GT Component Lifing

Gas Turbine Performance Short Course

(Montreal 21-24 Sep 2022)

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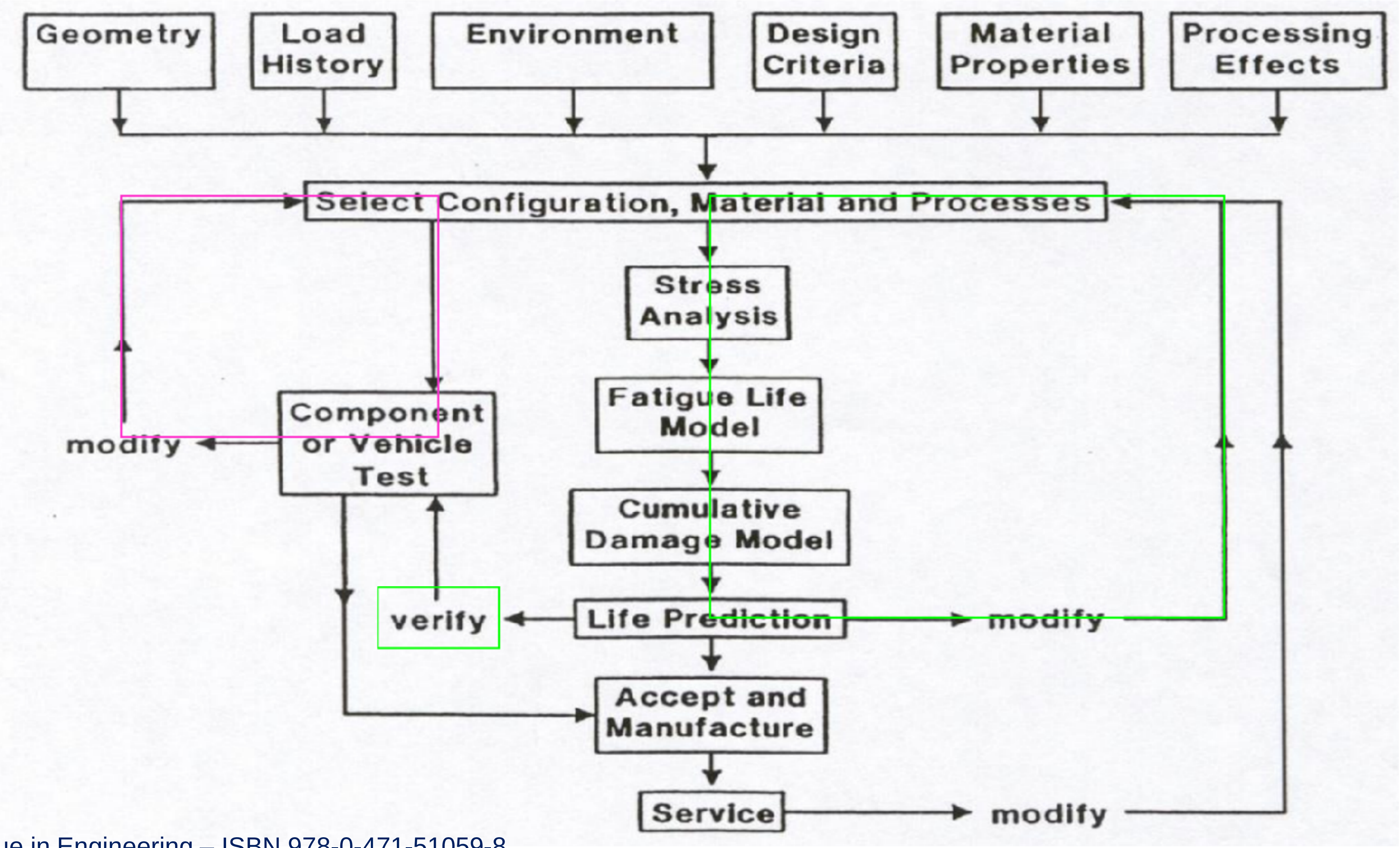
www.cranfield.ac.uk

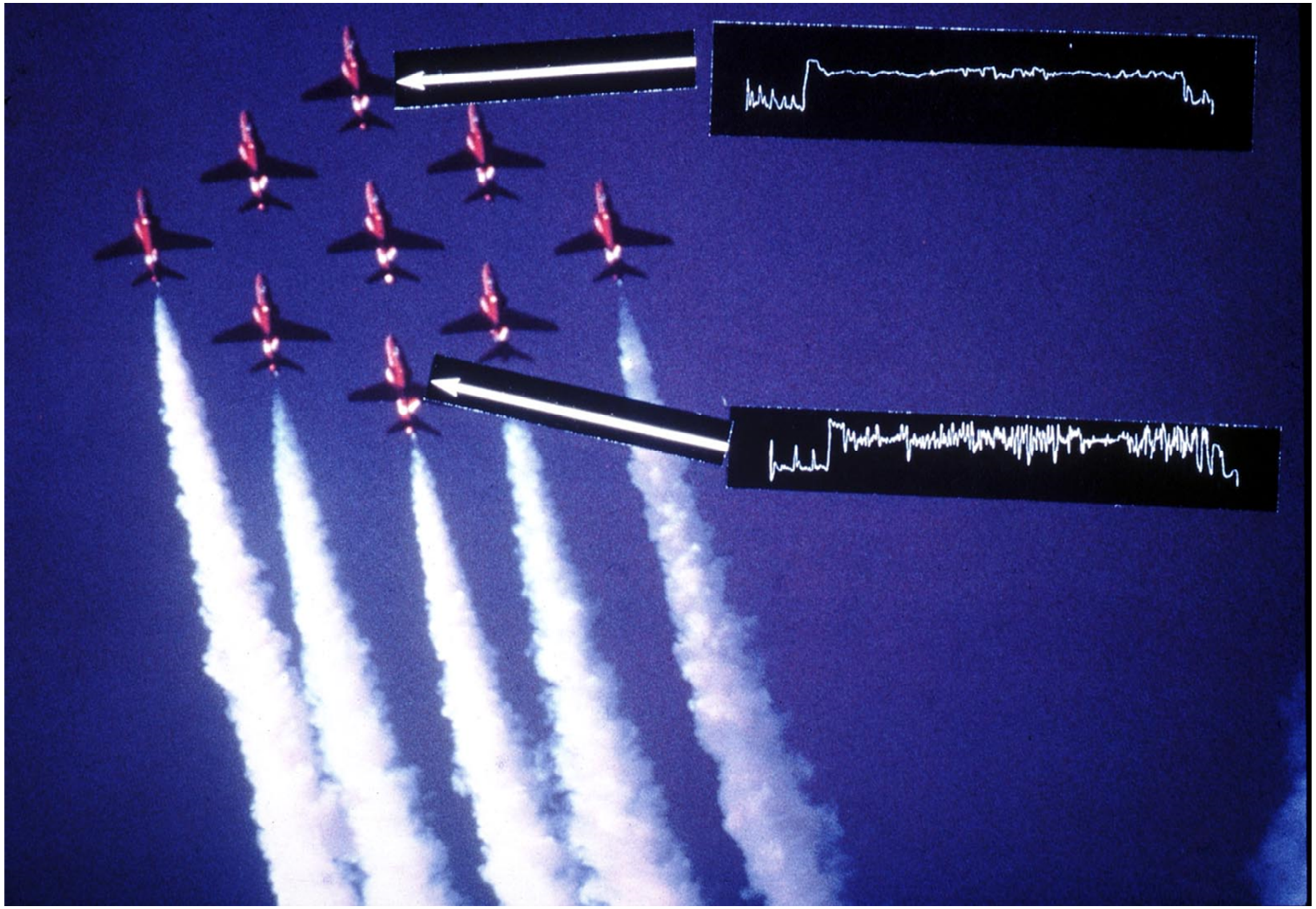
Strategies in Design



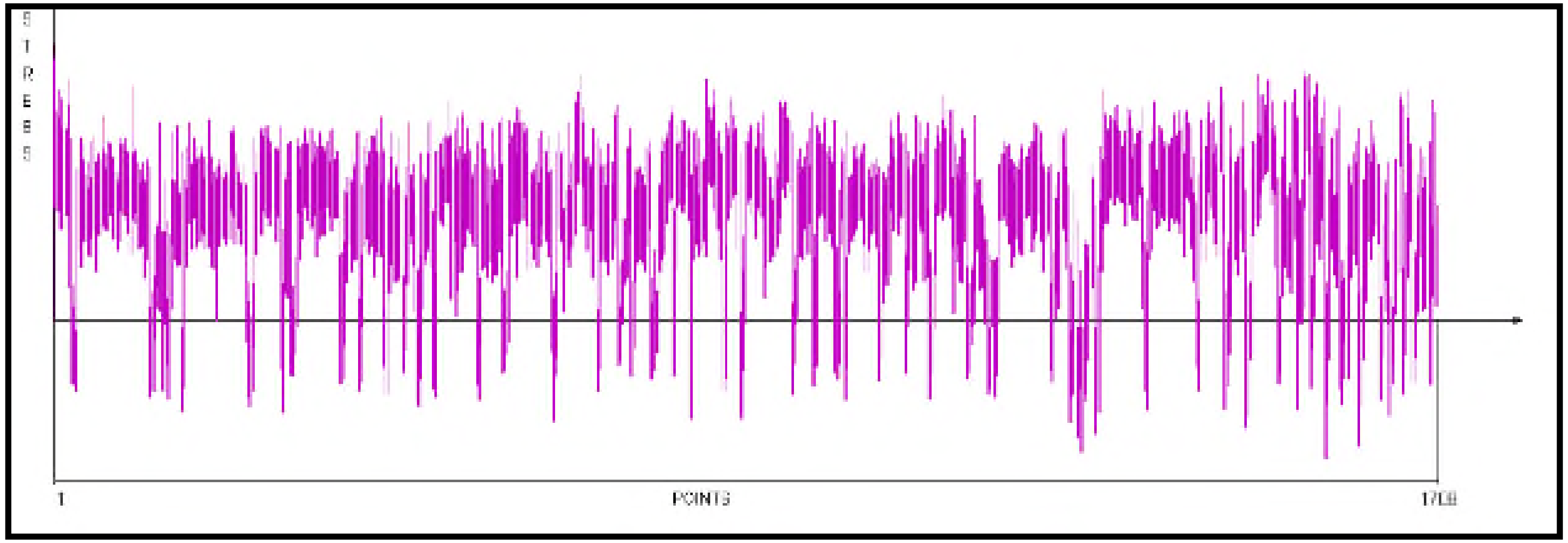
Ref-Metal fatigue in Engineering – ISBN 978-0-471-51059-8

