Maintenance Free Operating Period (MFOP) Simulation Modeling

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LogLab Subject Matter Expert

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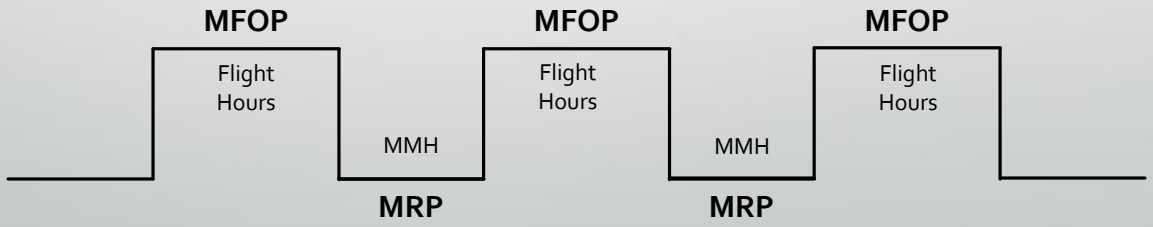
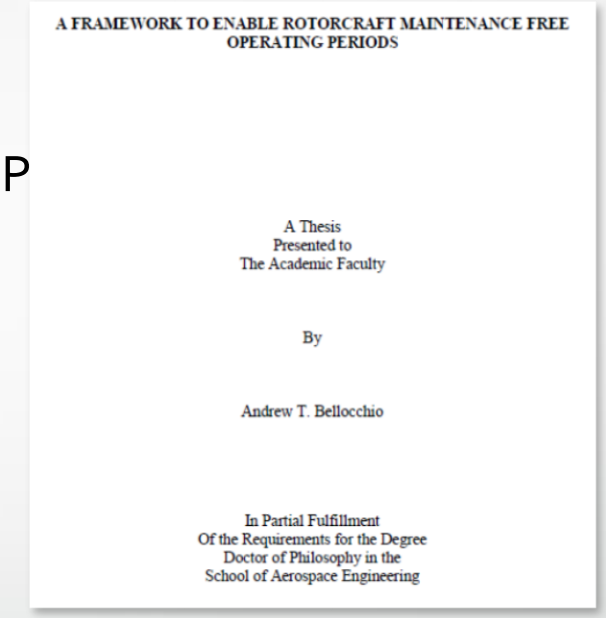
What is MFOP?

- Maintenance Free Operating Period (MFOP), a concept developed by the British Royal Air Force's Ultra Reliable Aircraft Pilot Study, provides an instance that requires an ultra reliable aircraft with very little time based maintenance [1]
- The definitions are below [2]
  - *MFOP: period of operation during which the equipment must be able to carry out all its assigned missions without any maintenance action and without the operator being restricted in any way due to system faults or limitations.*
  - *Maintenance Recovery period (MRP): The downtime during which appropriate scheduled or corrective maintenance is done to recover the system to its fully serviceable state so that it can achieve the next MFOP.*



MFOP and the LogLab

- US Military Academy (West Point) carried out the original MFOP study in 2018
  - An incredibly large improvement in reliability would be required to make MFOP Goal
- West Point re-evaluating MFOP with additional options
  - LogLab used this opportunity to internally develop an MFOP model
  - West Point's additional options needed evaluating beyond any single individual aircraft



A FRAMEWORK TO ENABLE ROTORCRAFT MAINTENANCE FREE OPERATING PERIODS

A Thesis
Presented to
The Academic Faculty

By

Andrew T. Bellocchio

In Partial Fulfillment
Of the Requirements for the Degree
Doctor of Philosophy in the
School of Aerospace Engineering

