Cavern Charts
A Graphical Technique for Evaluating the Maintenance Stagger in a Fleet of Aircraft

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Data-Lake  Holistic
Visualisation  Innovation
Machine-Learning  Automation
Tools  Optimisation
AI  ERP
Maintenance-Stagger
Stochastic-Modelling  Forecasting
What questions can Cavern Charts answer?

- What is the optimal maintenance stagger for my fleet?
- When acquiring a new fleet, at what rate should I field new tails?
- What will happen if I reduce or extend the duration of a maintenance check?
- How many maintenance bays does my fleet require?
- How will changes in the fleet rate of effort affect the stagger?
- Can I reduce the compute time of advanced optimisation techniques?
Why use a Cavern Chart?

• Simple
  – No complex mathematics required
  – No special software required
  – No large or difficult to obtain data sets required
  – Visual and intuitive results

• Fast
  – 3-4 hours from zero to hero
  – Compute time of a couple of minutes (in Excel)

• Deployable Now
Understanding the Problem
A definition of fleet stagger

Fleet stagger is the gradient of the dotted line ($\kappa$)

(Note: fleet stagger ≠ the goal line on a traditional stagger or aircraft flow chart)
Constructing a Cavern Chart
One aircraft, one service type

The aircraft state, $S_i$ at time $t_i$ can will be 0 during maintenance checks and 1 when available.
Constructing a Cavern Chart
One aircraft, four service types

\[ S_i = \min \left\{ \max \left\{ \text{mod} \left( \frac{t_i - \psi}{I} \right) - D + 1, 0 \right\}, 1 \right\} \]

\[ I_a = 2B \]
\[ I_b = 4B \]
\[ I_c = 8B \]
\[ I_d = 8B \]

\[ \phi_a = \psi \]
\[ \phi_b = \psi + B \]
\[ \phi_c = \psi + 3B \]
\[ \phi_d = \psi + 7B \]

0 = in maintenance
1 = available

for a single aircraft
Constructing a Cavern Chart
The whole fleet

Number of aircraft in maintenance for the whole fleet
Therefore the number of aircraft in maintenance ($M$) is a function of maintenance duration ($D$), base interval ($B$), fleet stagger ($k$) and number of aircraft in the fleet ($n$).

A cavern chart shows how $M$ will vary if values of $D$, $B$, $k$ or $n$ are altered.

To draw a cavern chart:

• Choose a variable to be altered.

• Calculate $M$ for full maintenance cycle ($t_k(n-1)$ to $t_k(n-1) + 8B$) for each value of the variable and calculate the percentage of time with:
  – 0 aircraft in maintenance
  – 1 aircraft in maintenance
  – 2 aircraft in maintenance
  – ....

• Draw a stacked area chart of the calculated percentages.
• Fleet of 12 aircraft \( (n) \).

• Base interval of 365 days \( (B) \).

• Check durations \( a=7, b=21, c=61, d=112 \) days \( (D) \).

• Vary stagger \( (k) \) from 0 to 730 days. (2 years, 0 to 2B)
Cavern Chart Example
 Altering two variables

For the example fleet of 12 aircraft:

• If maintenance interval is usage based
• And flying rate is increased by 18%

Does maintenance capacity need to be increased?
Conclusion

Cavern Charts are a simple graphical tool to assist answering:

- How many maintenance bays do I require?
- What is an optimal fleet stagger?
- What should the acquisition tempo of a new fleet be?
- How will changing rate of effort effect the fleet stagger?
- What happens if the duration of a maintenance check is changed?
- What is a good starting point for more advanced optimisation techniques?

- Cavern Charts are fast
- You can use them now