flight wing-root stress sequence for tactical military aircraft
    - Prior to FALSTAFF, structural testing relied heavily on simplified "block loading" (which omitted realistic sequence effects)

"…honor spurs me on. Yeah, but what if honor spurs me off once I'm on, and picks me out to die? What happens then?..."

***General Falstaff**, Henry IV, Part 1, Act 5, Scene 1*



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Development of FALSTAFF

- Why it Was Developed
  - Replaced simplified, unrealistic block-loading tests with real-world flight load sequences
  - Created a common baseline to evaluate fatigue crack propagation and validate load-interaction/retardation models
  - Provided a normalized baseline to assess material fatigue performance and determine design allowables prior to prototype testing

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What Can FALSTAFF do for you?

Although FALSTAFF was developed in 1975, it is difficult to find studies that show how it compares to other, aircraft specific spectra, which makes it difficult to know how it should be used.

So our core research questions are:

- How applicable is FALSTAFF to the broader Damage Tolerance Analysis (DTA) community today?
- Can FALSTAFF serve as a valid surrogate when platform-specific spectra are unavailable?
- What are the specific boundary conditions where FALSTAFF is effective vs. non-conservative?

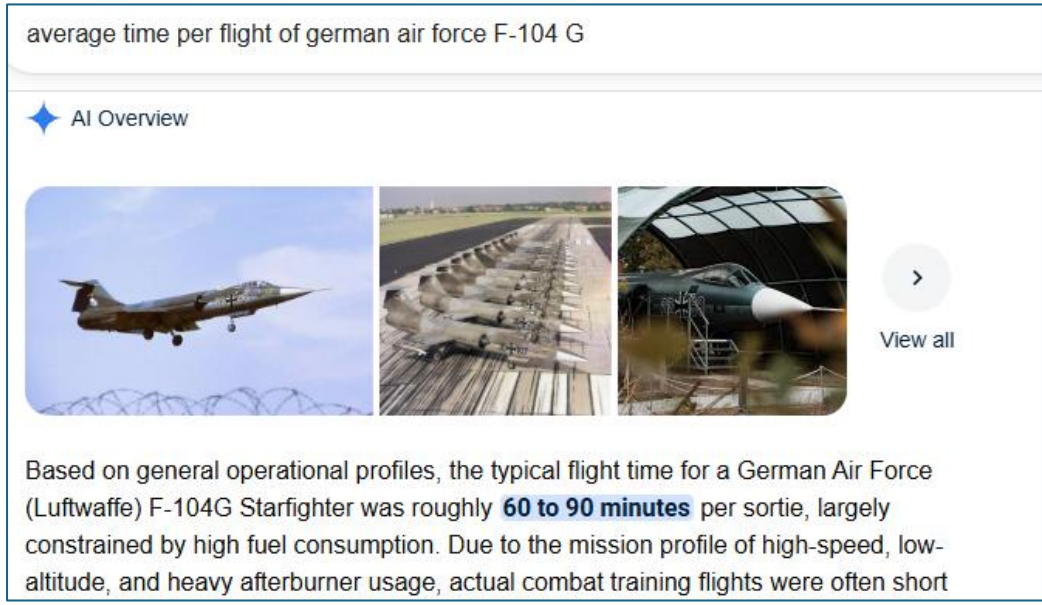
So how many Flights per pass do we use?

- FALSTAFF Source Data:

Aircraft-Type	Operator
Lockheed F-104 G	German Air Force
Fiat G-91	German Air Force
Lockheed F-104 G	Royal Netherlands Air Force
Northrop NF - 5 A	Royal Netherlands Air Force
Dassault Mirage III S	Swiss Air Force

3.2.2 Selection of Individual Flights

From each recorded data sample 40 individual load factor flight histories were selcted in accordance with the respective aircraft operation, thus providing a total of 200 flights.



- 200 flights, but how many flight hours?
  - Min: 100 flight hours, Max: 300 flight hours, Average: 200 flight hours
- **But what was the mission mix?**

Aircraft	Internet Average Flight (minutes)
German F-104 G	60 – 90 minutes
G-91	60 minutes
NLR F-104 G	60 – 75 minutes
NF-5 A	45 – 90 minutes
Mirage III S	30 minutes

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FALSTAFF Mission Mix Derivation

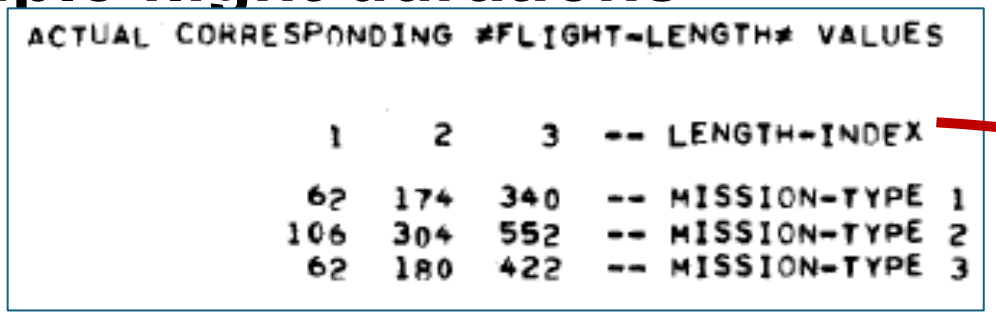
- **Only 8 unique number of cycles per flight**
- **Flights with fewer cycles occurs more frequently**
  - **No direct correlation between cycles and frequency**

Flight Number	Cycles in Flight
1	62
2	422
3 …	106
24 …	304
32 …	552
39 …	180
75 …	174
87	340

Cycles in Flight	# of Flight Occurrences
62	68
106	44
180	23
174	20
422	19
304	13
552	7
340	6
Sum:	200

Flight Length Assumptions

- Assuming that a specific cycle count is a certain aircraft and time
- Assume fewer cycles are shorter duration flights
- Apply a “short” and a “long” flight duration to all aircraft with multiple flight durations