Component Lifing

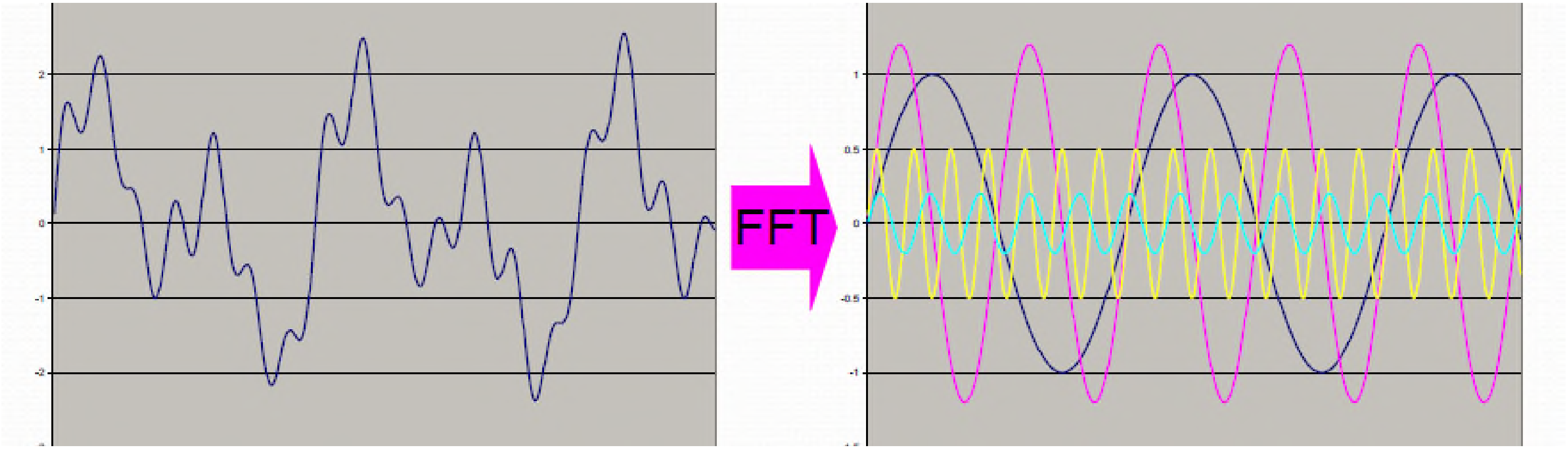
Engine Component Life



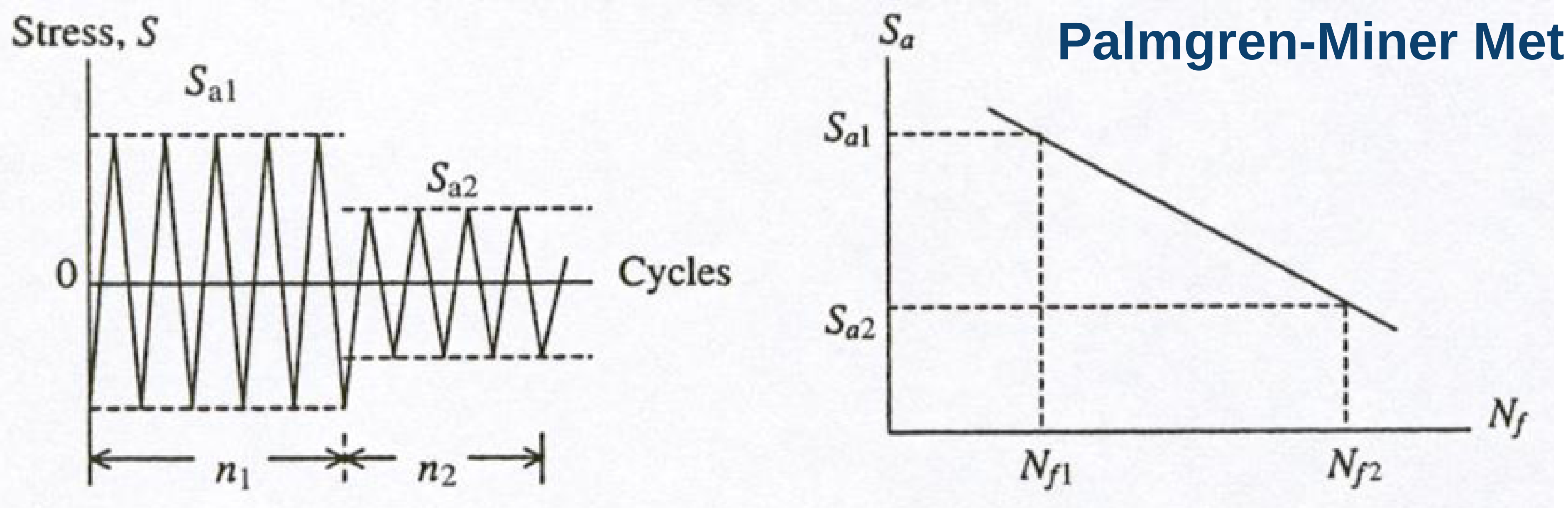
Understanding Complex Loading



Complex Loading Profile



Linear Damage Method



Palmgren-Miner Method

The damage caused by one cycle is defined as D= $1/N_f$ where N_f is the number of repetitions of this same cycle that equals life to failure. The damage produced by n such cycles is then nD= n/N_f.

$$\sum \frac{n_i}{N_{fi}} = \frac{n_1}{N_{fi}} + \frac{n_2}{N_{f2}} + ... = 1$$

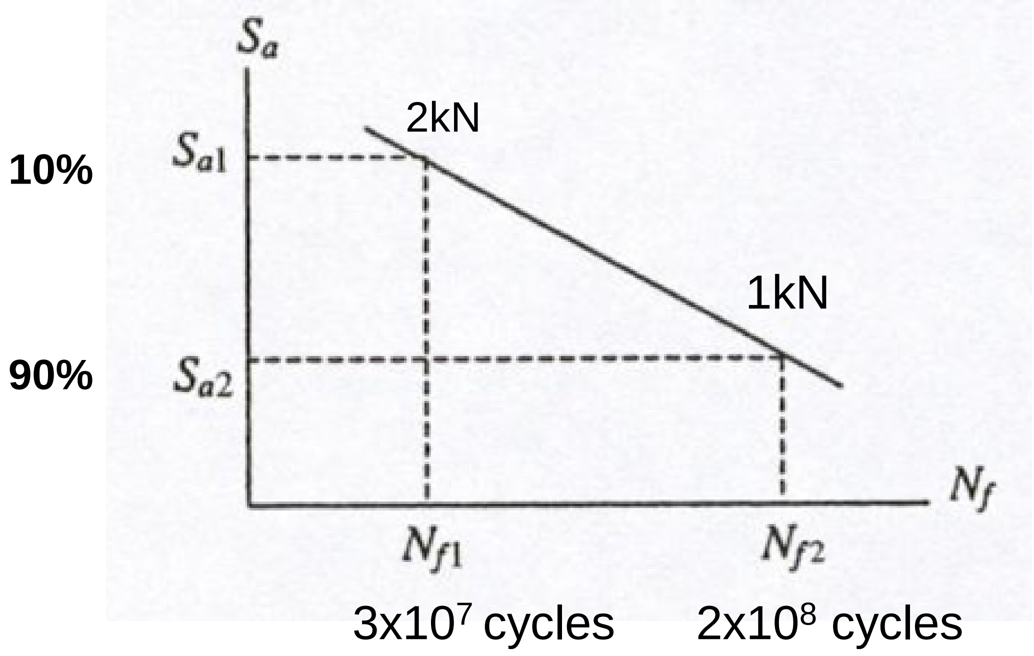
Failure is predicted when the sum of all ratios becomes 1 or 100%.

Life Estimation using P-M Method

Example

The data for certain bearing is provided

How many cycles can we expect the bearing to last if the load is 1 kN 90% of the time and 2 kN 10% of the time?



Linear Damage Rule

- Sequence of loading and interaction of other events may have major influences on total life estimated .
- The rate of damage accumulation may depend on the load amplitude
- Experimental evidence often indicates that $\sum n_i/N_f \neq 1$ for a low-to-high or a high-to-low loading sequence.

Even though the linear damage rule ignores these effects, it is most widely used because of its simplicity and the fact that none of the other proposed methods achieves better agreement with data from many different tests.

Non-Linear Damage Theories

To overcome the deficiencies with the linear damage assumption, many nonlinear cumulative damage rules have been proposed.

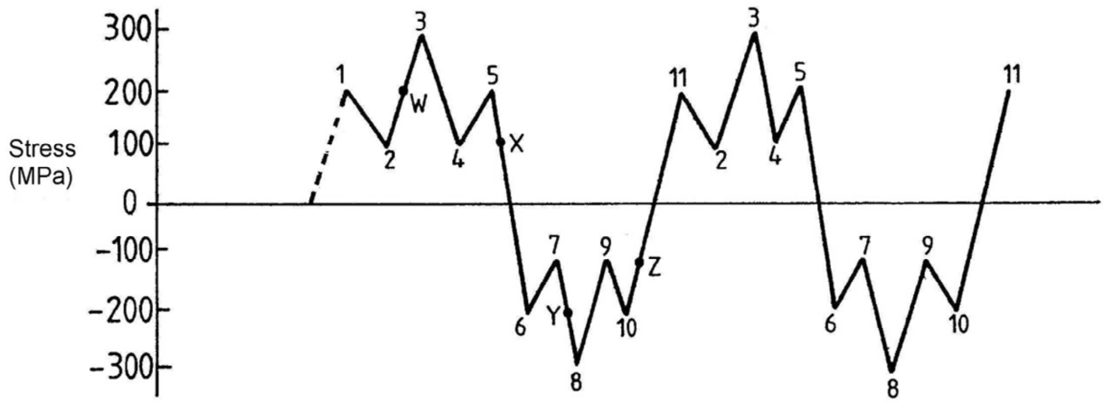
A. Fatemi and L. Yang, "Cumulative Fatigue Damage and Life Prediction Theories: A Survey of the State of the Art for Homogeneous Materials," Int. J. Fatigue, Vol. 20, No. 1, 1998.