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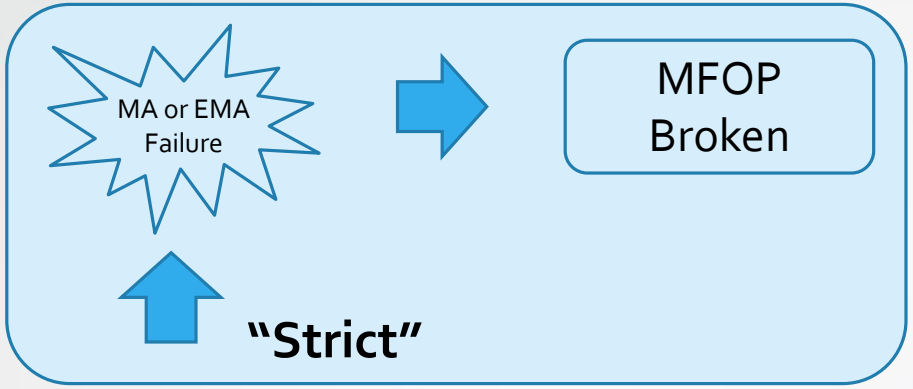
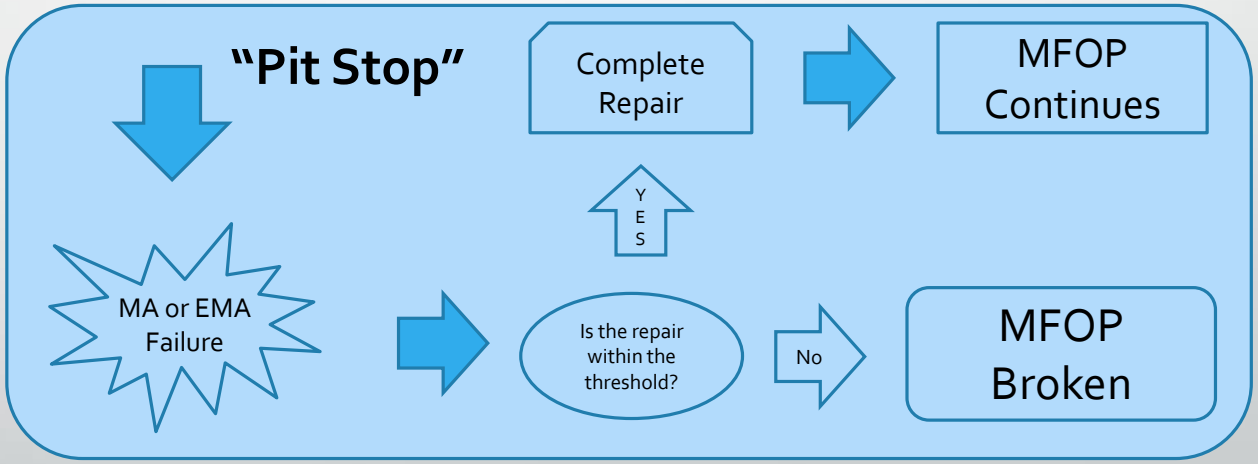
- The LogLab is a collaboration between logistics and engineering organizations. Our goals are to:
  - Influence design for sustainment
  - Identification of technologies and gaps related to Logistics/Supportability
  - Assessment of sustainment improvement/technologies

West Point MFOP Modeling

- **"Strict" Scenario** : Any Essential Maintenance Action or Mission Abort breaks MFOP
- **"Pit Stop" Scenario**: Any failure with **service time greater than the repair threshold** breaks the MFOP



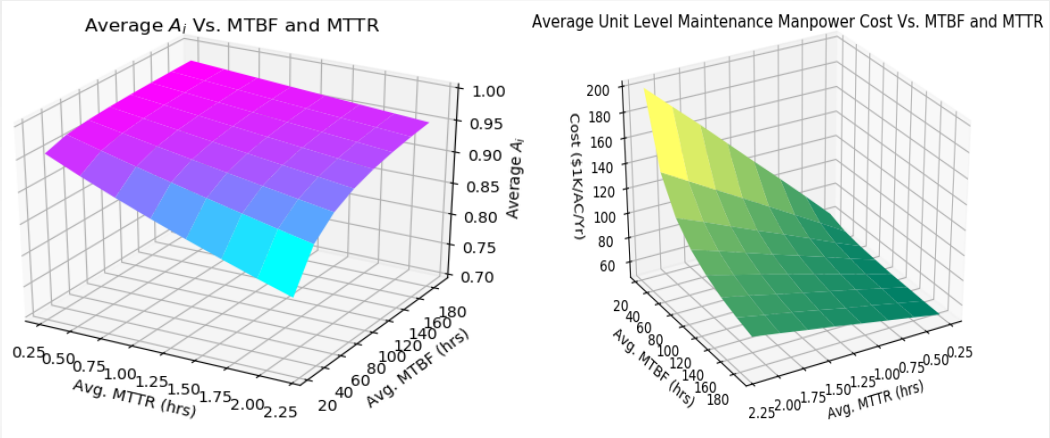
MFOP Starts



West Point and Future Vertical Lift (FVL) Cross Functional Team (CFT) are working in conjunction to analyze MFOP