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ACTUAL CORRESPONDING #FLIGHT-LENGTH# VALUES

                1     2     3   -- LENGTH-INDEX

               62   174   340   -- MISSION-TYPE 1
              106   304   552   -- MISSION-TYPE 2
               62   180   422   -- MISSION-TYPE 3
```

Aircraft	Internet Average Flight (minutes)	Short Flight (hours)	Long Flight (hours)
German F-104 G	60 – 90 minutes	1	1.5
G-91	60 minutes	Not Applicable	Not Applicable
NLR F-104 G	60 – 75 minutes	1	1.25
NF-5 A	45 – 90 minutes	.75	1.5
Mirage III S	30 minutes	Not Applicable	Not Applicable

1	2	3	
Mirage III S	German F-104 G (short)	German F-104 G (long)	Mission 1
NF-5 A (short)	G-91	NLR F-104 G (long)	Mission 2
Mirage III S	NLR F-104 G (Short)	NF-5 A (Long)	Mission 3

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Flight Duration Applied to Mission Mix

- **Apply assumed flight duration based on cycles in flight**

Cycles in Flight	# of Flight Occurrences	Assumed A/C	Assumed Duration (hours)
62	68	Mirage III S	0.5
106	44	NF-5A (short flight)	0.75
174	20	G-91	1
180	23	German F-104G (short flight)	1
304	13	NLR F-104G (short flight)	1
340	6	NLR F-104G (long flight)	1.25
422	19	NF-5A (long flight)	1.5
552	7	German F-104G (long flight)	1.5

- **Resulting flight hours per spectrum pass: <u>169.5 hours</u>**

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Alternate Scenarios

- What if cycle count doesn't relate to flight hours?
  - Longer flights could be ferry flights with lots of cruise time, which could result in low cycle counts
- Case of assuming longer flights correspond to shorter cycle count flights resulted in 253 flight hours per spectrum pass
- Seven other scenarios of flight duration were assumed per cycle count
  - Average result was 219 flight hours per spectrum pass