These theories account for the non-linear nature of fatigue damage accumulation by using nonlinear relations such as $D = \sum (n_i/N_{fi})^{\alpha_i}$

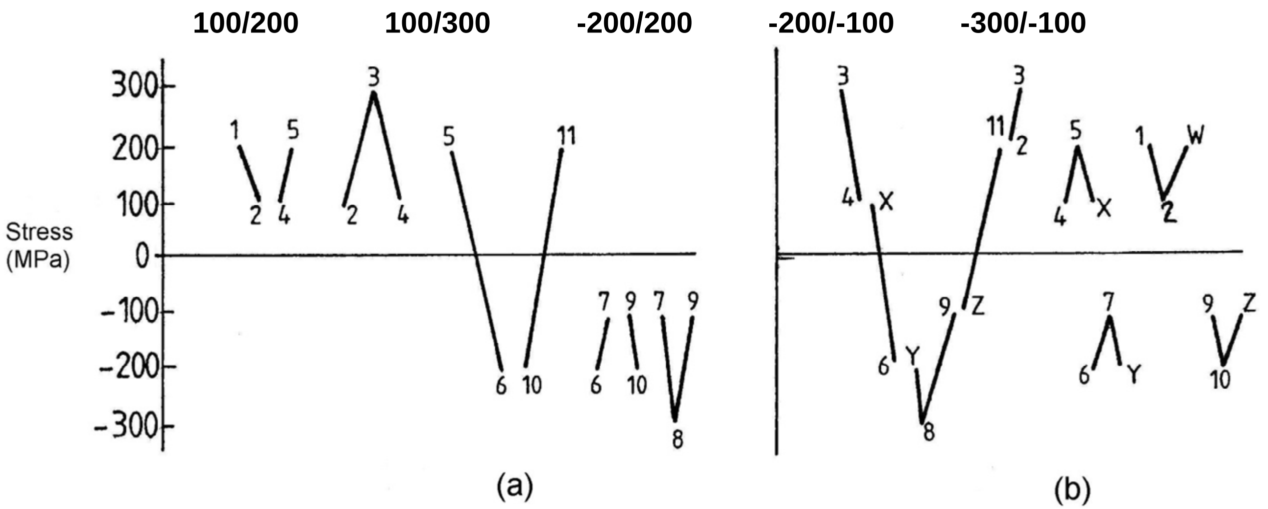
where the power α_i depends on the load level

Though many nonlinear damage models have been developed, unfortunately none can encompass many of the complicating factors encountered during complex variable amplitude loading.

Understanding Load Cycles



The above could be analysed in either of the following ways

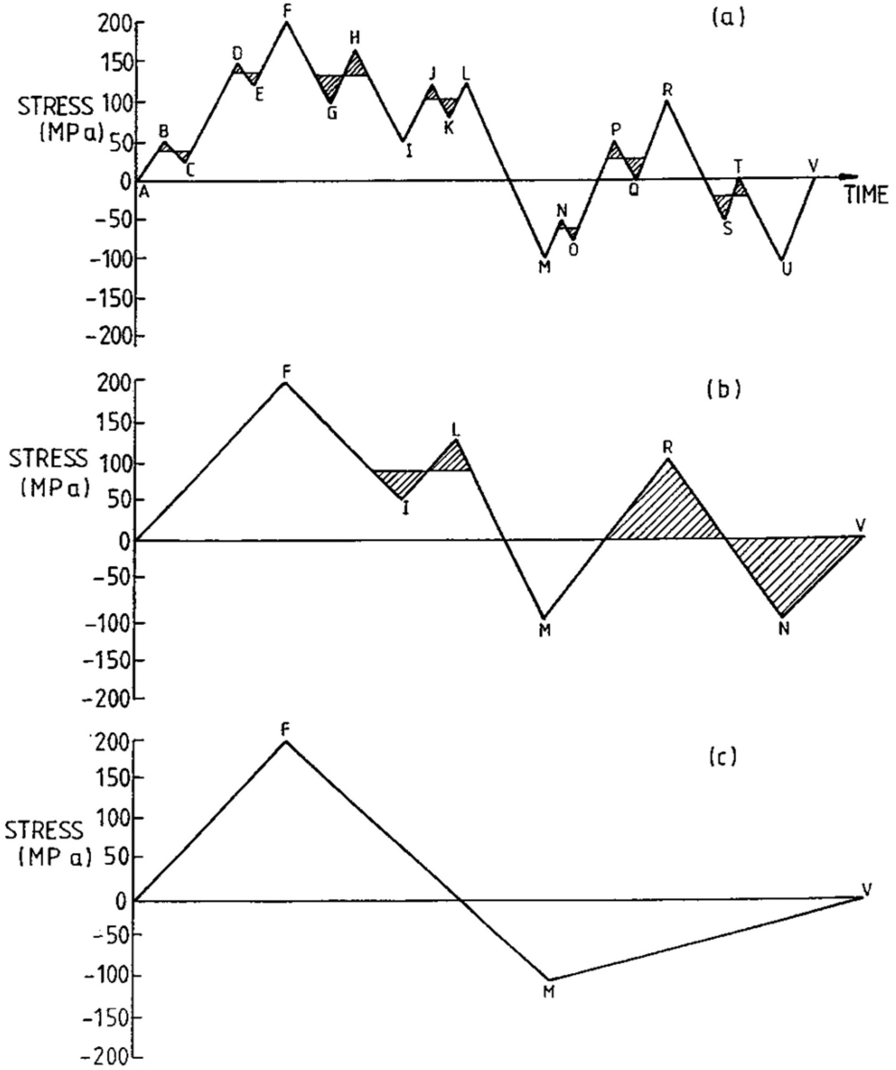


-300/300 100/200 (twice)
-200/-100 (twice)

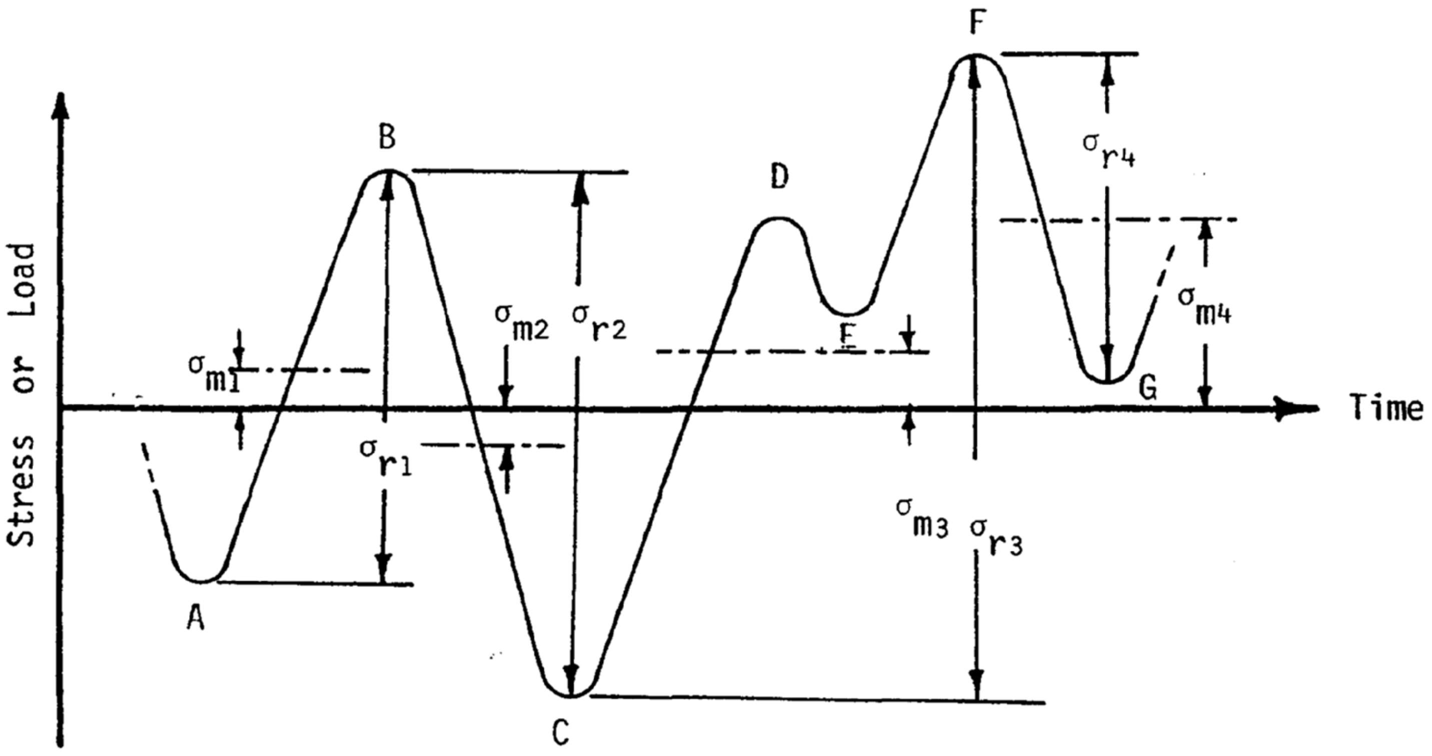
Cycle Counting Methods

- Range Pair Method
- Range Mean Analysis
- Rain Flow or Pagoda Roof Analysis
- Race Track Counting method
- Level Crossing Method
- Peak Counting Method
- Bathtub counting method

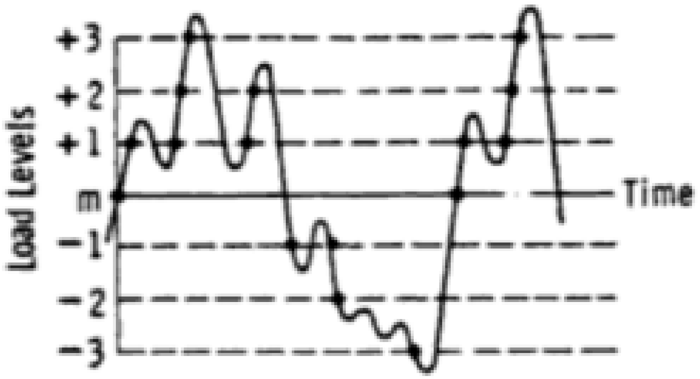
Range Pair Method



Range Mean Method

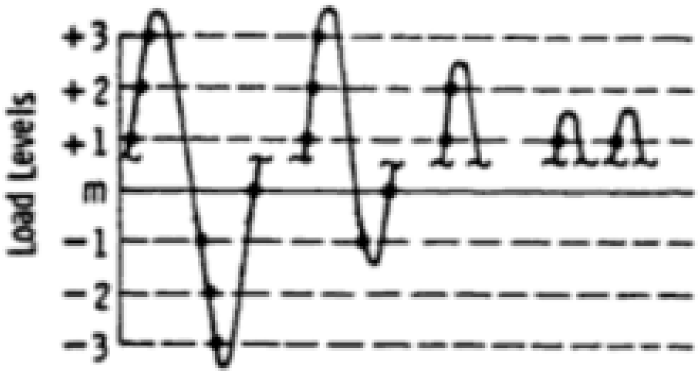


Level Crossing Method



(a)