LOGSIM IMPACT ANALYSIS

- LogSIM provides impact analysis across system characteristics using discrete-event simulation
  - LogLab Sensitivity Studies show trends across several design variables
  - Assessment of IPS elements
  - Parametric Sensitivity Studies to provide answers to many difficult "what-if" questions posed by PM
  - Risk Analysis performed utilizing sensitivity study capabilities
  - KPP/KSA analysis over wide range of potential scenarios
- Analysis products directly influence sustainment and design decisions improving affordability and availability



Ground Rules and Assumptions

- Rotorcraft fleet modeled with 21 aircrafts
- Simulation duration is 1 year with 12 MFOP periods
- Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) are notional but similar to those of current Army Aviation Aircrafts
  - MTBF EMA and MA= 2.21 Hours
  - MTTR = 2.22 Hours
- Model has infinite maintainers available for repair
  - All AH-64 sustainment MOS's (15 Series)
- All aircraft components start the simulation with 0 flight hours
- MRP Period includes over 100 hours of scheduled maintenance divided equally by the 6 MOS types
  - This time represents both standard scheduled maintenance and preventative maintenance
- Prognostic Health Check included
  - SME assumption that 3% of Rotorcrafts will fail their health checks

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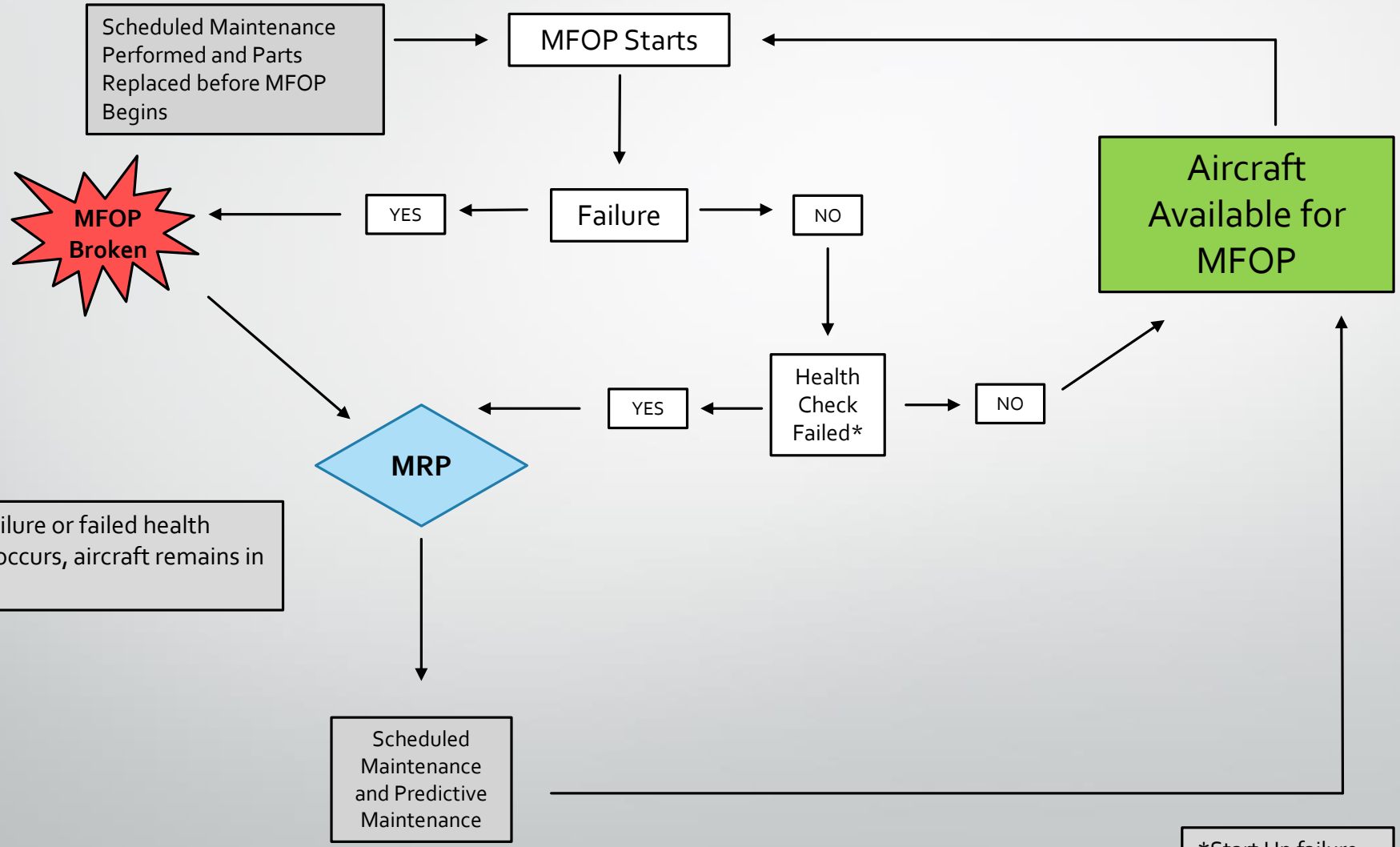
"Strict" Scenario: All Failures Break MFOP