- FALSTAFF represents 200 flights, which corresponds to somewhere between 170 and 253 flight hours per pass

For this Analysis, 170 flight hours per pass was used

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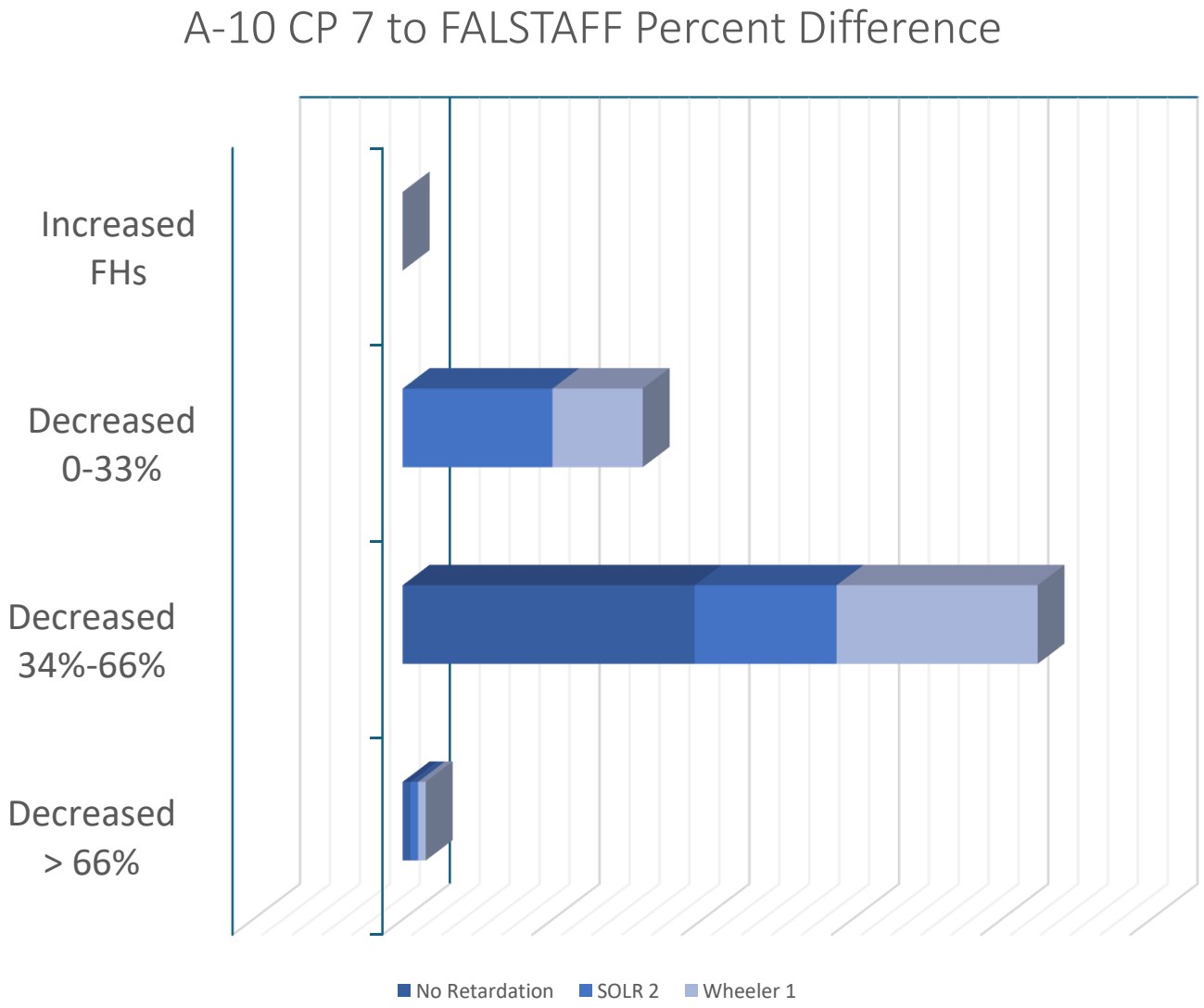
How the comparison was done

- Baseline Geometry & Tools
  - Using the A-10 Critical Inspection Points as a basis, a set of geometries was established.
- Comparative Spectra Evaluated
  - Various Wing Bending spectra were used from the F-15, F-16, T-38, and A-10 (CP-7) Platforms
  - The FALSTAFF load sequence was then mapped and compared to each individual spectra using AFGROW
- Analysis Execution & Sensitivity
  - All runs were executed both with and without crack growth retardation models to isolate load-interaction effects

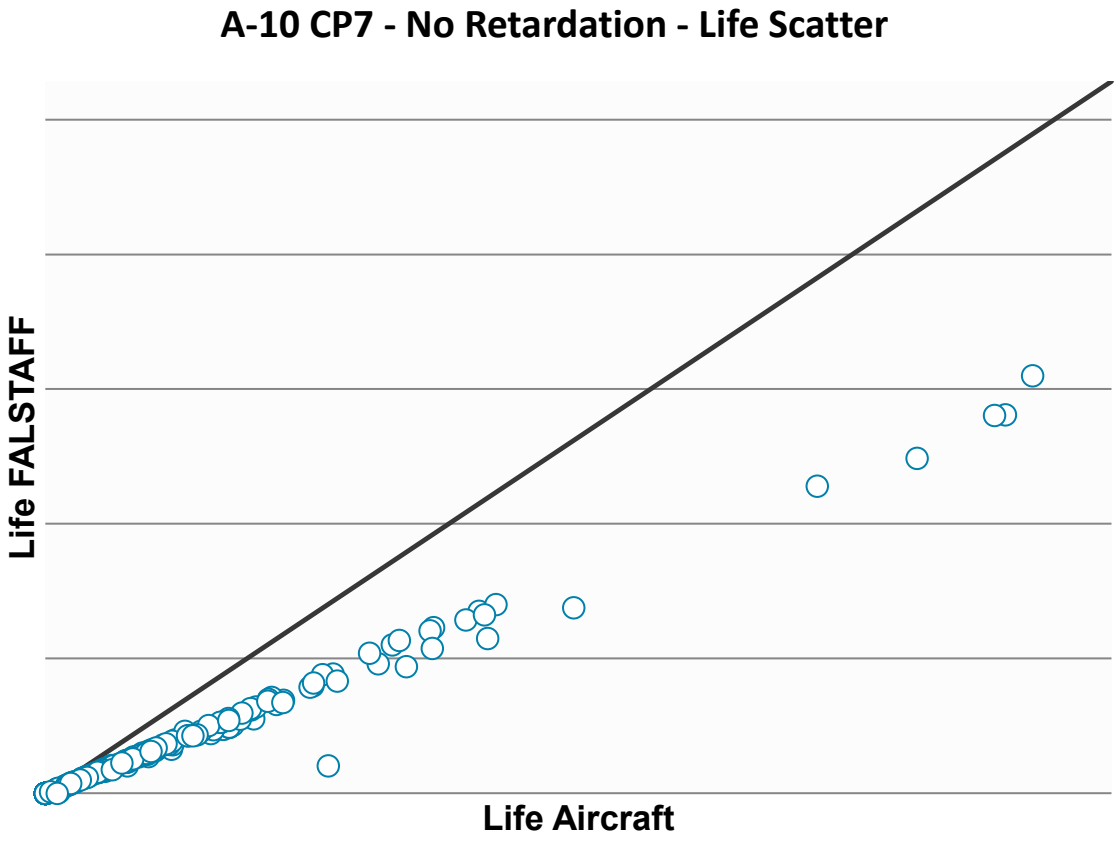
FALSTAFF and A-10 CP-7 Spectra



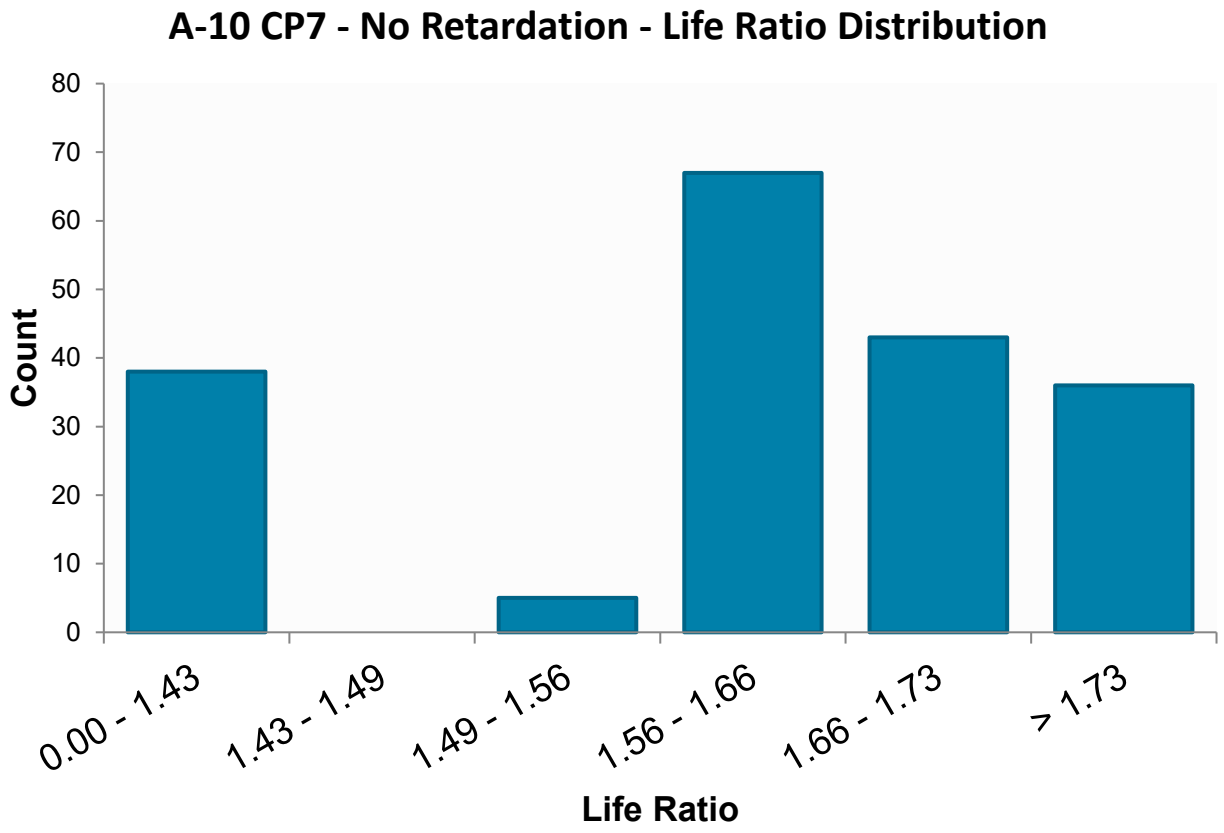
Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	0%	0%	0%
Decreased by 0-33%	0%	50%	30%
Decreased 34%-66%	97%	47%	67%
Decreased more than 66%	3%	3%	3%

FALSTAFF and A-10 CP-7 Spectra

1. The 1:1 Correlation Scatter Plot (The "Conservatism Test")



2. Life Ratio / Severity Factor Distribution (The "Predictability Test")



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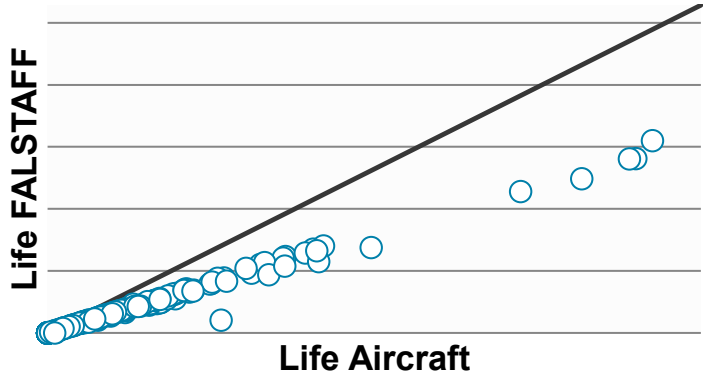
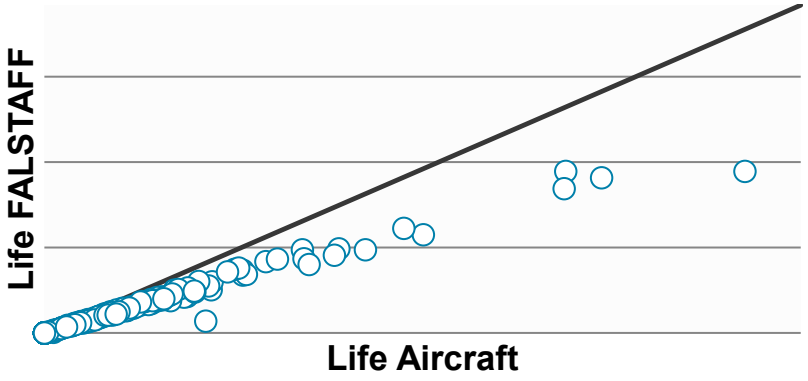
FALSTAFF and A-10 CP-7 Spectra

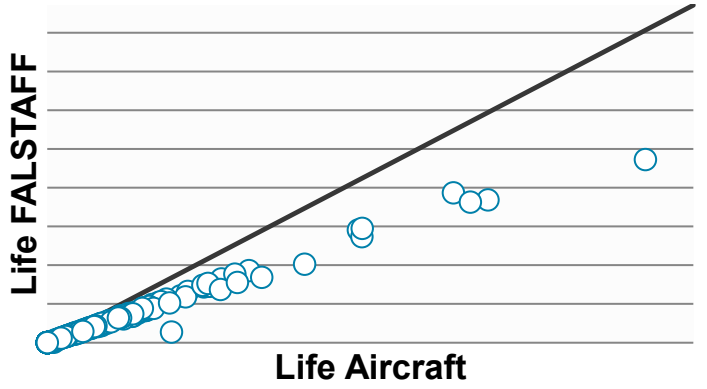
A-10 CP7 - No Retardation - Life Scatter



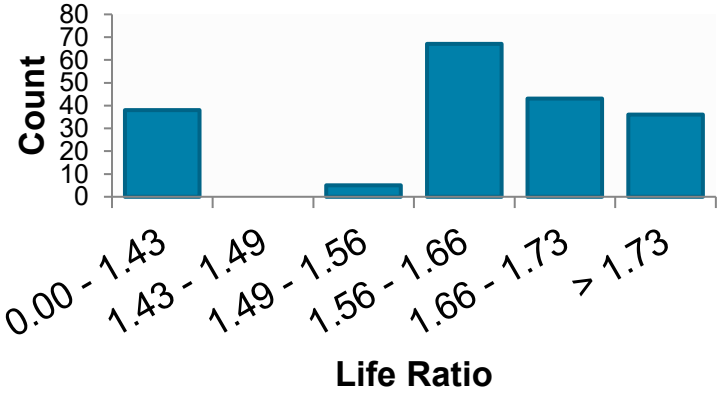
A-10 CP7 - Willenborg Retardation (SOLR 2) - Life Scatter



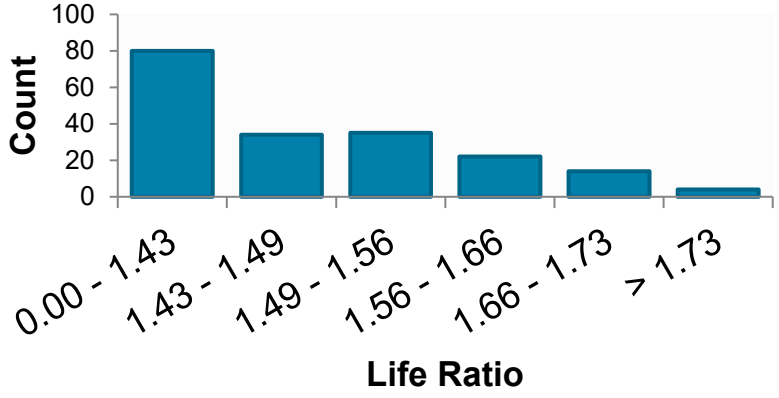
A-10 CP7 - Wheeler Retardation - Life Scatter



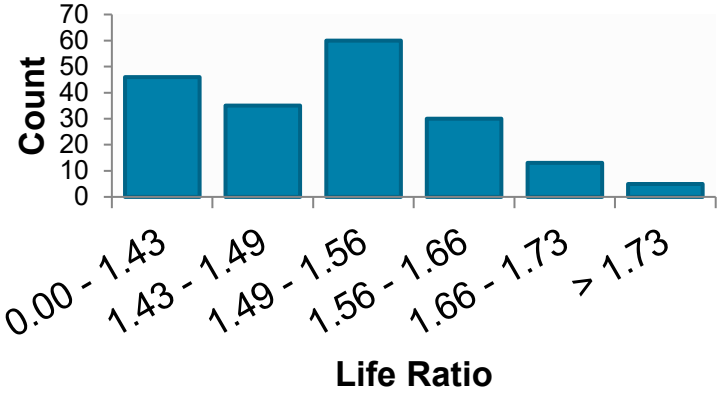
A-10 CP7 - No Retardation - Life Ratio Distribution



A-10 CP7 - Willenborg Retardation (SOLR 2) - Life Ratio Distribution



A-10 CP7 - Wheeler Retardation - Life Ratio Distribution