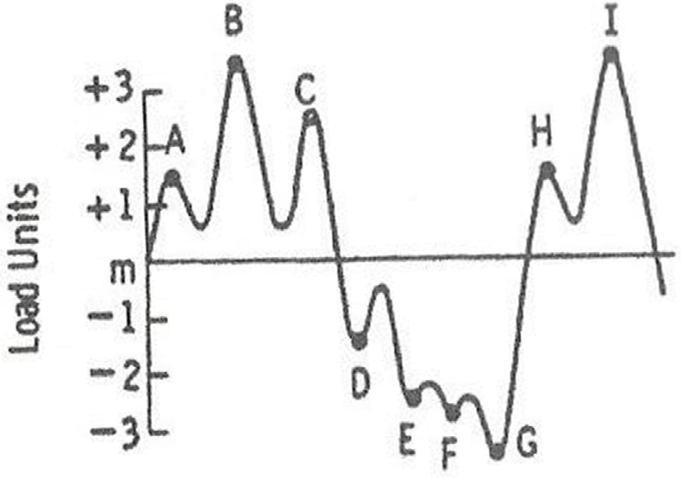
Level	Counts
+3	2
+2	3
+1	5
0	2
−1	2
−2	1
−3	1



(b)

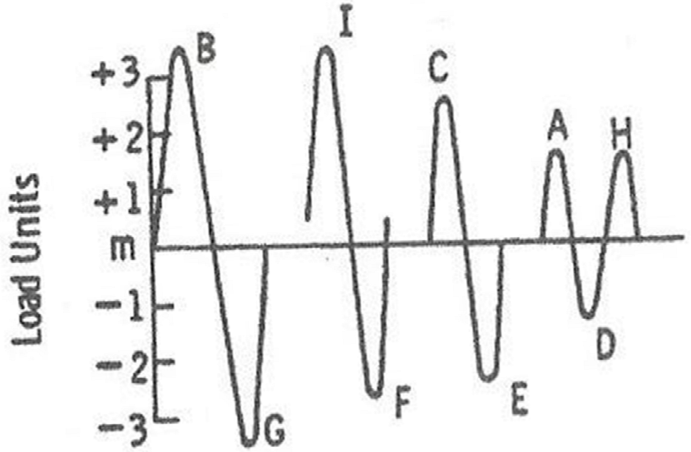
Range (levels)	Cycle Counts
7	1
6	0
5	1
4	0
3	0
2	1
1	2

Peak Counting Method



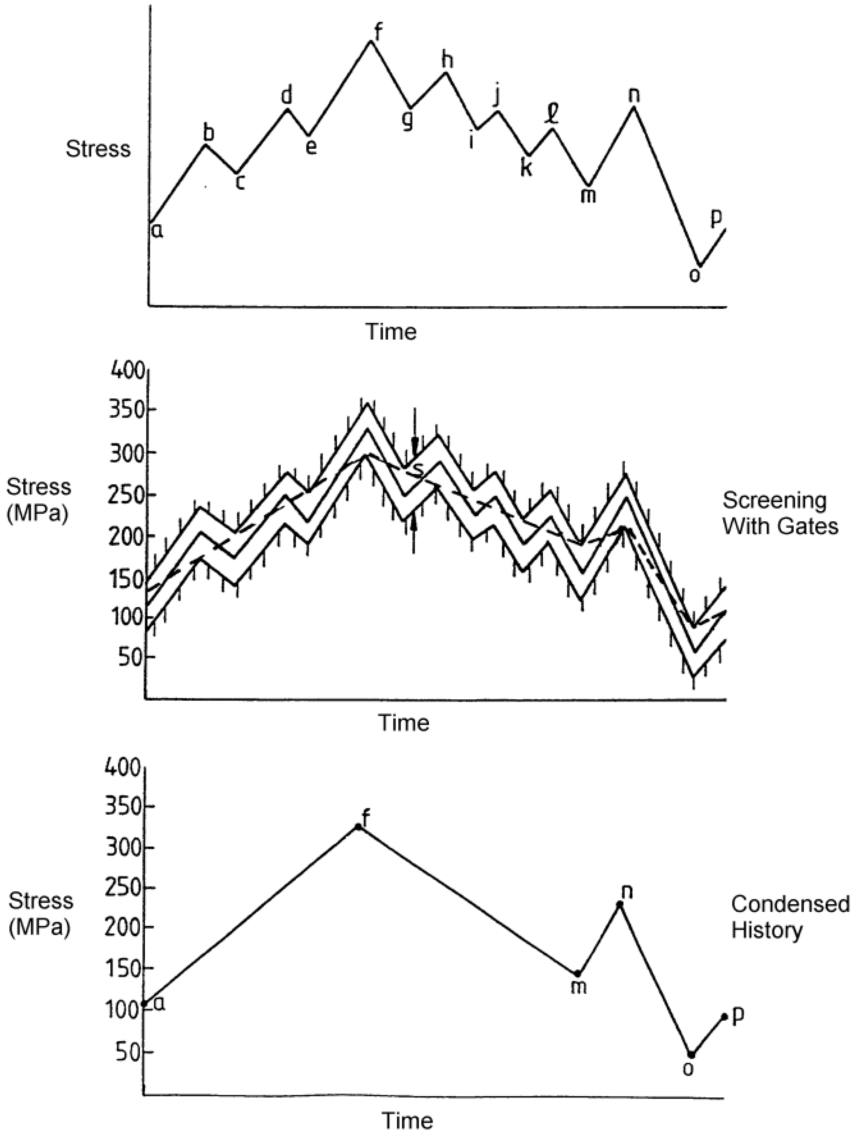
(a)