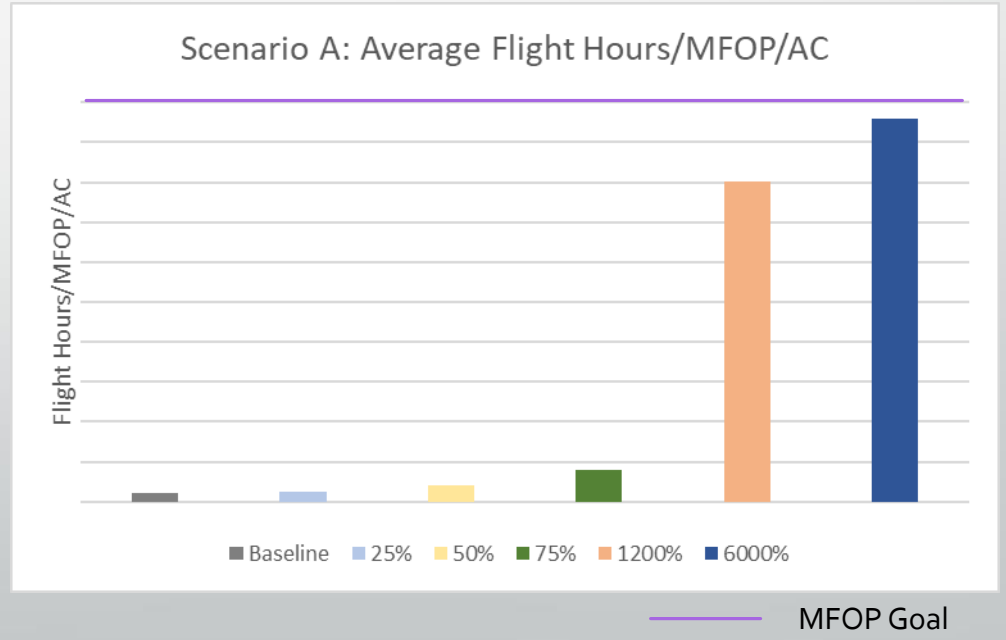
"Strict" Scenario Results

Scenario A: Baseline		
MFOP Period	Fleet Operating Time	Flight Hours/MFOP/AC
1	45.47	2.17
2	45.47	2.17
3	45.63	2.17
4	46.54	2.22
5	43.8	2.09
6	3.7	2.05
7	4.12	2.15
8	45.61	2.17
9	45.34	2.16
10	45.46	2.16
11	42.16	2.01
12	46.99	2.24
Average	45.06	2.15