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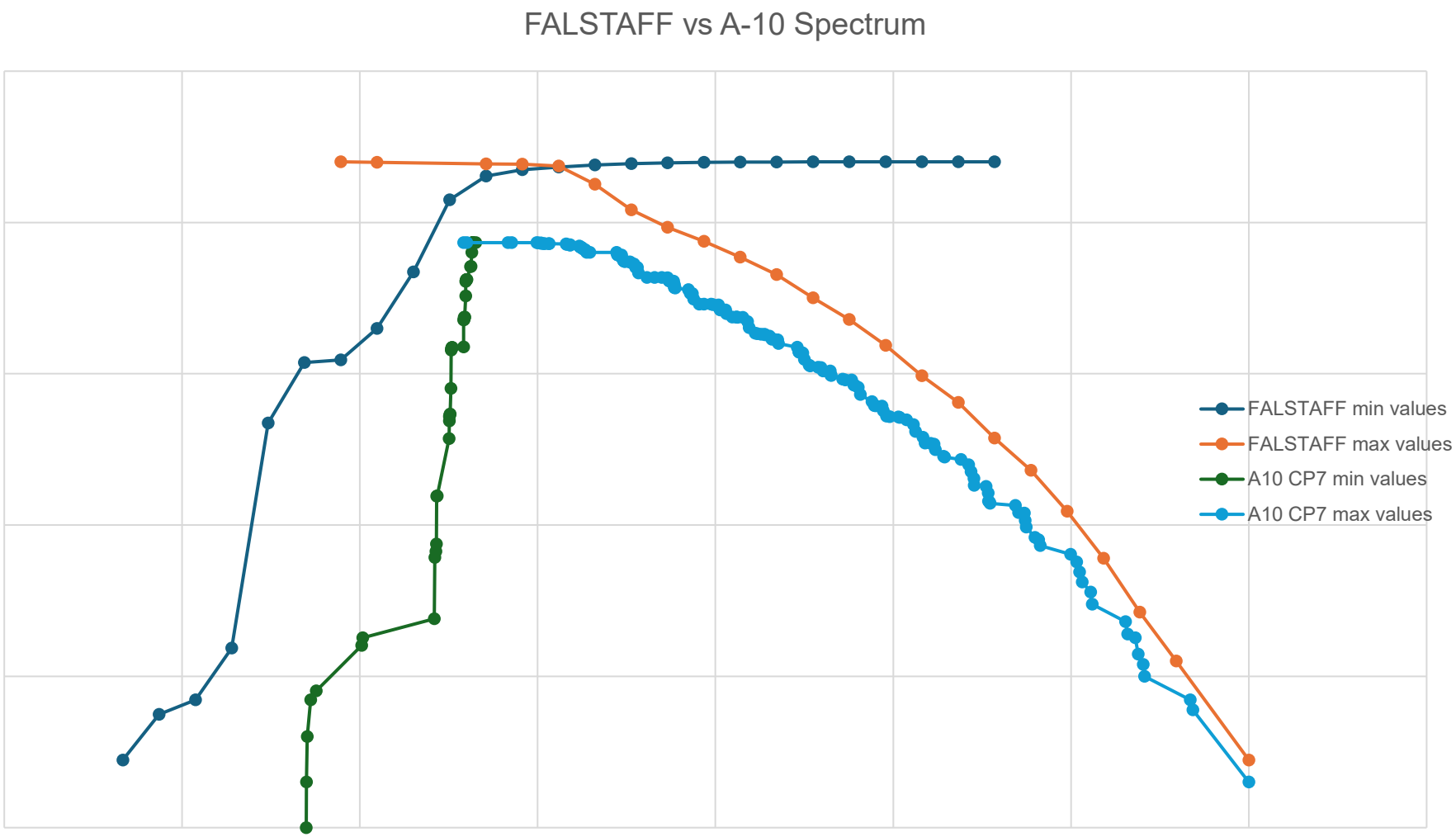
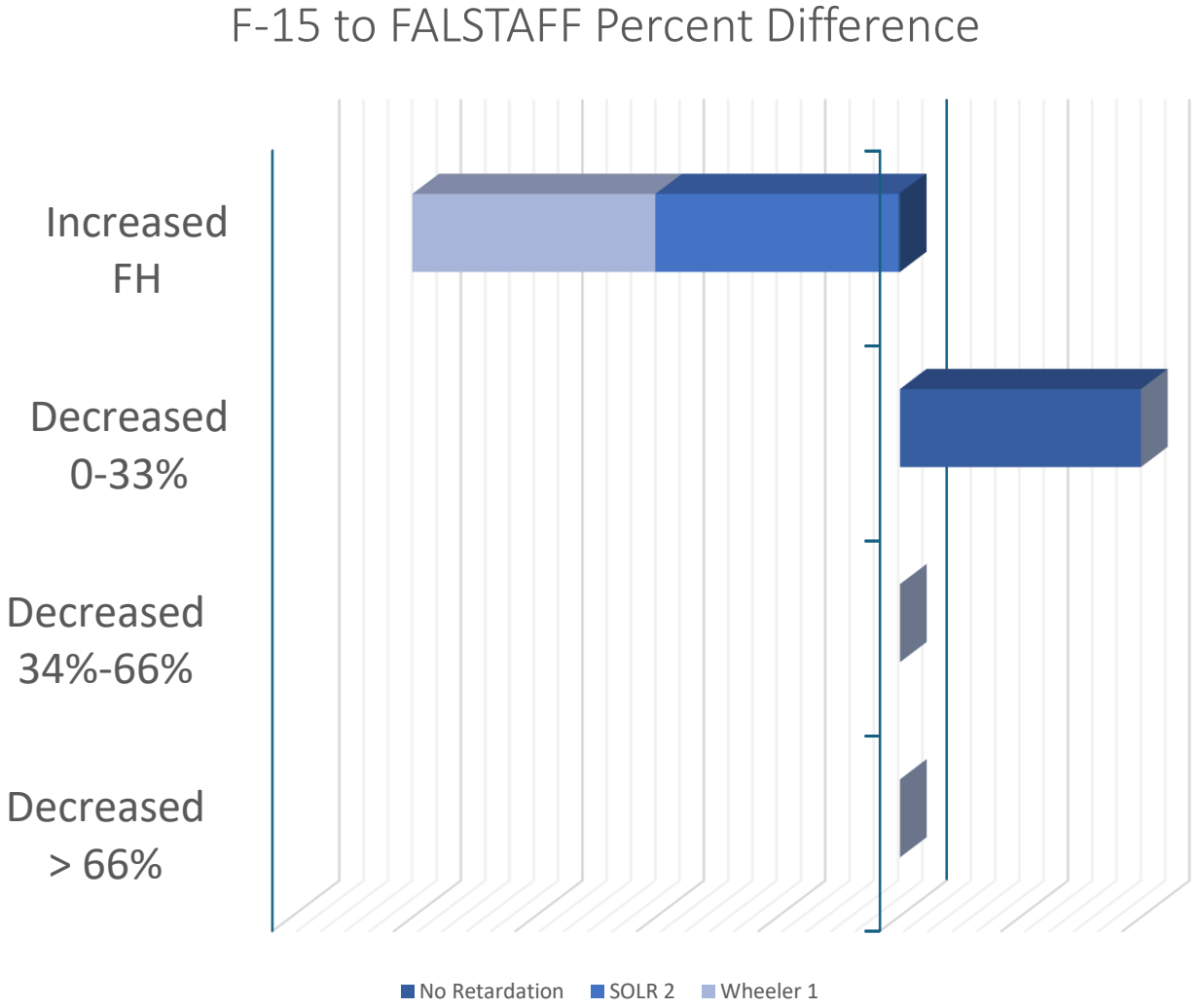
Exceedance Plot FALSTAFF to A-10 CP 7



Make legend big

FALSTAFF and F-15 Spectrum



Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	-1%	-100%	-100%
Decreased by 0-33%	99%	0%	0%
Decreased 34%-66%	0%	0%	0%
Decreased more than 66%	0%	0%	0%

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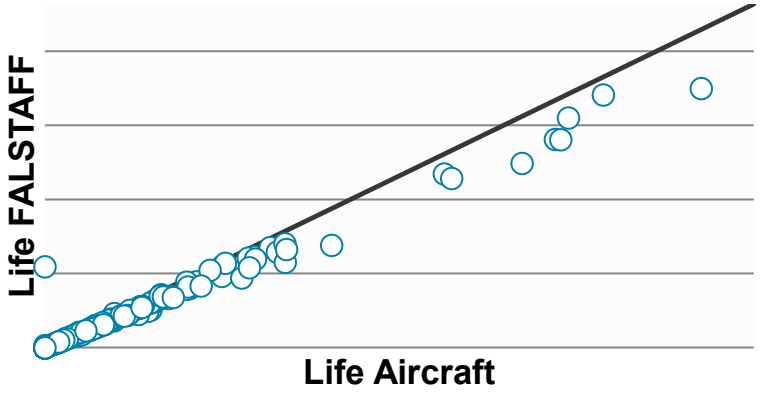
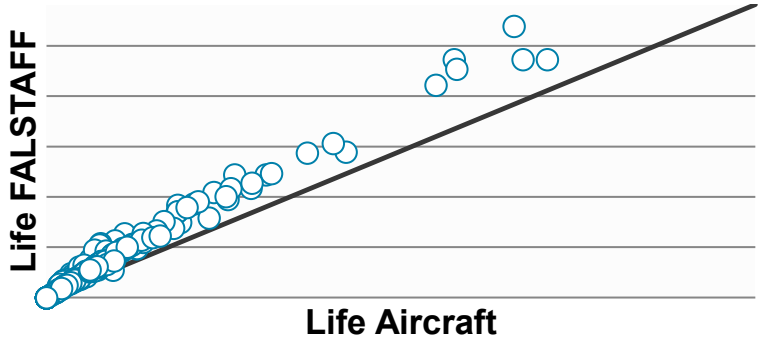
FALSTAFF and F-15 Spectra

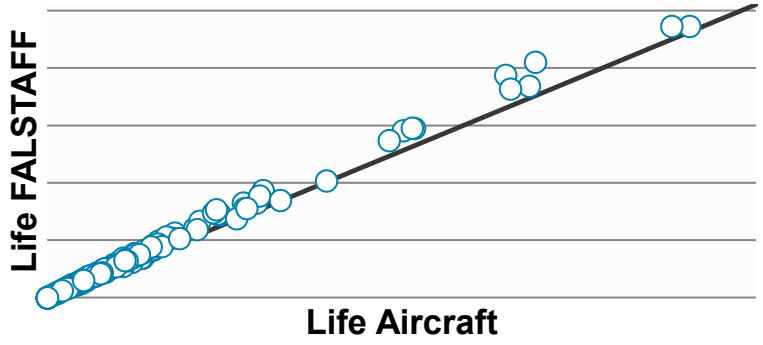
F-15 - No Retardation - Life Scatter



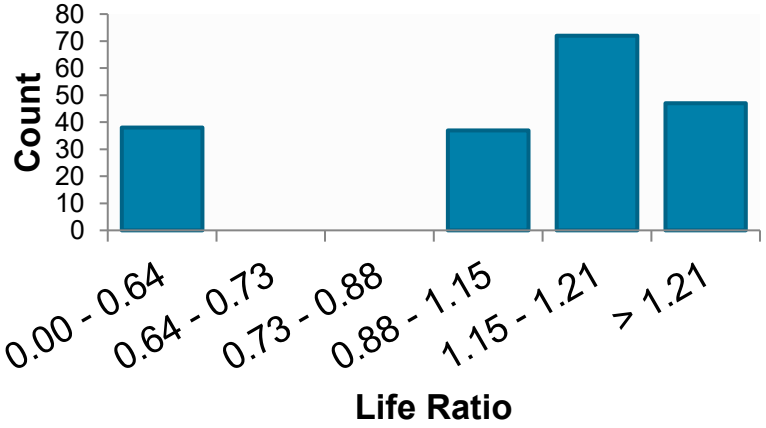
F-15 - Willenborg Retardation (SOLR 2) - Life Scatter



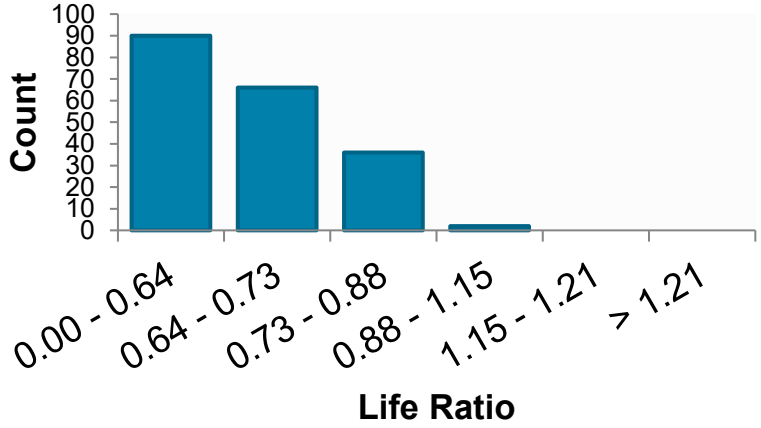
F-15 - Wheeler Retardation - Life Scatter



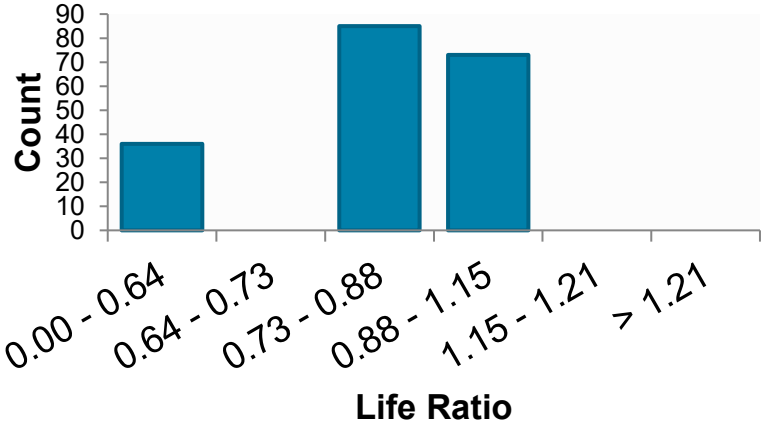
F-15 - No Retardation - Life Ratio Distribution



F-15 - Willenborg Retardation (SOLR 2) - Life Ratio Distribution



F-15 - Wheeler Retardation - Life Ratio Distribution



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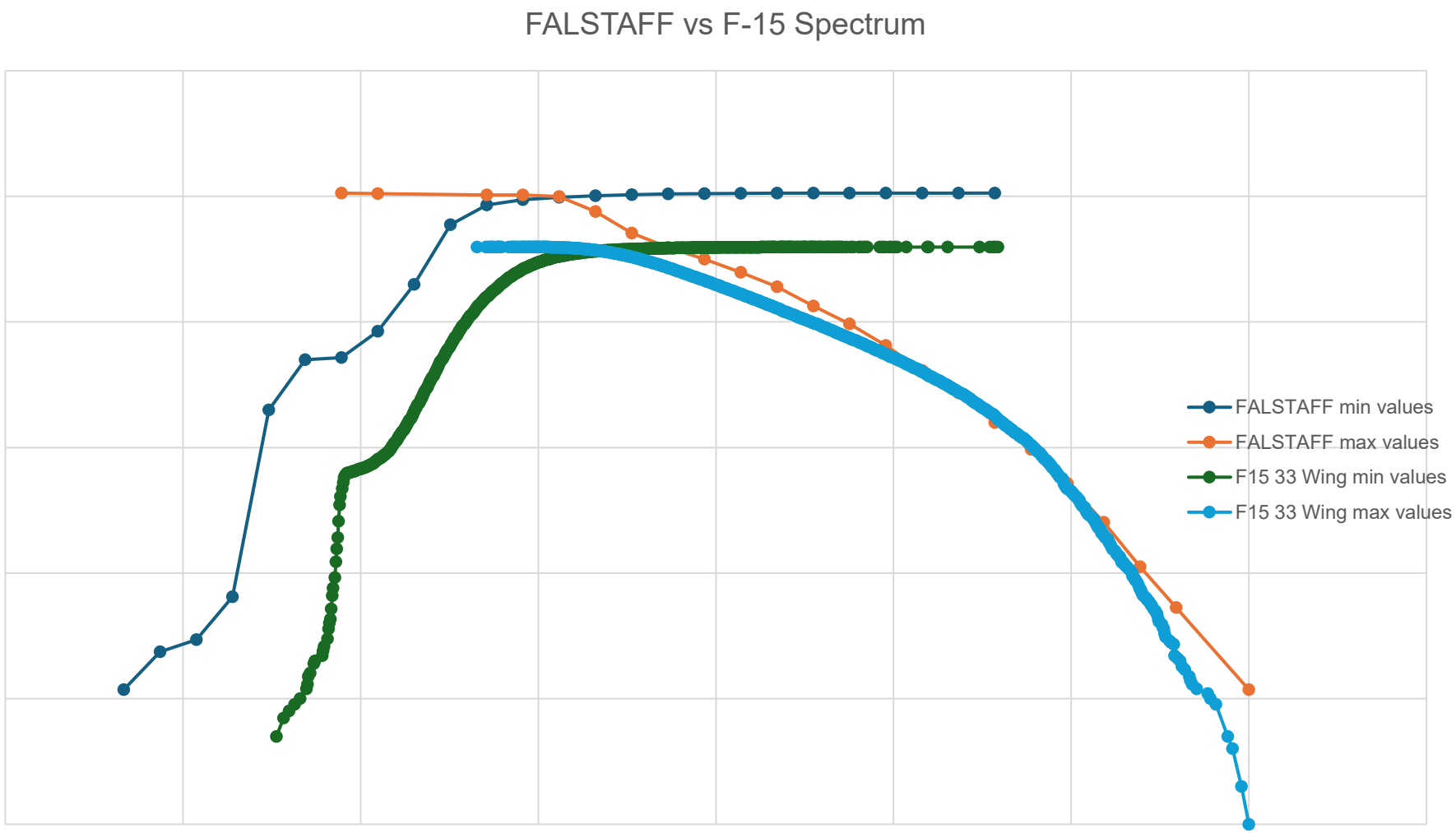
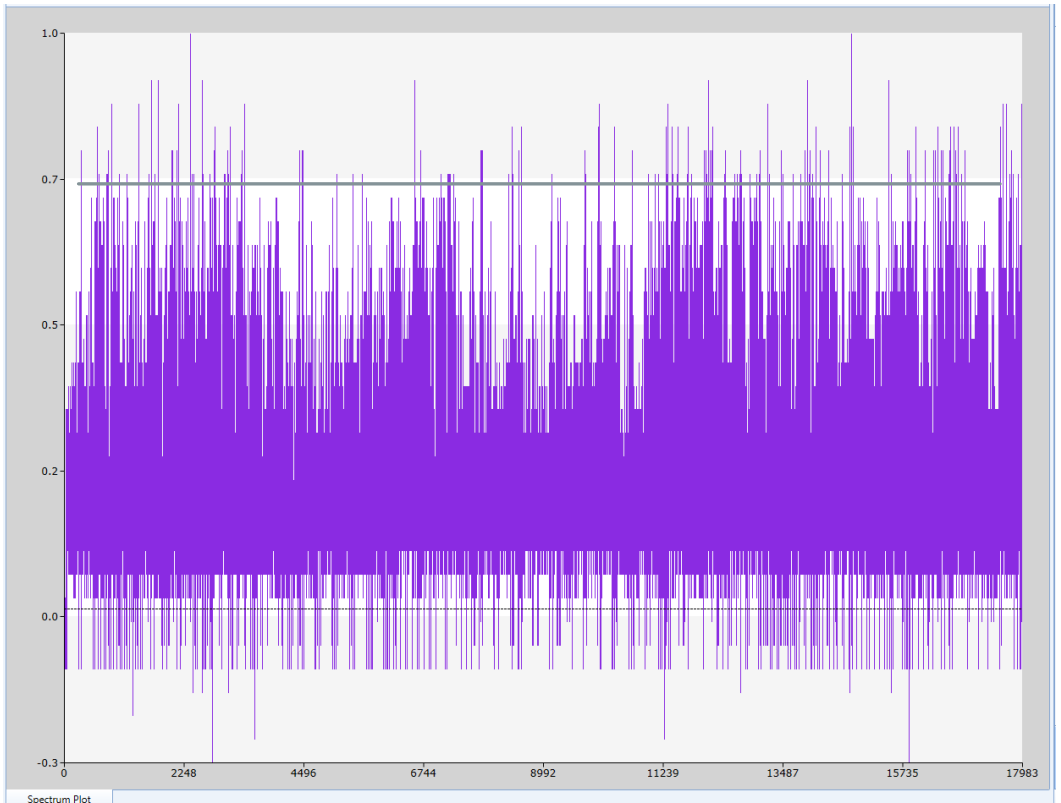
Exceedance Plot FALSTAFF to F-15



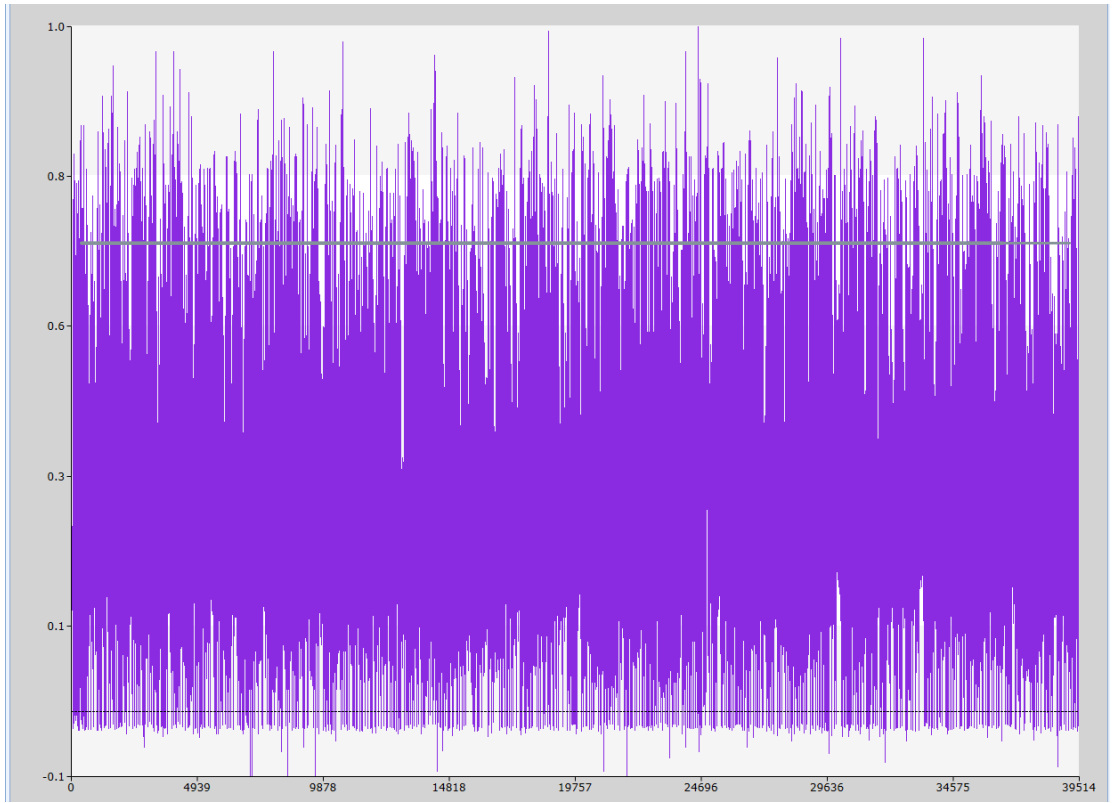
Why does retardation have so much effect?

Notice the amount of peaks that are above .7 in the F-15 spectrum compared to FALSTAFF. This is likely why the retardation has so much more effect on life.

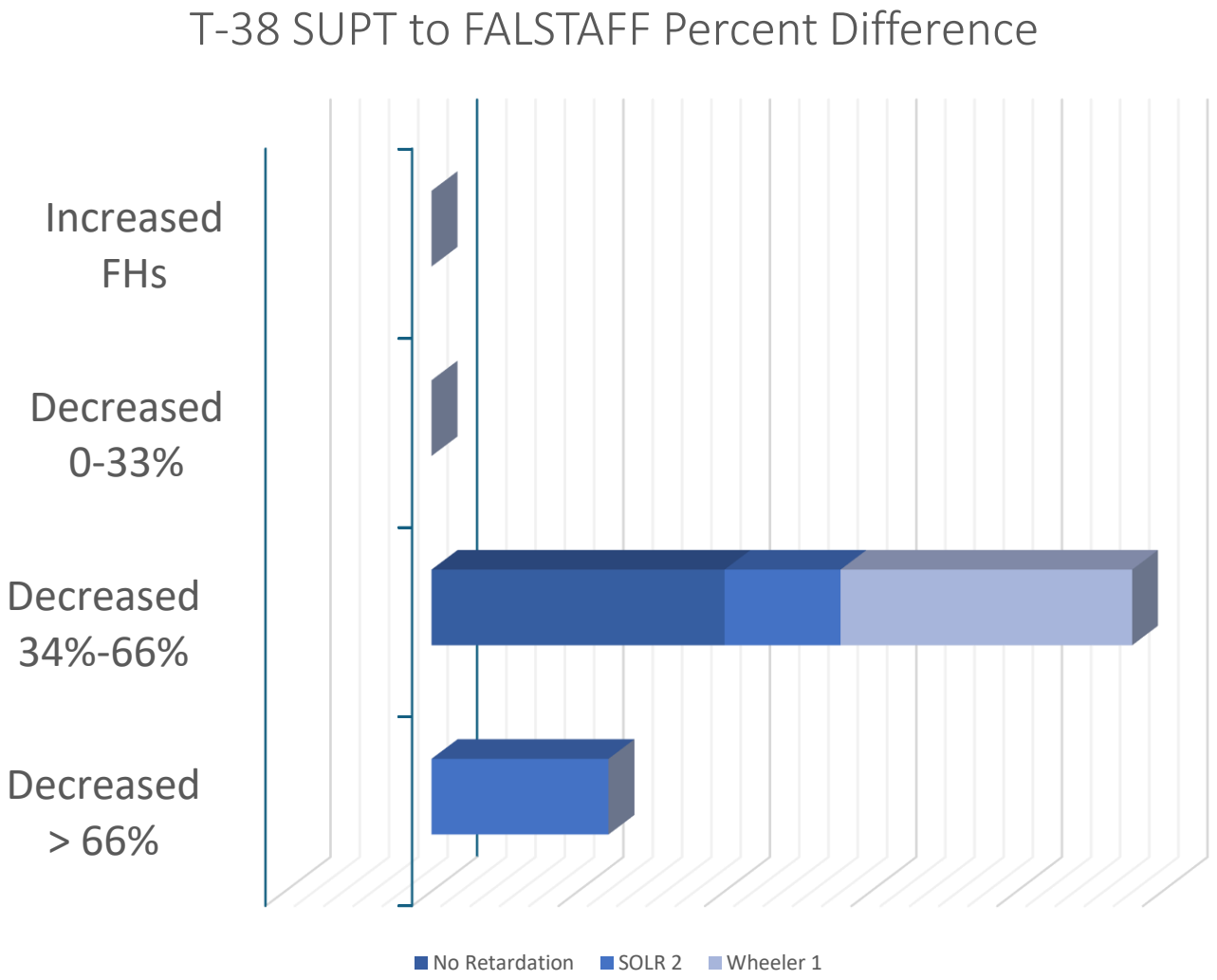
FALLSTAFF Normalized Spectrum



F-15 Normalized Spectrum



FALSTAFF and T-38 SUPT Spectra



Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	0%	0%	0%
Decreased by 0-33%	0%	0%	0%
Decreased 34%-66%	100%	40%	100%
Decreased more than 66%	0%	60%	0%

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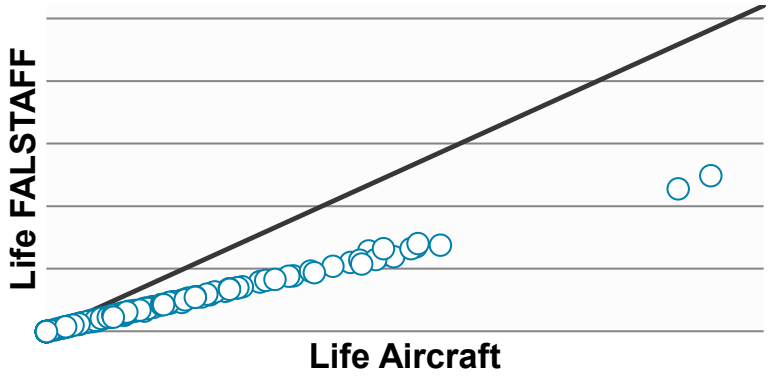