Peak	Counts
+3.5	2
+2.5	1
+1.5	2
−1.5	1
−2.5	1
−2.7	1
−3.5	1

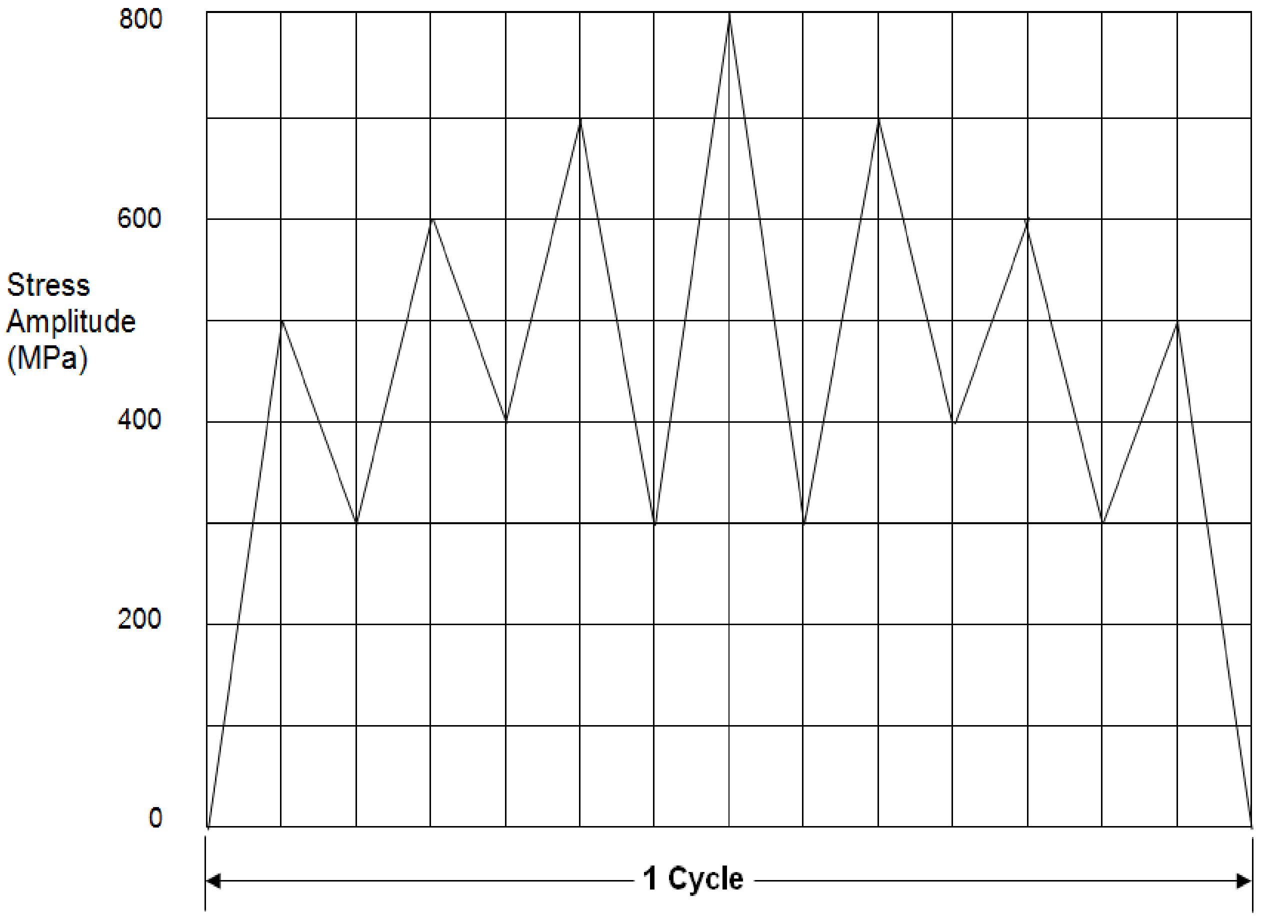


Range (units)	Cycle Counts
7	1
6.2	1
5	1
3	1.5

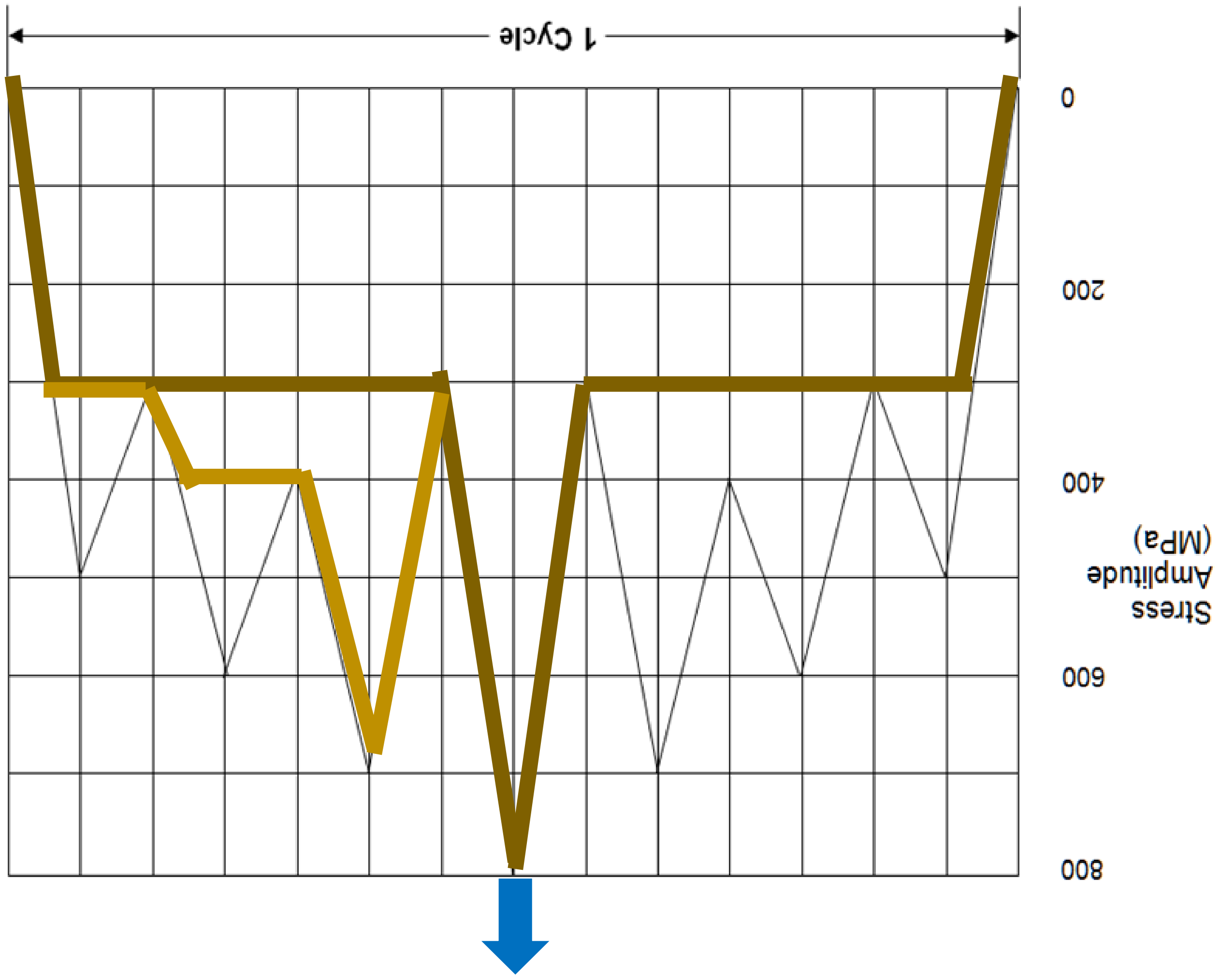
Race Track Method



Bathtub Method



Bathtub Method



Rainflow Method (Pagoda Method)