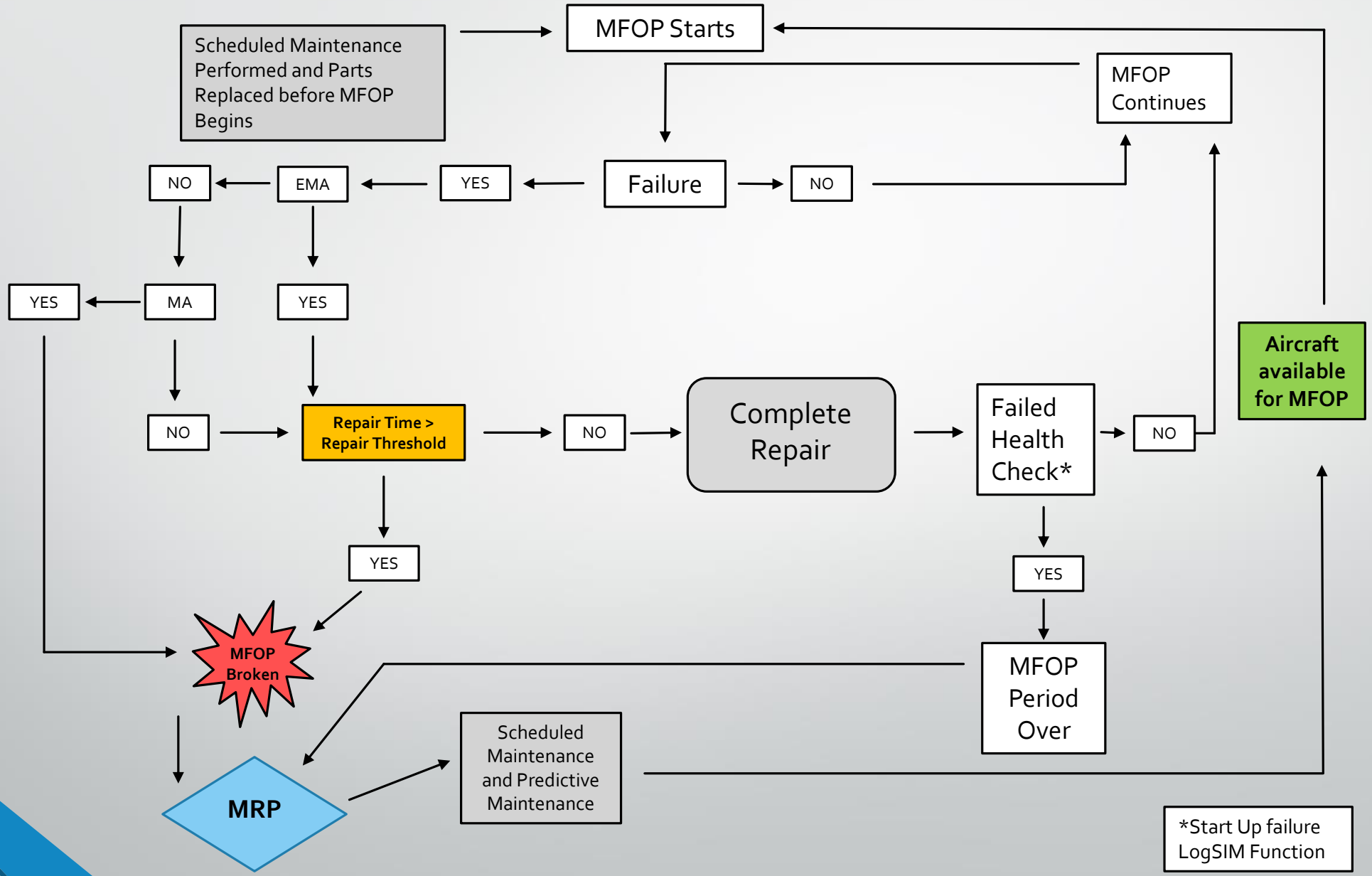
Scenario A: Baseline	
Metric	Value
MFOP Flight Hours Desired	25,200.00
Hours Flown	507.13
% of MFOP Achieved	2%

Reliability Improvements	
Model (% Improved)	MTBF
Baseline	2.2
25%	2.9
50%	4.4
75%	8.8
1200%	268.8
6000%	1323.7

- The notional aircraft will not successfully complete the MFOP with current MTBF
- Reliability improvements provide the most effective way to increase the probability of MFOP success
- MTBF of the system needs to be well over 100 hours to ensure MFOP success



"Pit Stop" Scenario: Repair Threshold



"Pit Stop" Scenario results

Scenario B: Baseline		
MFOP Period	Fleet Operating Time	Average Flight Hours/MFOP/AC
1	102.59	4.89
2	91.53	.36
3	106.37	.07
4	105.14	.0
5	106.70	5.08
6	102.[illegible]	4.88
7	[illegible]	4.92
8	11[illegible]26	5.39
9	105.16	5.01
10	106.45	5.07
11	103.27	4.92
12	100.66	4.79
Average	103.90	4.95