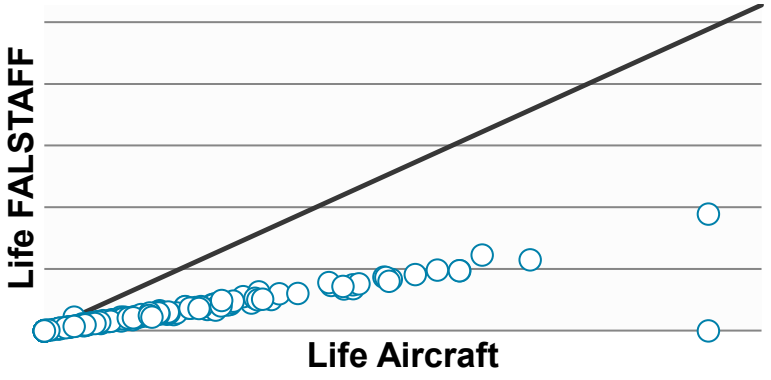
FALSTAFF and T-38 SUPT Spectra

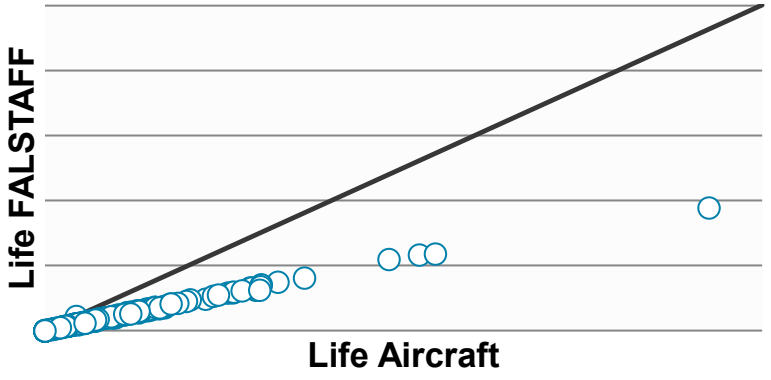
T-38 SUPT - No Retardation - Life Scatter



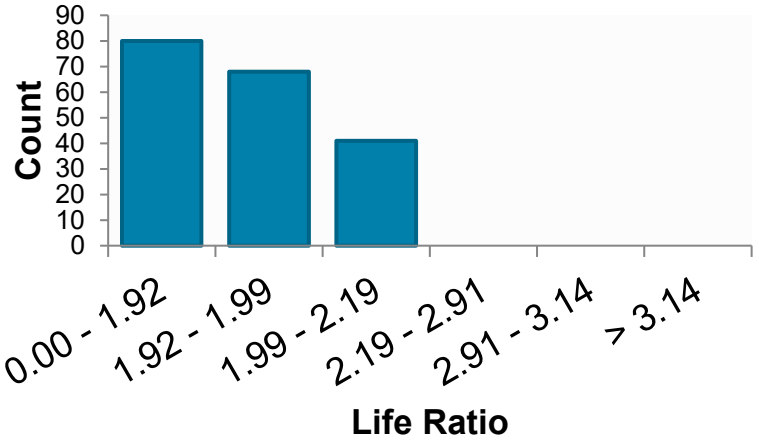
T-38 SUPT - Willenborg Retardation (SOLR 2) - Life Scatter



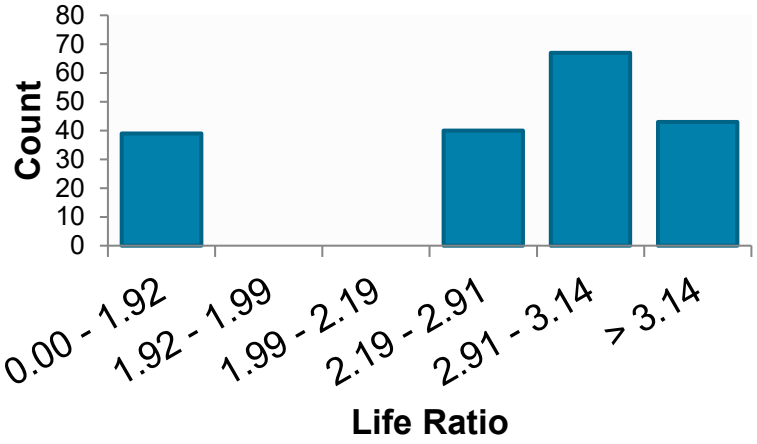
T-38 SUPT - Wheeler Retardation - Life Scatter



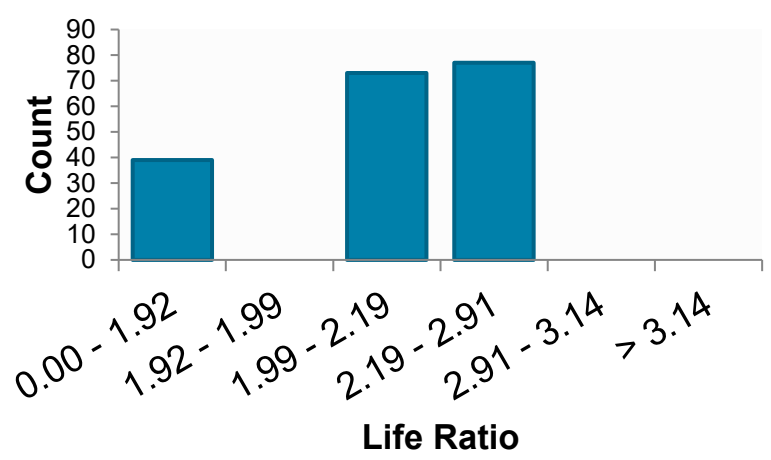
T-38 SUPT - No Retardation - Life Ratio Distribution



T-38 SUPT - Willenborg Retardation (SOLR 2) - Life Ratio Distribution



T-38 SUPT - Wheeler Retardation - Life Ratio Distribution



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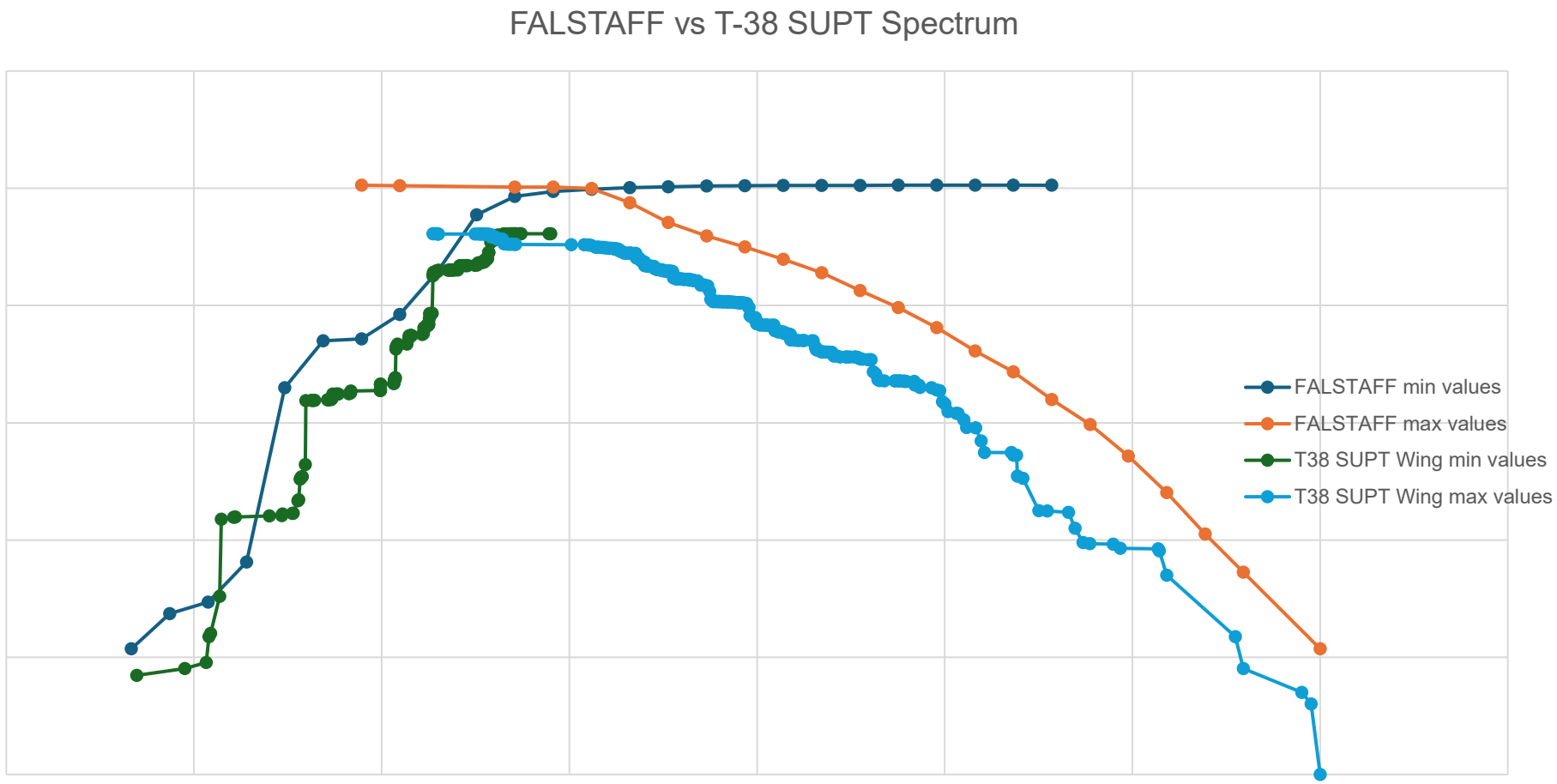
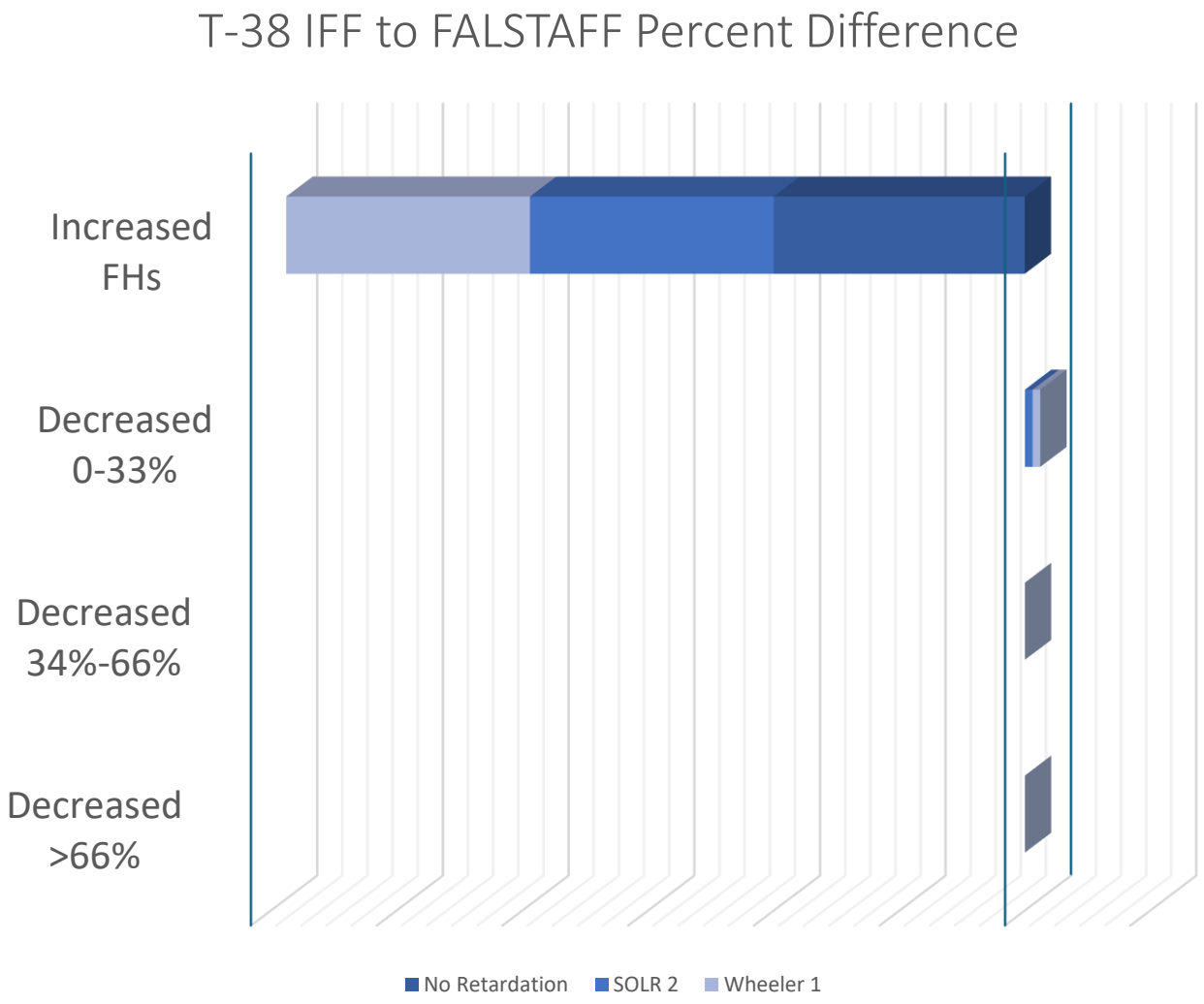
Exceedance Plot FALSTAFF to T-38 SUPT



FALSTAFF and T-38 IFF Spectra



Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	-100%	-97%	-97%
Decreased by 0-33%	0%	3%	3%
Decreased 34%-66%	0%	0%	0%
Decreased more than 66%	0%	0%	0%

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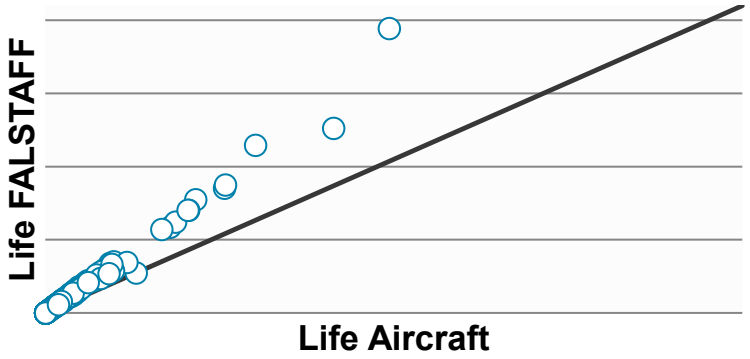
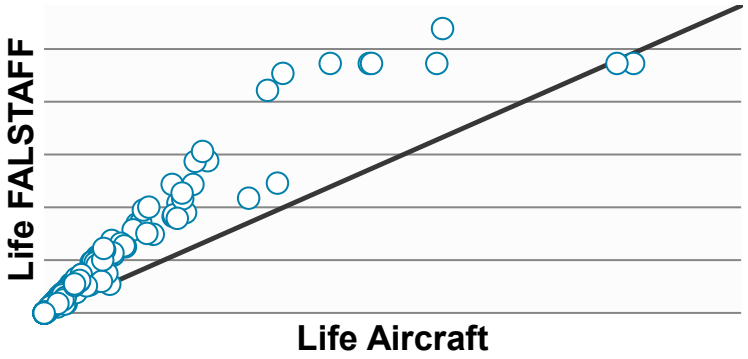
FALSTAFF and T-38 IFF Spectra

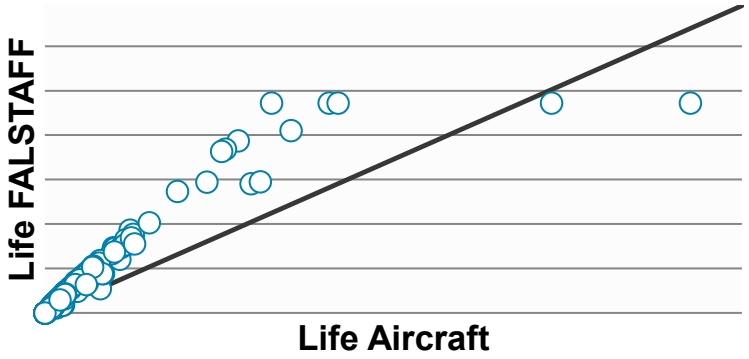
T-38 IFF - No Retardation - Life Scatter



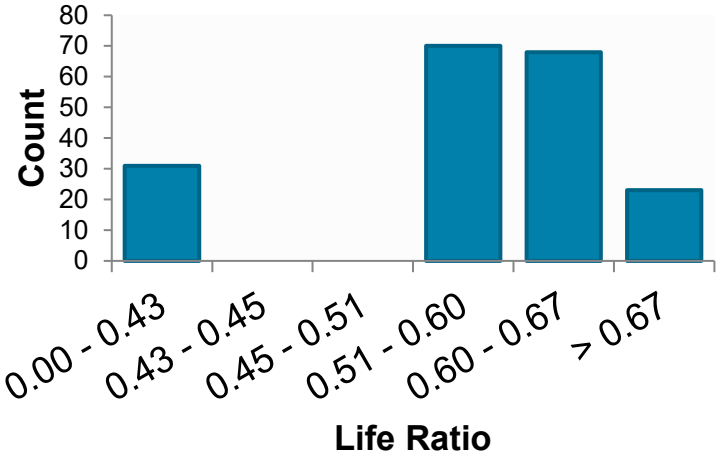
T-38 IFF - Willenborg Retardation (SOLR 2) - Life Scatter



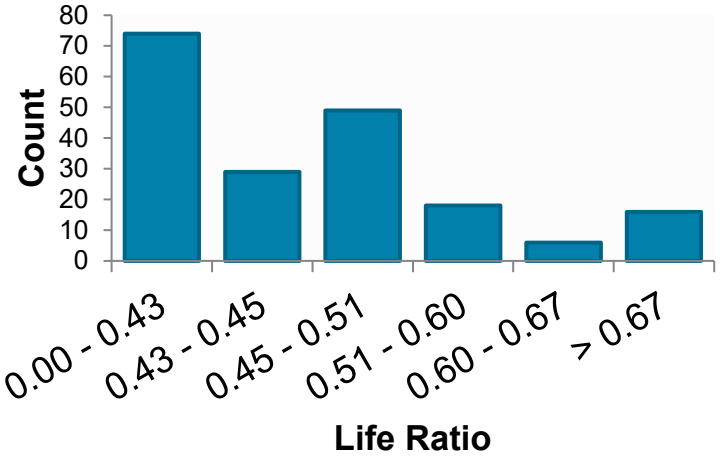
T-38 IFF - Wheeler Retardation - Life Scatter



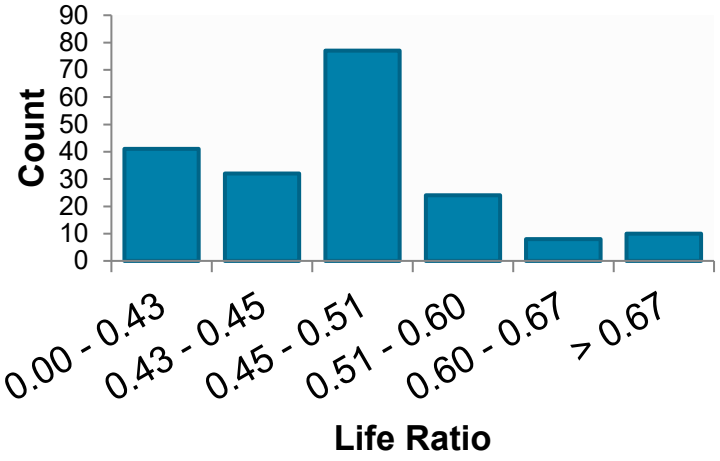
T-38 IFF - No Retardation - Life Ratio Distribution



T-38 IFF - Willenborg Retardation (SOLR 2) - Life Ratio Distribution



T-38 IFF - Wheeler Retardation - Life Ratio Distribution



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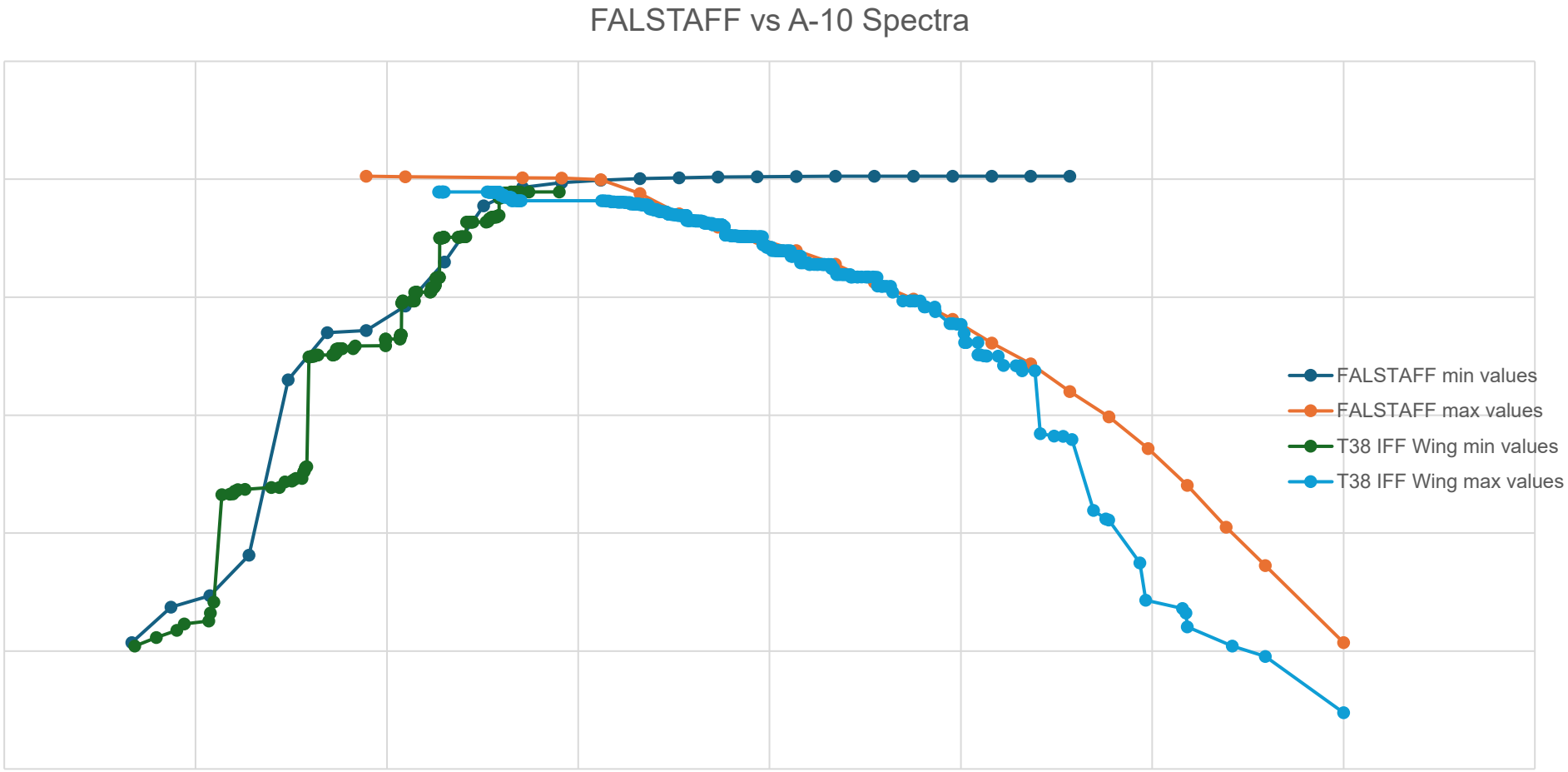
Exceedance Plot FALSTAFF to T-38 IFF



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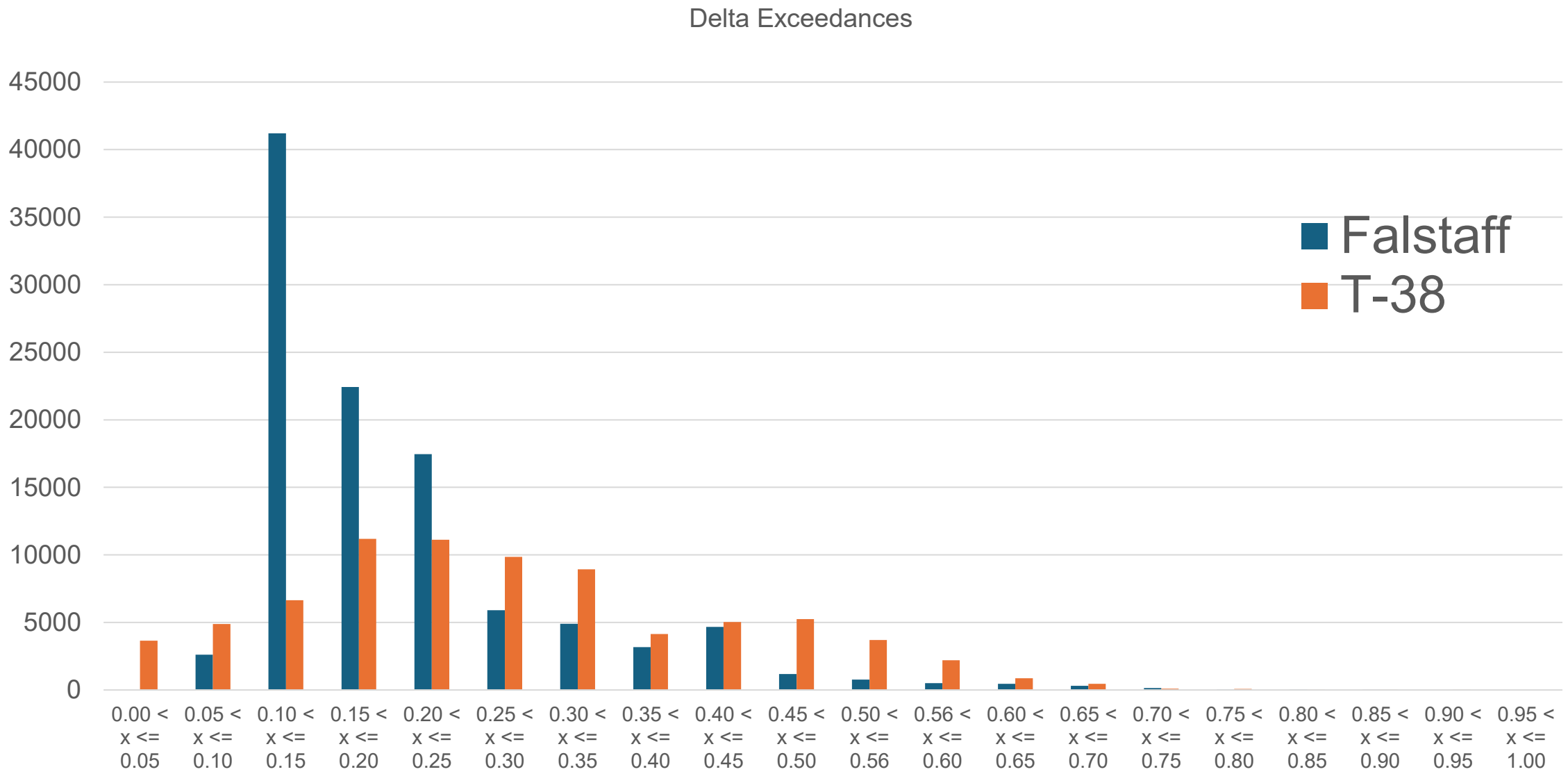