Endo and Matsuishi

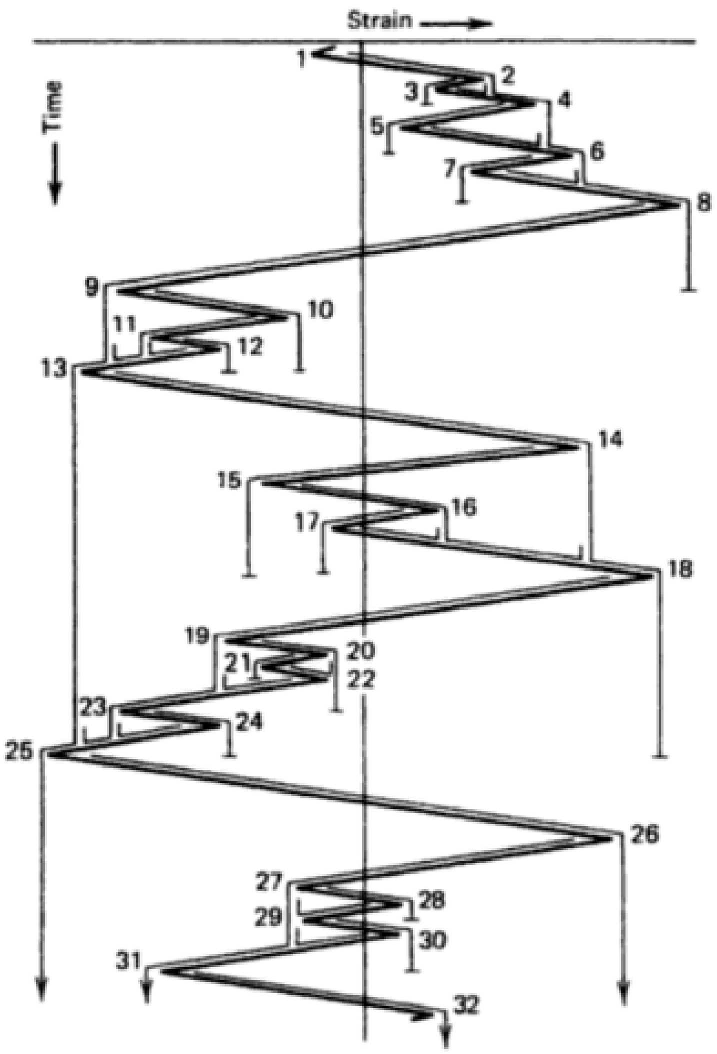
Proposed this method in 1968

ASTM E 1048-85(2005) Rainflow Counting Method

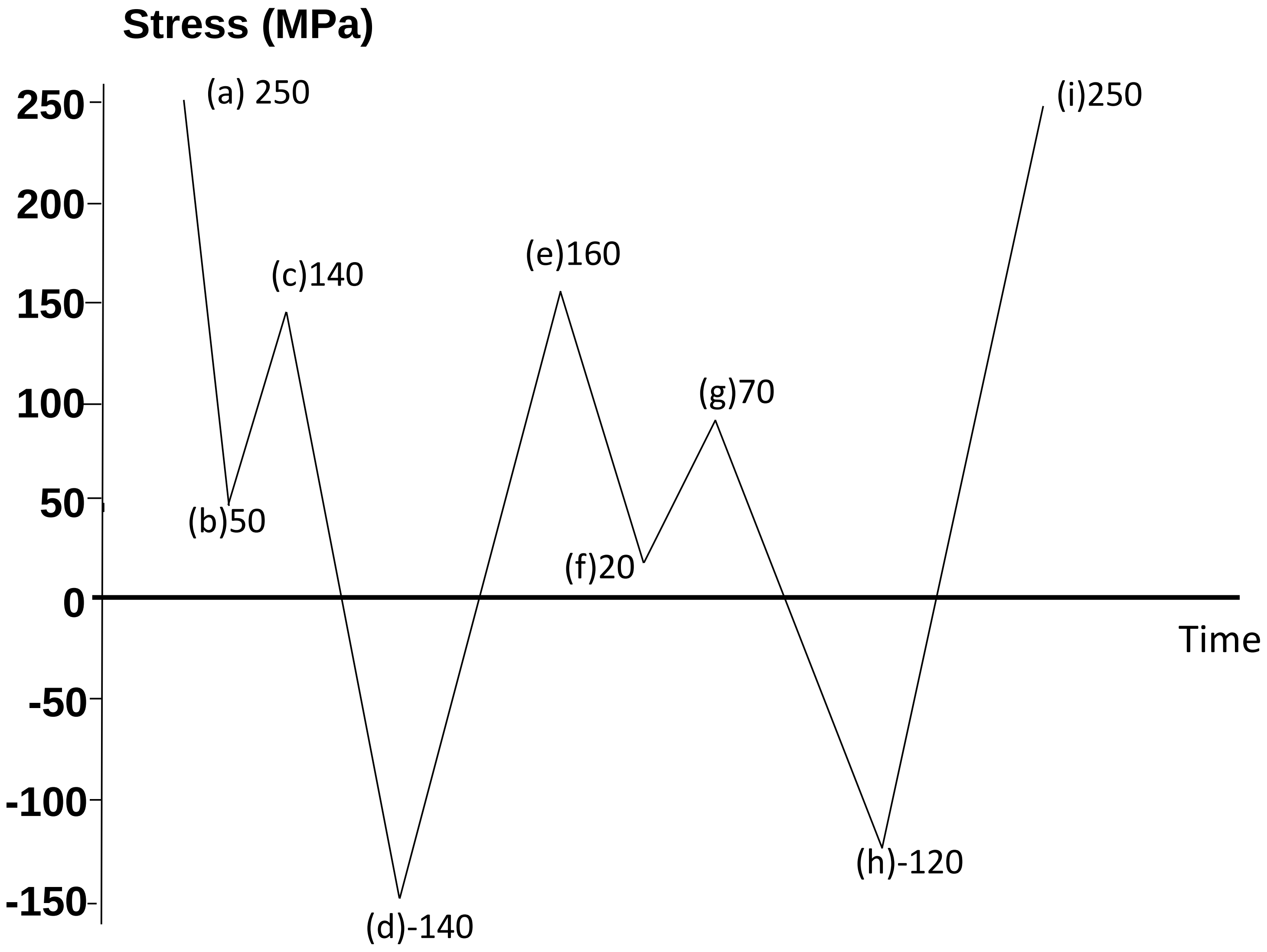
Rainflow Method Rules

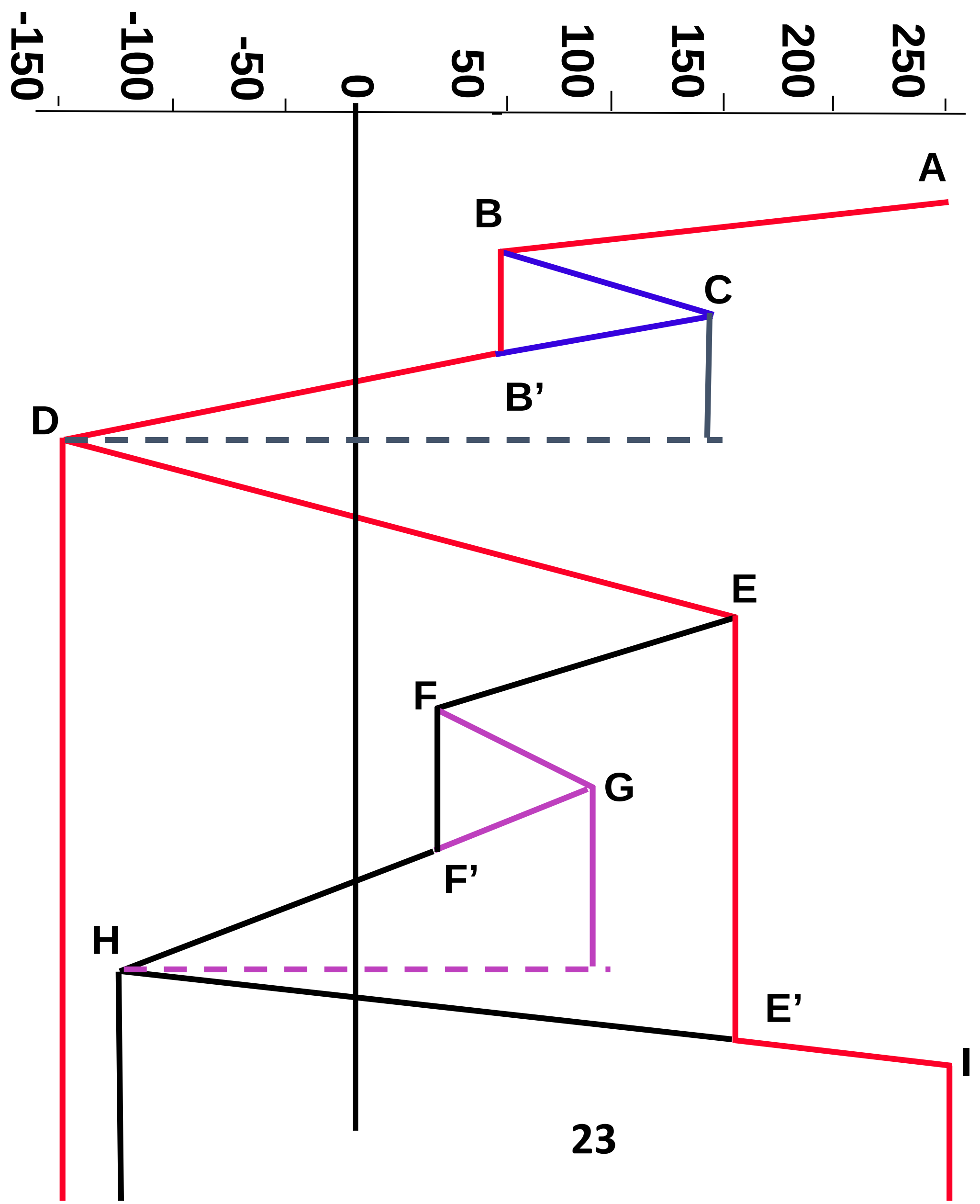
- Rainflow starts at the beginning of the test and again at the inside of every peak.
- Rain is allowed to flow on the roof and drip to the next slope till it comes opposite to a valley more negative than the valley from where it originated.
- Rain also stops when it is joined by rain from a pagoda roof above
- The beginning of the sequence is a minimum if the initial straining is in tension.
- The horizontal length of each Rainflow is then counted as half cycle at the strain range.

Rainflow Counting



Rainflow Counting - Example

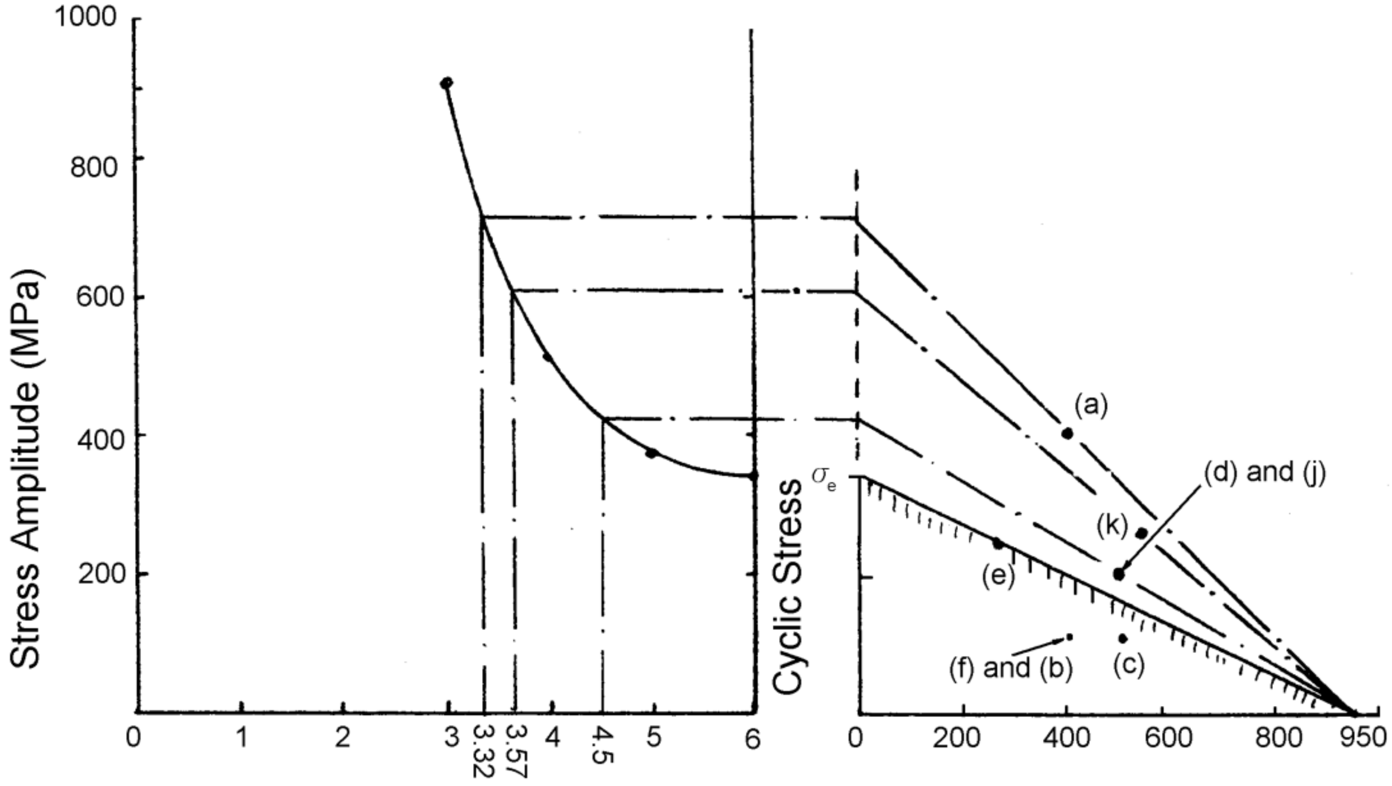




Path	Range	Cycles
ABB'D	250/-140	0.5
BCB'	50/140	1
DEE'I	-140/250	0.5
EFF'H	160/-120	0.5
FGF'	20/70	1
HE'	-120/160	0.5