Notional

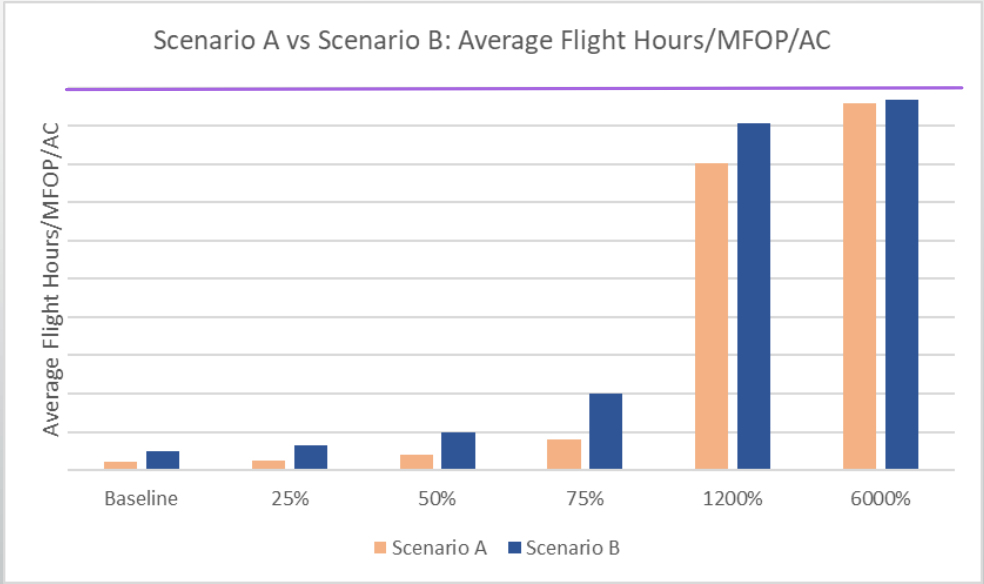
Scenario B: Baseline	
Metric	Value
MFOP Flight Hours Defined	25,200.00
Hours Flown	1,246.76
% of MFOP Achieved	5%

Notional

Reliability Improvements	
Model (% Improved)	MTBF
Baseline	2.2
25%	2.9
[illegible]%	4.4
75%	8.8
1200%	268.8
6000%	1323.7

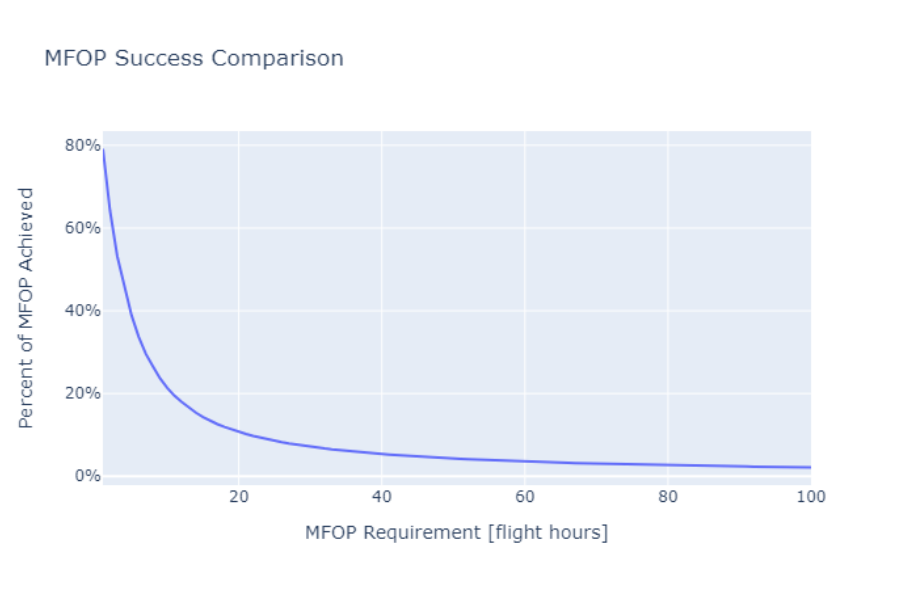
Notional

- Allowing repairs with durations longer than 6 hours increased the likelihood of MFOP success
- Even with this Scenario of MFOP there need to be major reliability improvements to ensure MFOP success