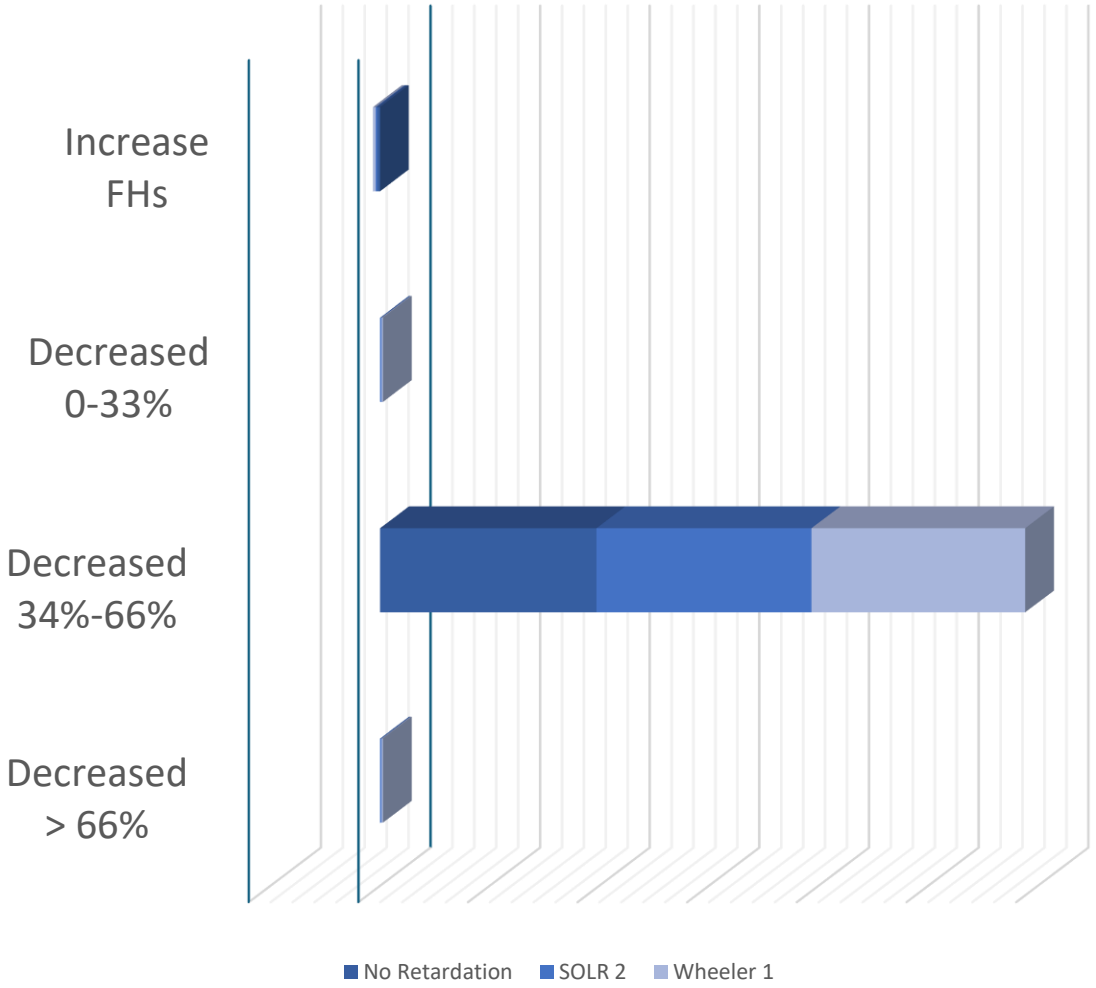
FALSTAFF/T-38 IFF Delta Exceedance Plot



FALSTAFF and F-16 Spectra

F-16 to FALSTAFF Percent Difference



Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	-1%	-1%	-1%
Decreased by 0-33%	0%	1%	1%
Decreased 34%-66%	99%	98%	97%
Decreased more than 66%	0%	1%	1%

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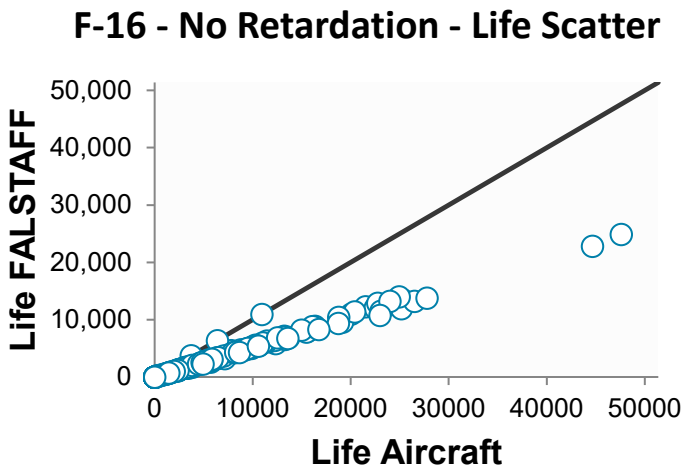
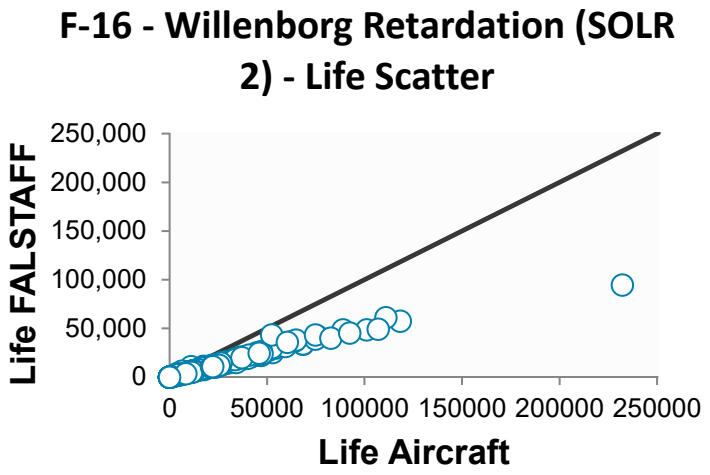
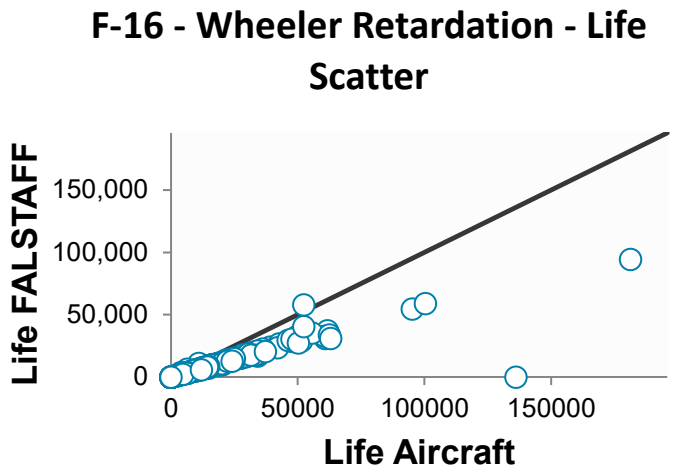
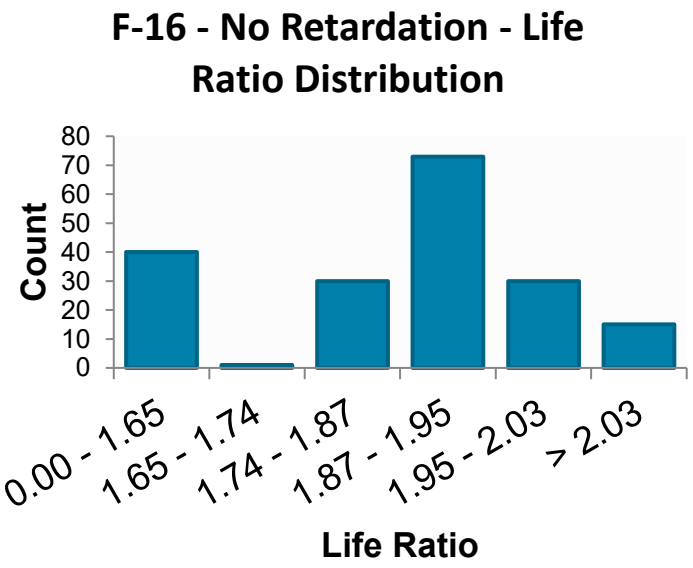
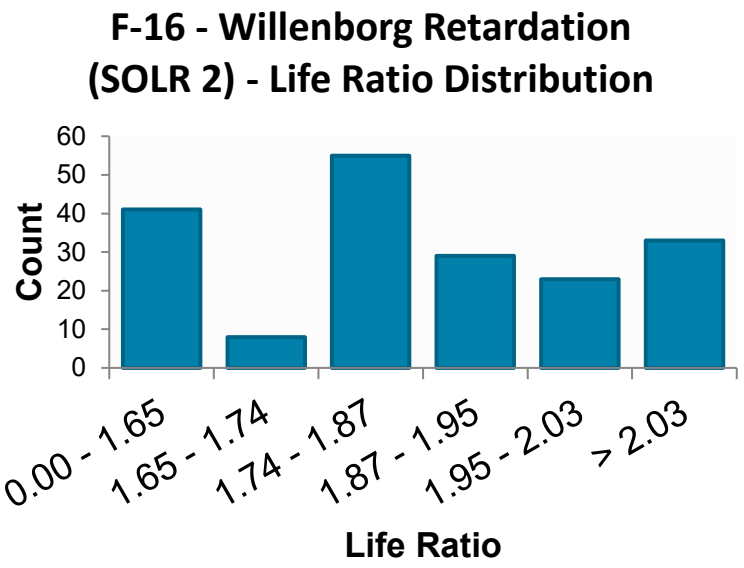
FALSTAFF and T-16 Spectra

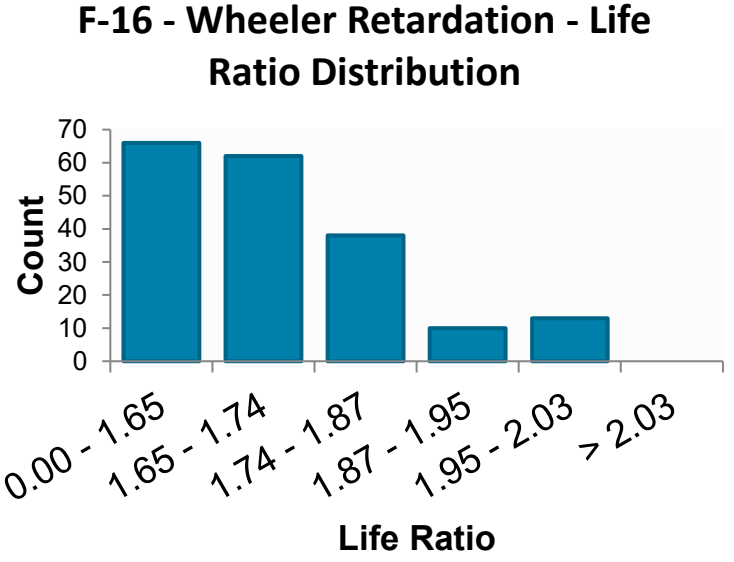












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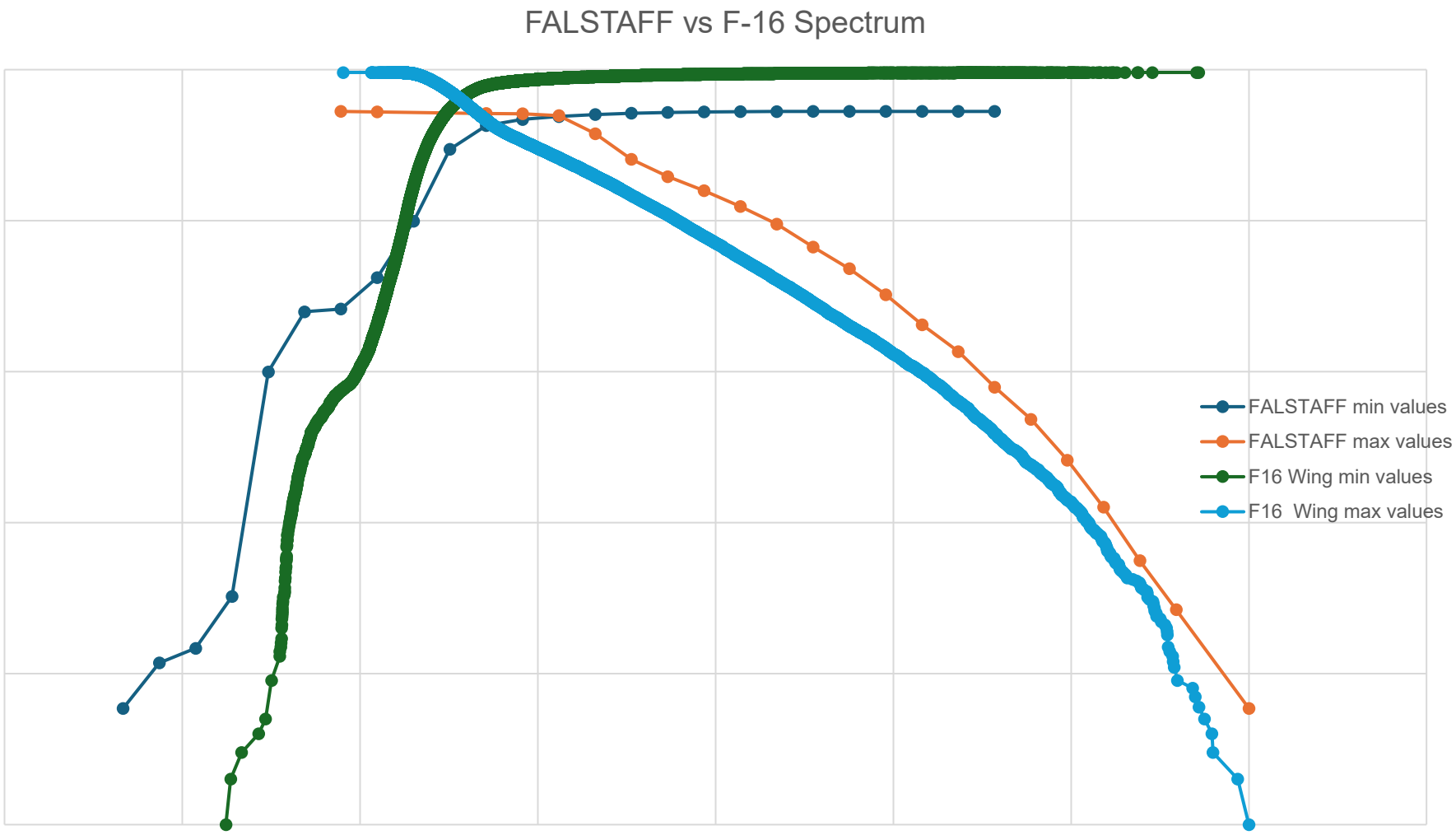
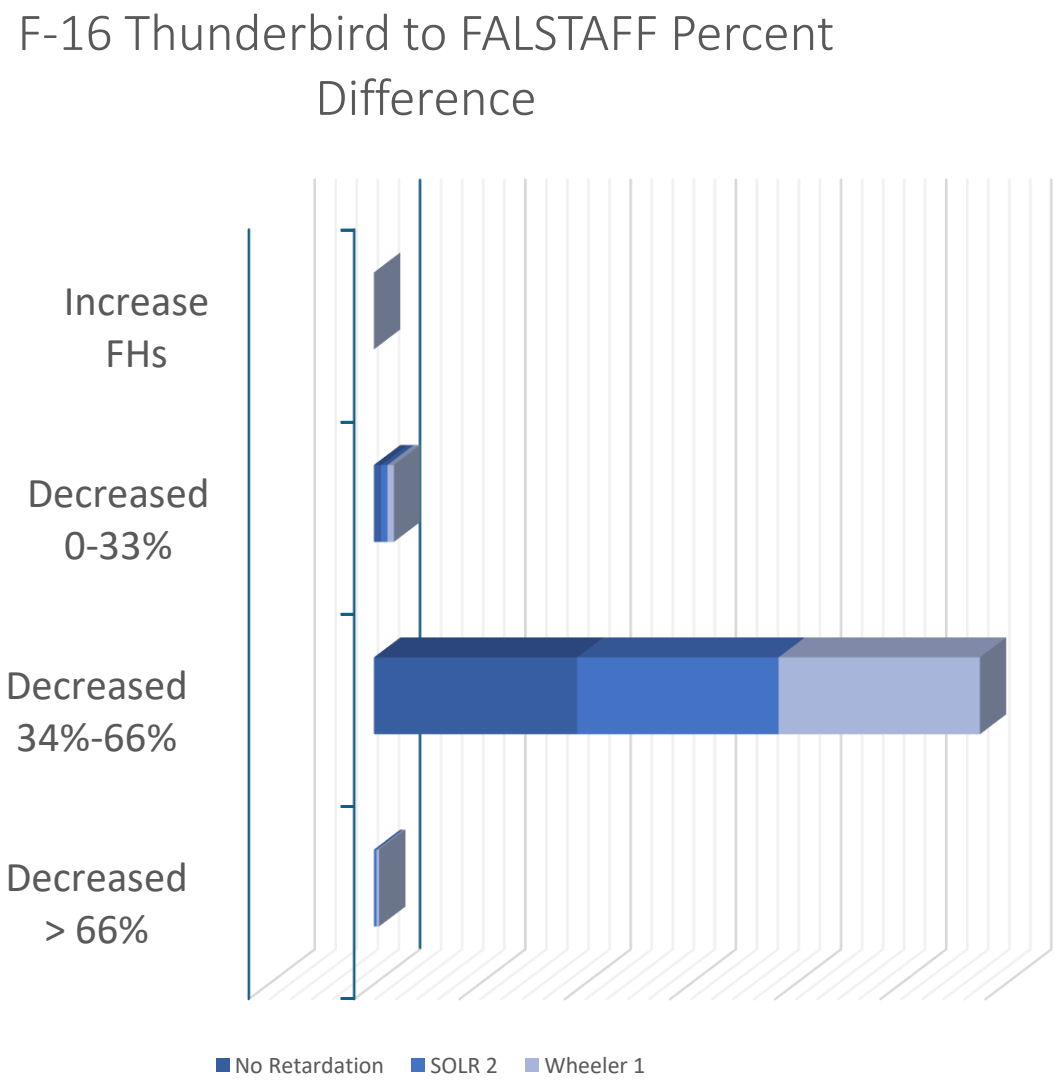
Exceedance Plot FALSTAFF to F-16



FALSTAFF and F-16 Thunderbird Spectra



Change In flight Hours	No Retardation	SOLR 2	Wheeler 1
Increase flight hours	0%	0%	0%
Decreased by 0-33%	3.40%	3.03%	3.03%
Decreased 34%-66%	96.40%	95.76%	95.76%
Decreased more than 66%	0%	1.21%	1.21%

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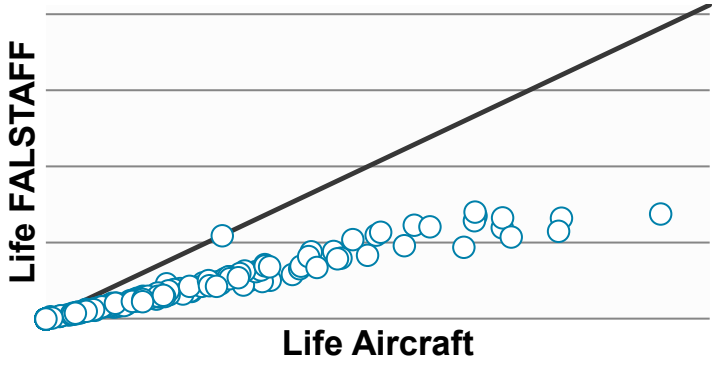
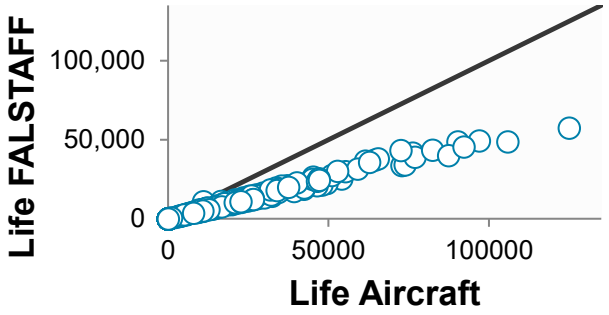
FALSTAFF and F-16 Thunderbird Spectra

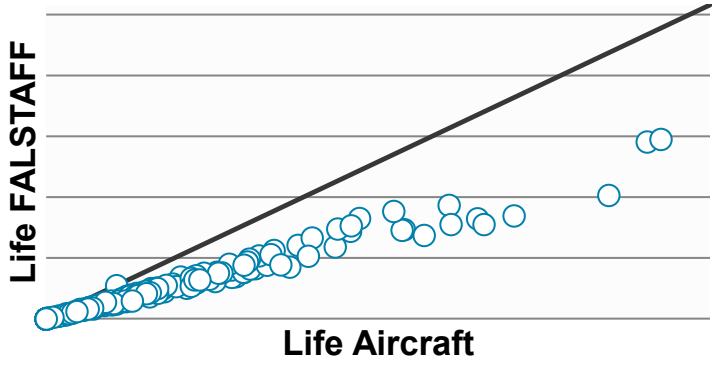
Thunderbird F-16 - No Retardation - Life Scatter



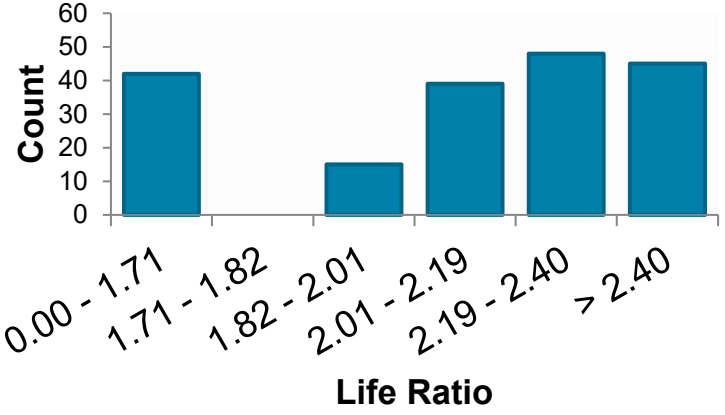
Thunderbird F-16 - Willenborg Retardation (SOLR 2) - Life Scatter



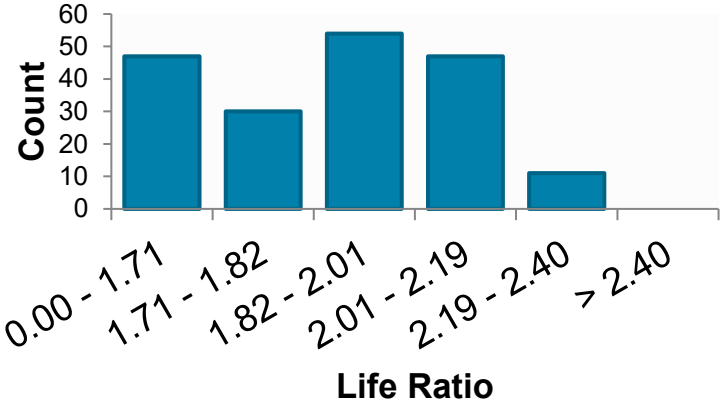
Thunderbird F-16 - Wheeler Retardation - Life Scatter



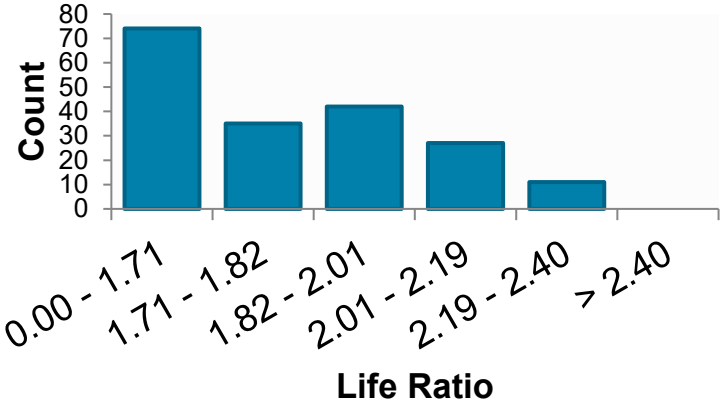
Thunderbird F-16 - No Retardation - Life Ratio Distribution



Thunderbird F-16 - Willenborg Retardation (SOLR 2) - Life Ratio Distribution



Thunderbird F-16 - Wheeler Retardation - Life Ratio Distribution