Range	σ_m	σ_a
250/-140	55	195
50/140	95	45
-120/160	20	140
20/70	45	25

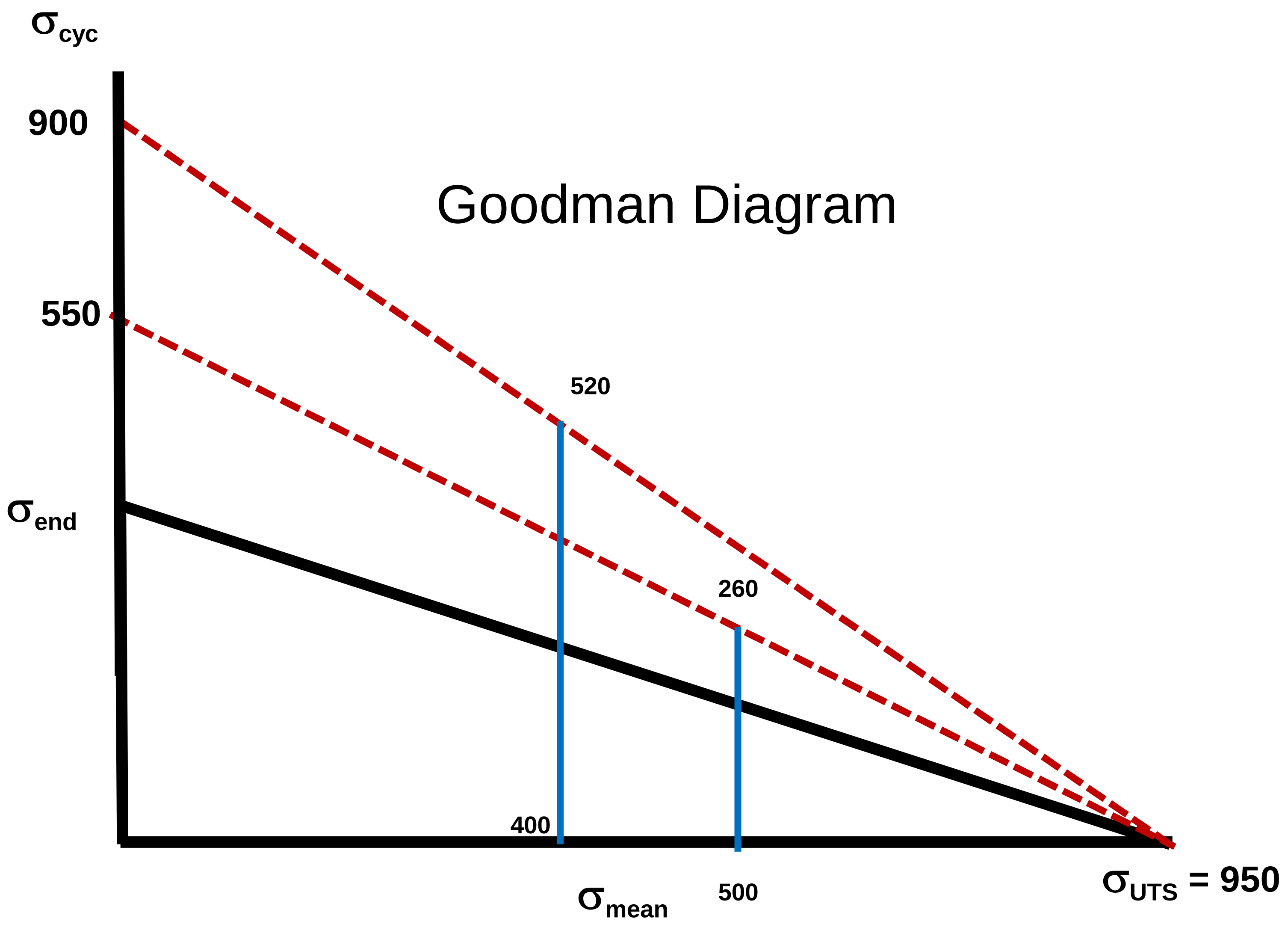
Rainflow Counting - Example



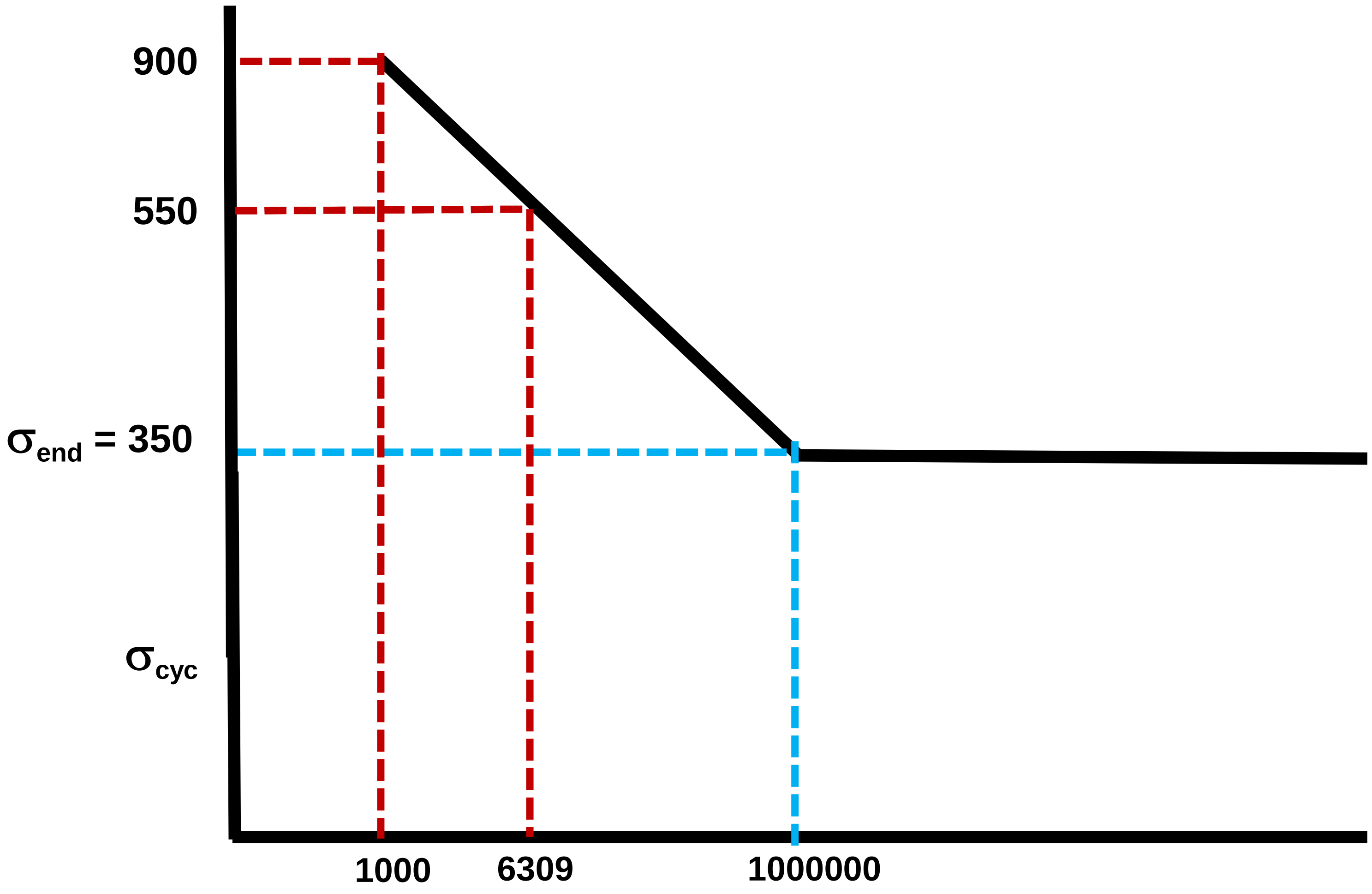
S-N Diagram

Goodman Diagram

Extrapolation of stress levels



Lifing limiting conditions using SN Diagrams



Rainflow Counting – Classroom Exercise

Number of Cycles when 900 MPa = 1000 Cycles (1 Cycle)

Number of Cycles when 550 MPa = 6300 Cycles (2 Cycles)

Total Number of Cycles= 759

Including factor of Safety – 500 cycles

Life of Component is = 500 x 3 = 1500 hrs

Rainflow Counting – Classroom Exercise

Hence Log N_{fa} = 3.35 and N_{fa} = 2239 cycles

and Log $N_{fd/e}$ = 4.85 and $N_{fd/e}$ = 70795 cycles

and $I/N_T = 1/2239 + 2/70795$ and N_T = 2106 cycles

Further iterations would produce a result of approximately (2106+759)/2 = 1432 cycles

If a FOS of 1.5 is included, then we could guarantee 1000 cycles.

VSTOL Thrust Vectoring and Balancing: Degradation Mitigation Strategies

 23 September 2022

The Sea Harrier- VSTOL

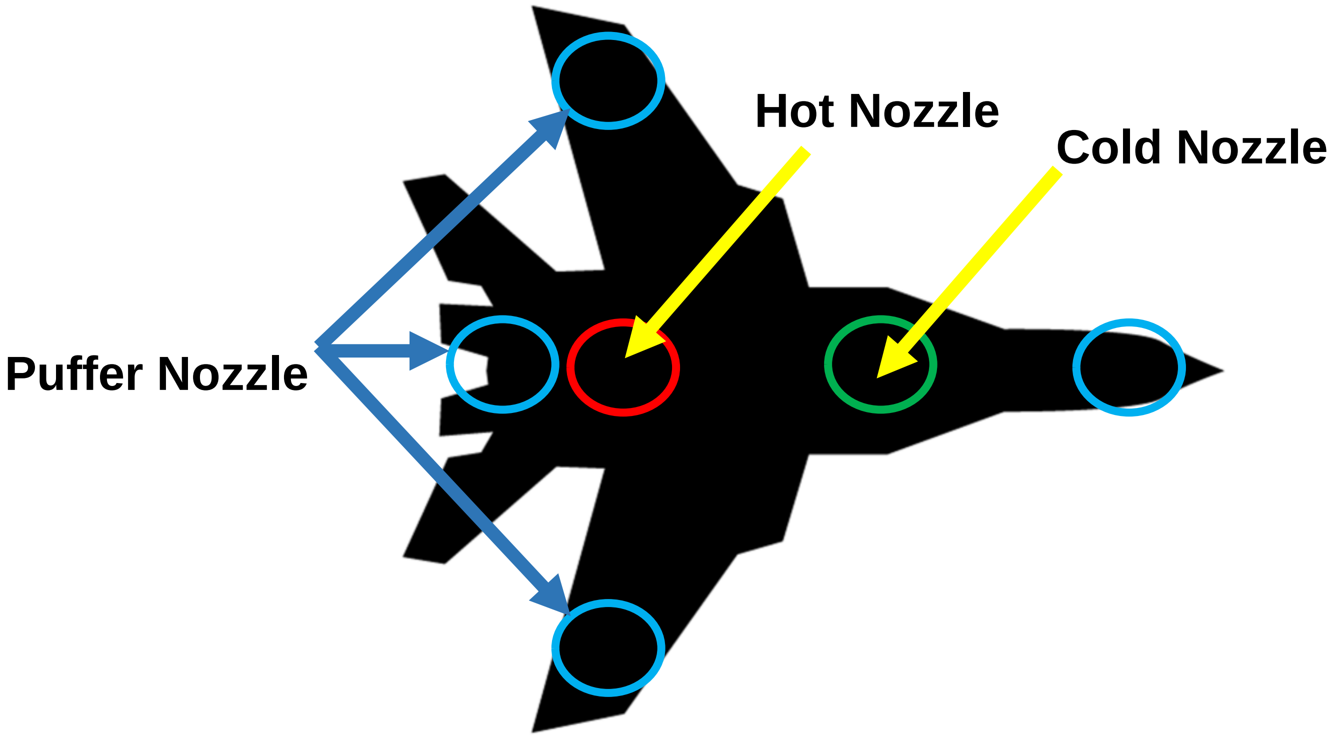
Image Courtesyhttps://alchetron.com/British-Aerospace-Sea-Harrier