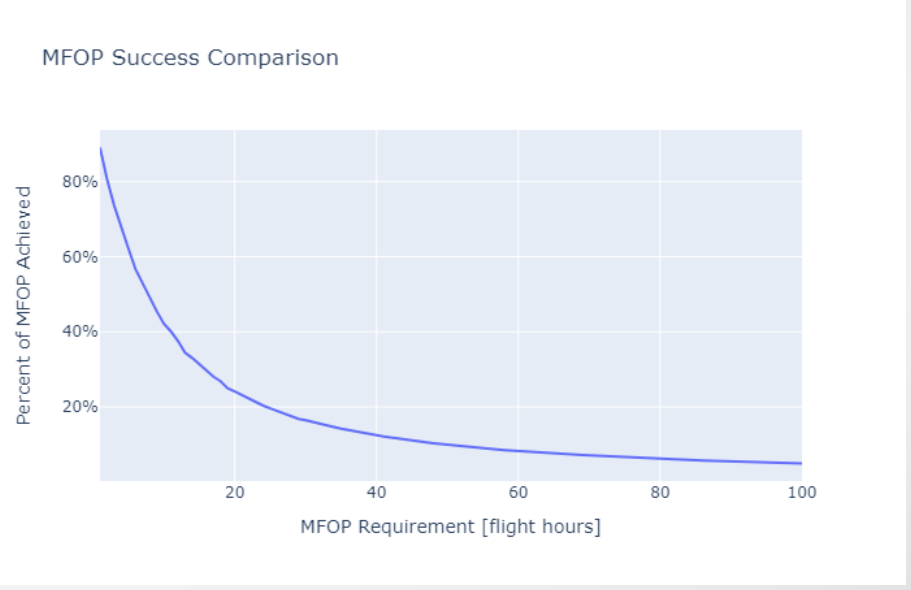


Comparing Scenarios

"Strict" Scenario

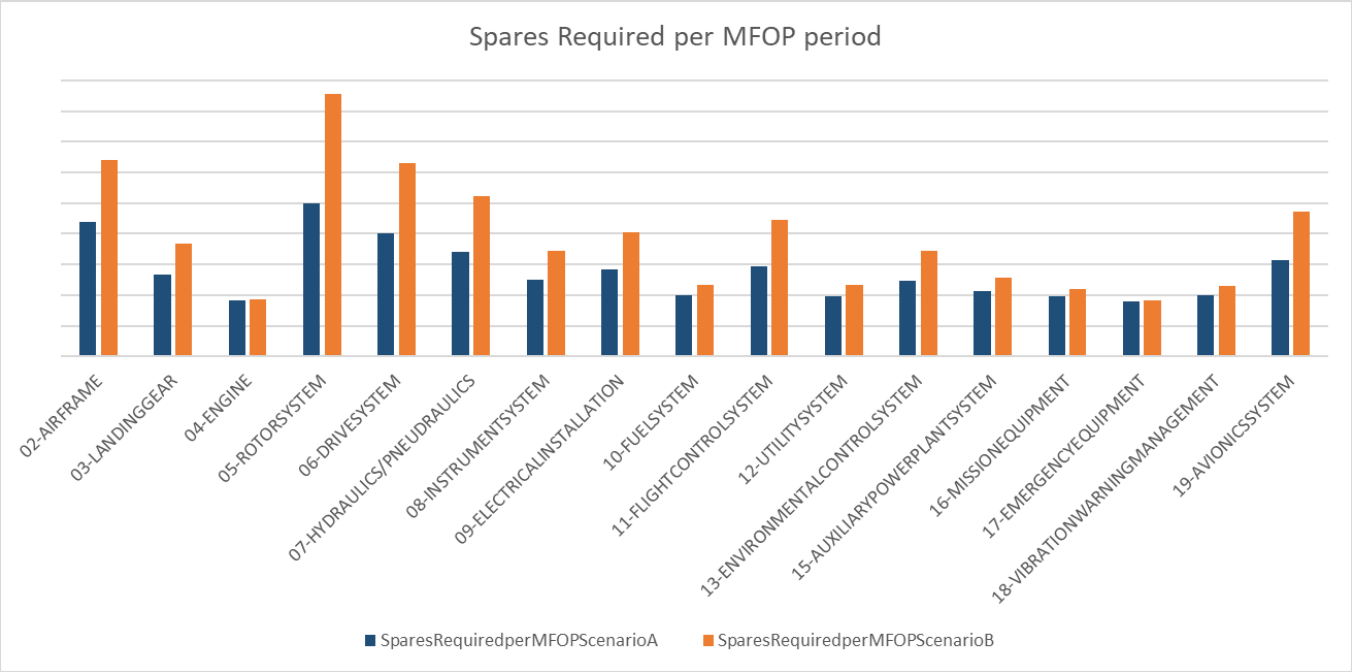


"Pit Stop" Scenario



- Over 200 models and 6,000 trials were tested for different MFOP durations, ranging from 1-100 hours
- The "Pit Stop" Scenario provides a better chance of making your MFOP goal by allowing certain repairs to be done while in the MFOP period