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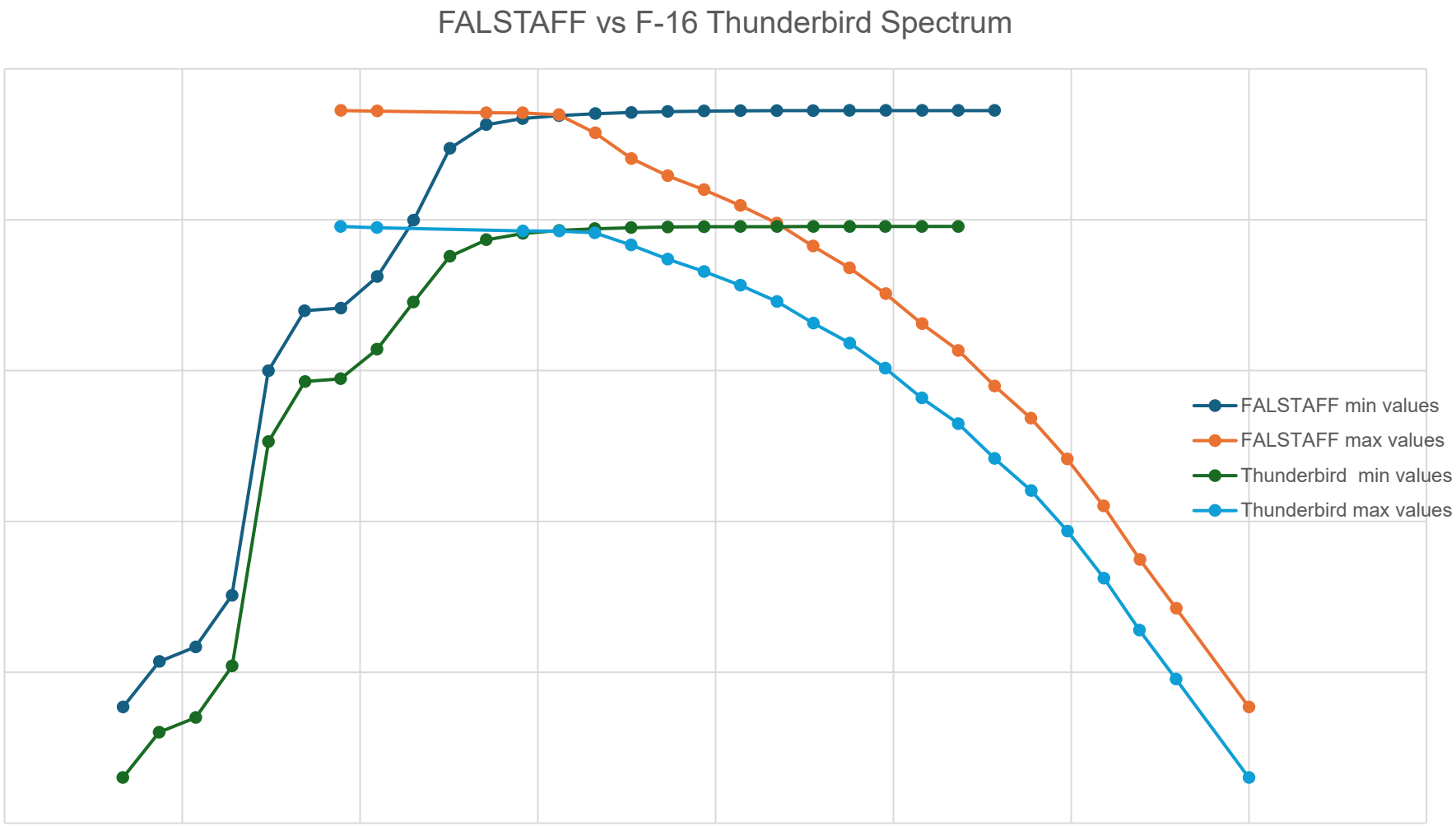
Exceedance Plot FALSTAFF to F-16 Thunderbird



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Spectrum Applicability & DTA Conservatism

- Alignment with Fighter Operational Scope
  - FALSTAFF generally falls within the representative stress/life bounds of legacy tactical fighter aircraft (A-10, F-15, F-16, T-38).
  - Predicts a more conservative structural life (fewer flight hours) across the majority of evaluated Critical Inspection Point (CIP) geometries.
  - Because it can predict significantly lower total life in specific geometries, caution must be exercised before using FALSTAFF to drive major fleet sustainment or life-extension decisions.

- Key Analytical Exceptions to Conservatism
  - Non-conservative relative to severe baseline operational profiles (e.g., T-38 IFF) dominated by high continuous stress amplitudes.
  - Spectrum comparisons shift when accounting for crack retardation; legacy spectra with higher frequencies of peak overloads induce stronger retardation effects than FALSTAFF.

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Operational Utility & Recommendations

- Primary Use Cases & Advantages
  - Serves as a viable surrogate "in a pinch" when platform-specific operational spectra are unavailable (e.g., early conceptual/new aircraft design).
  - Highly effective as a standardized baseline to compare material fatigue performance and evaluate crack growth allowables across alloys.
  - Provides an unclassified, standardized spectrum to evaluate and compare aircraft structural performance across platforms without exposing sensitive operational flight data.

- Final Engineering Recommendation
  - Platform-specific or closely matched empirical spectra remain the preferred standard whenever available.