Spares Demand



- MRPs will not have enough time to order parts, meaning they all need to be on hand
- The simulation estimates the number of parts from each FG needed per MFOP
- Redefining the Scenario from "Strict" to "Pit Stop" causes more flight hours, increasing the number of spares required

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Maintenance Recovery Period (MRP)

- A key part of the MFOP process is ensuring that all the repairs, scheduled maintenance, and preventative maintenance can be completed in a timely manner
- The MRP Duration < MFOP Duration * Maintenance Ratio (MR)
- Modeling a successful MRP assumes improvements to the current scheduled maintenance definitions for Army Aviation platforms
- Model Assumption that impacts MRP time
  - All Scheduled and Preventative maintenance can be done in parallel

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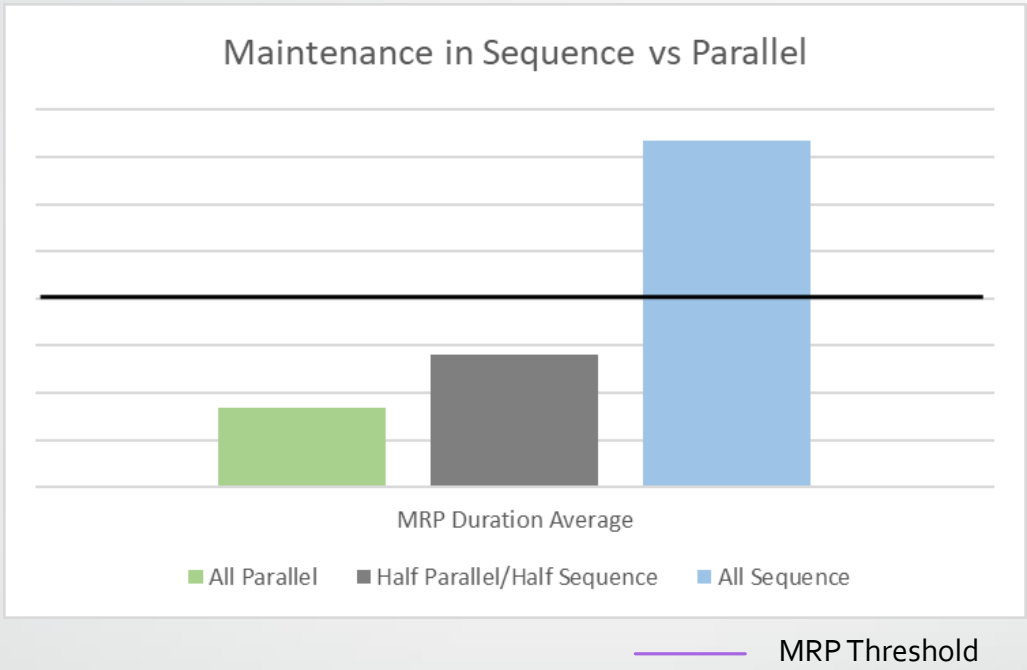
Designing for Parallel Repairs



- It is crucial to ensure different areas of the aircraft can be accessed and repaired while other repairs are happening
- Not all Scheduled and Preventative Maintenance need to be done in parallel to keep the MRP duration reasonable
- If none of the repairs can be done in parallel it's important to reduce the time required for scheduled and preventative maintenance

Summary

- It will be unlikely to guarantee the success of an MFOP without significant advancements in aircraft reliability
- Even with reliability improvements, the true MFOP, the "Strict" scenario may never be realized
- Redefining MFOP for some allowable failures improves the chances of success
- MFOP will have a large burden on Logistics
  - Ensuring all spares and necessary equipment is available
  - Adequate man-power will be required to ensure mission readiness
  - Intense operations may have an impact on the life limit of the aircraft
- MFOP can be useful in terms of aircraft design
  - Reduce the amount and frequency of time based scheduled maintenance
  - Design maintenance actions so that multiple maintainers can access and repair the aircraft at once

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References

[1] C. J. Hockley and D. P. Appleton, "Setting the Requirements for the Royal Air Force's Next Generation Aircraft," in Proceedings of the 1997 Annual Reliability and Maintainability Symposium, Philadelphia, 1997.

[2] C. J. Hockley, "Design for success," Proceedings of the Institution of Mechanical Engineers, vol. 6, no. 212, pp. 371-8, 1998.