  - FALSTAFF is best utilized as a normative comparative benchmark and preliminary design surrogate, rather than a final certification baseline for platforms subject to severe, overload-dominated loading.

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A special thank you to the following

Jacob Warner, Reliant Aero, A-10 ASIP

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Kaylon Anderson, SwRI, A-10 ASIP

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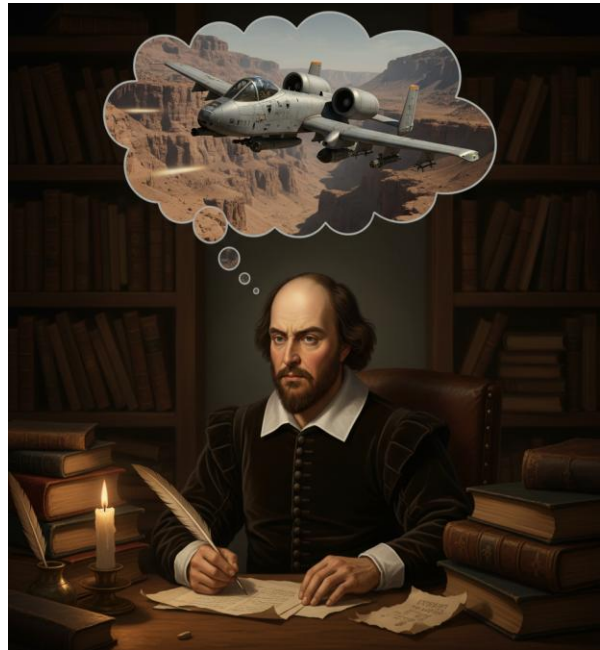
Questions?

"…honor spurs me on. Yeah, but what if honor spurs me off once I'm on, and picks me out to die? What happens then? Can honor set a broken leg? No. Or an arm? No. … What is honor? A word. What is in that word, "honor?" What is that "honor?" … A guy who died last Wednesday. Does he feel it? No. Does he hear it? No. It can't be detected, then? …Honor is nothing more than a gravestone...

***General Falstaff**, Henry IV, Part 1, Act 5, Scene 1*



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Backup slides

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Hours per Pass

- FALSTAFF- 170
- A-10- 240
- F-15- 1000
- T-38- 1000
- F-16- 500
- miniTWIST- 8000

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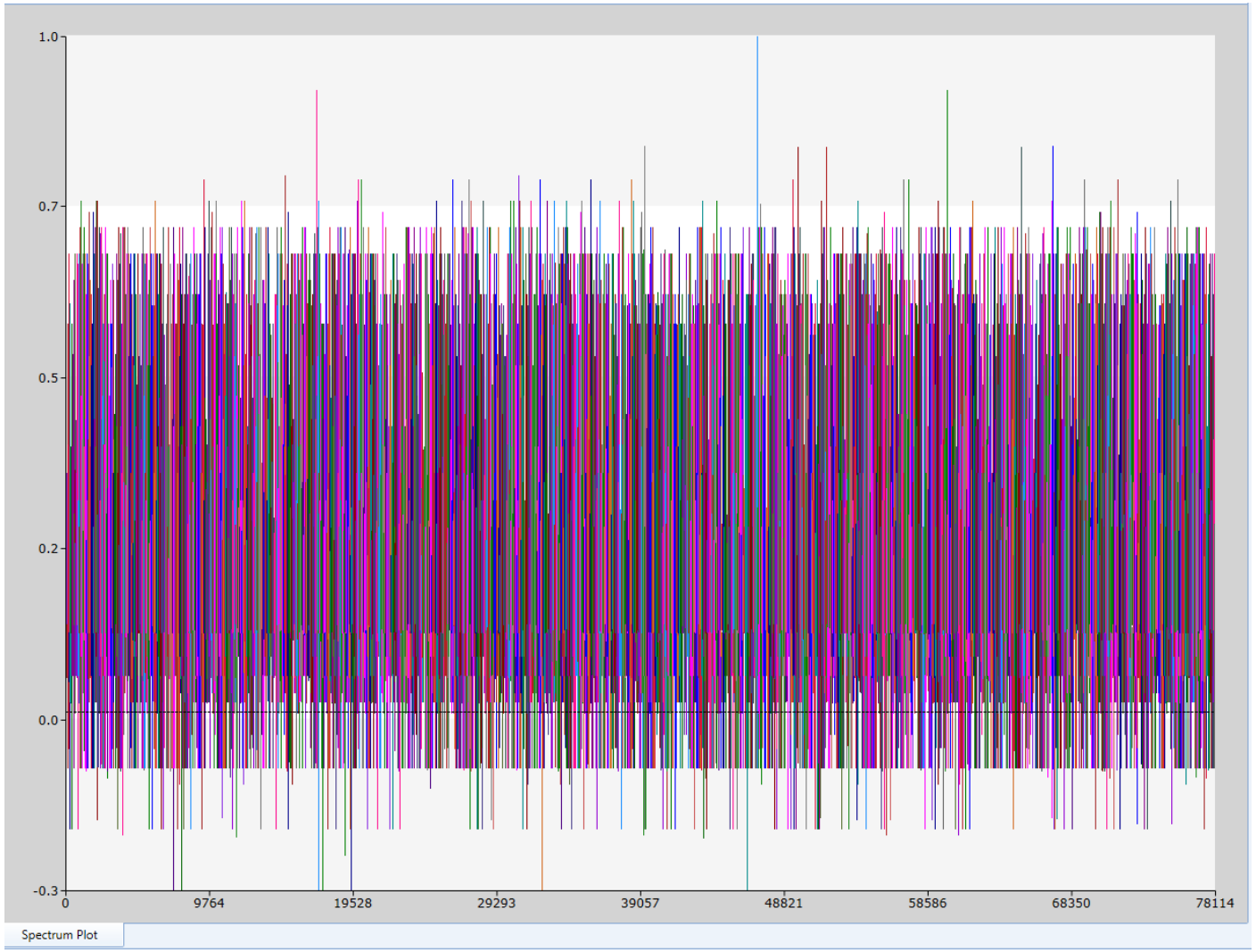
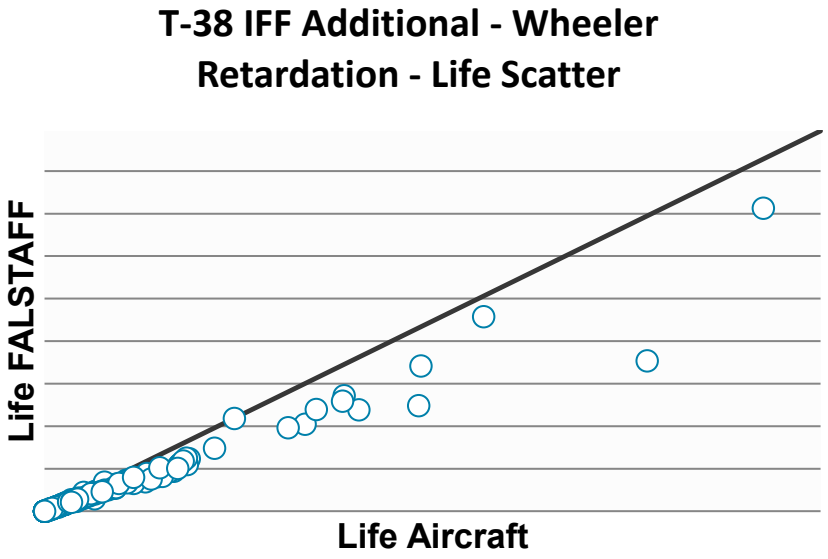
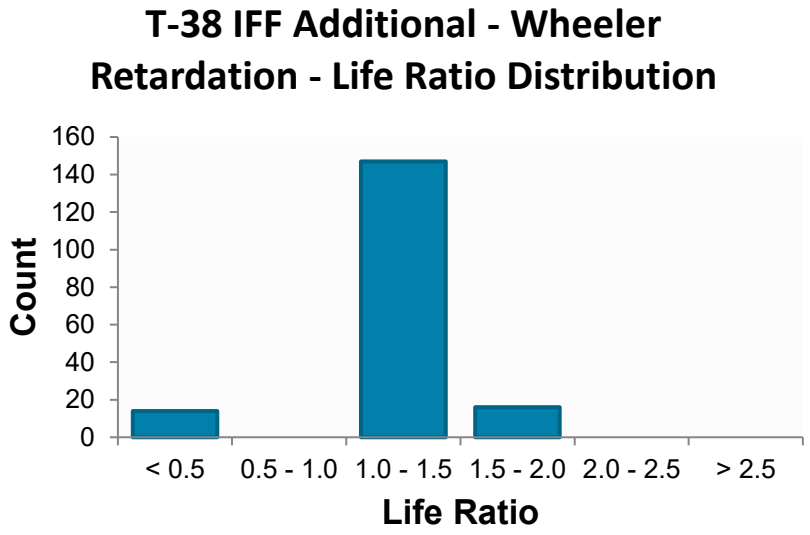
Why is FALSTAFF Less Severe?



- Baseline spectrum displays near-constant amplitude cycling concentrated around 0.7, rendering it substantially more damaging than FALSTAFF.
- A lack of isolated peak tensile overloads prevents significant crack growth retardation, accelerating baseline damage accumulation.

FALSTAFF and T-38 at .8 Factor

- By trimming the FALSTAFF spectrum by a factor of .8, and then normalizing it back to 1, there was significant improvement in how it correlated to the T-38 IFF spectrum.