The Sea Harrier- VSTOL

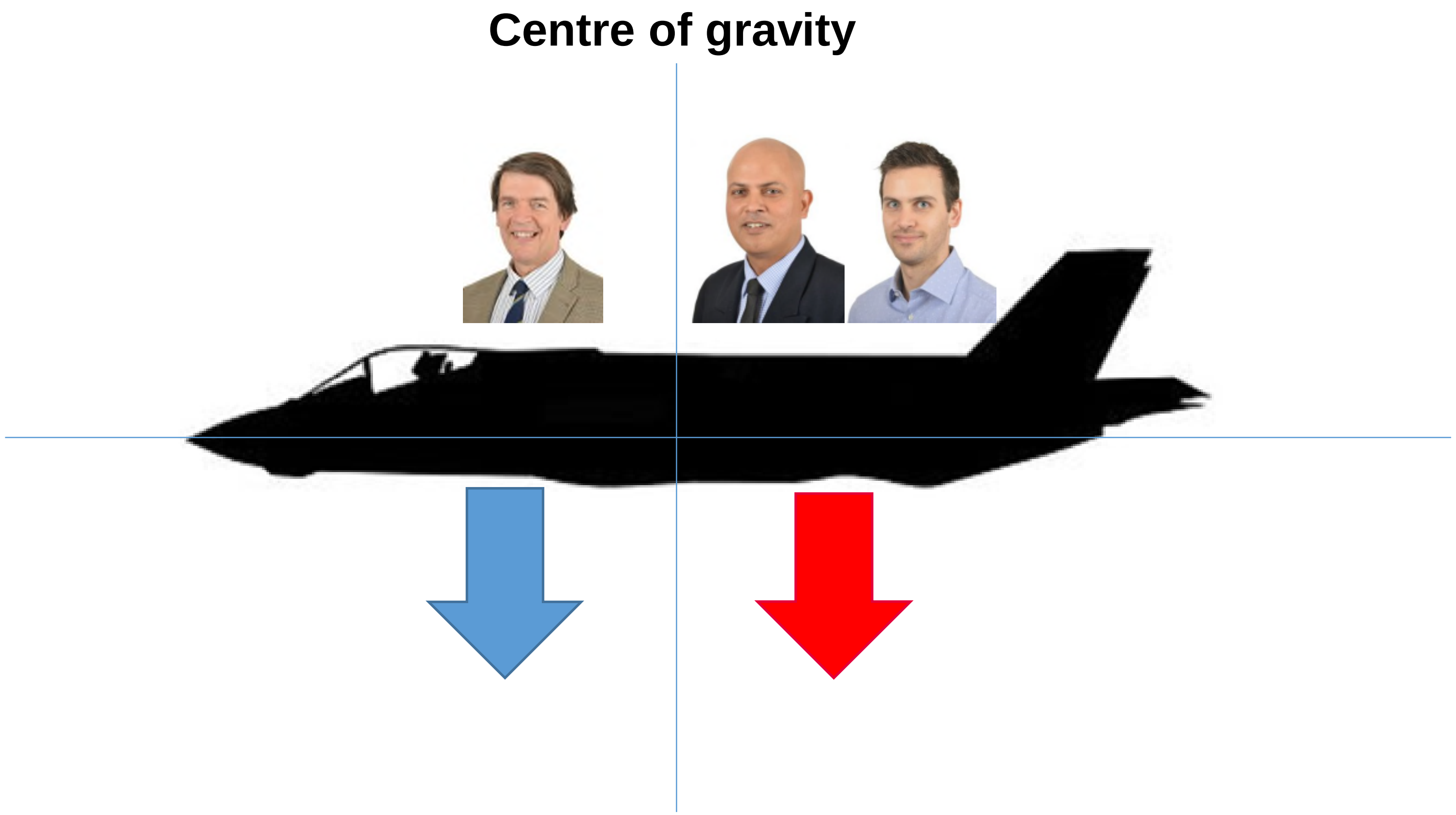
Image Courtesy:https://nationalinterest.org/feature/look-out-america-china-wants-its-own-vertical-takeoff-jets-15220

Thrust Vectoring- Configuration

Nozzle Configuration

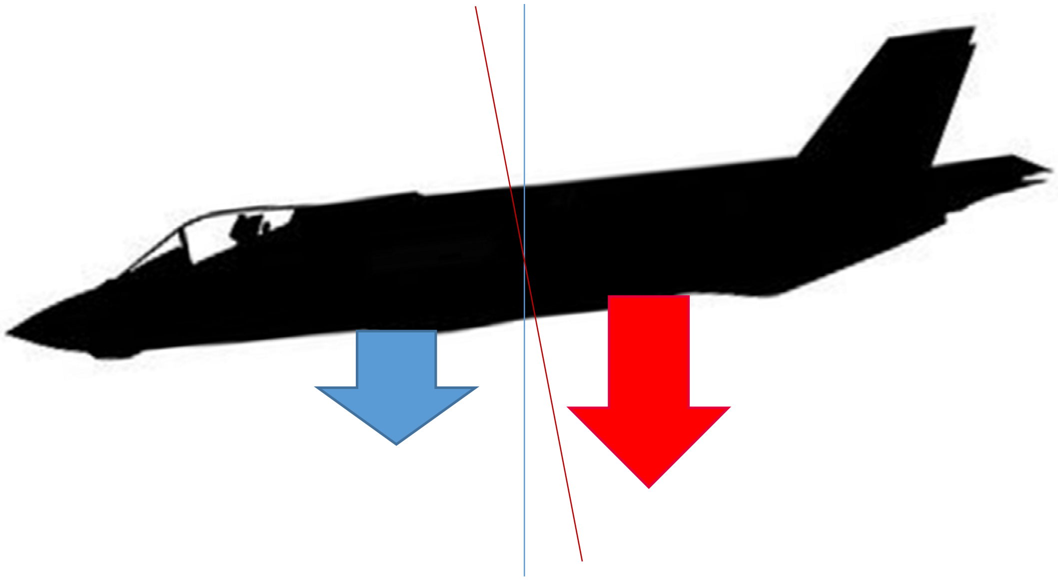


Thrust Vectoring- The Balancing act !



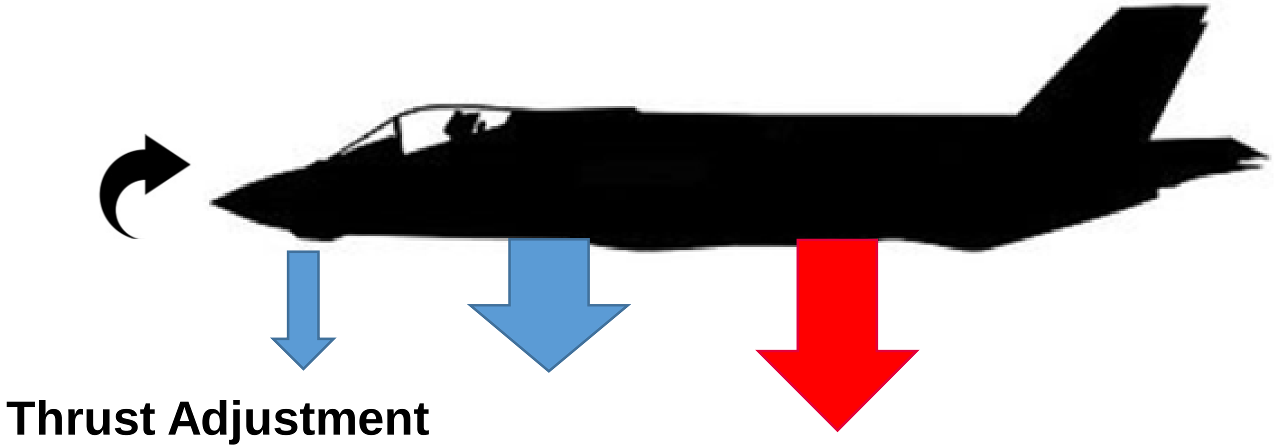
Considering Equal Thrust or equal righting moment

Thrust Unbalance in Nozzle



Unbalance due to mismatch in Thrust-Degradation – A possibility

Correction of Unbalance

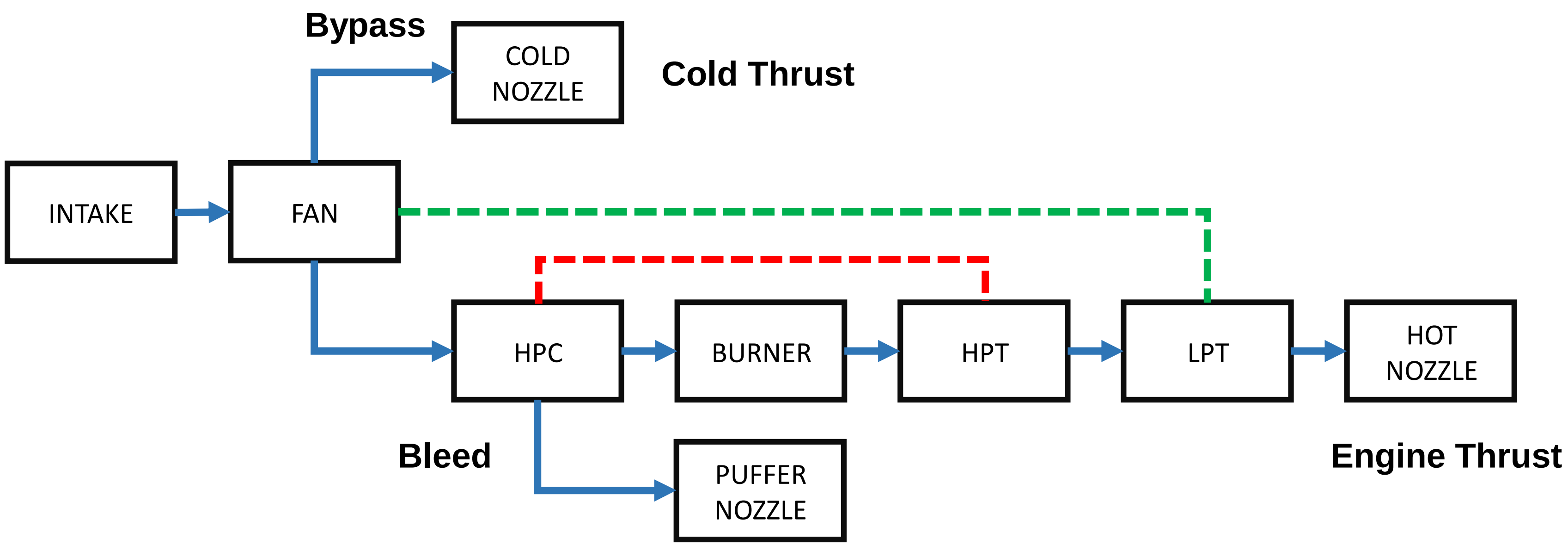


Restoration by opening HPC bleed

Engine Performance Modelling

Modelling using "Turbomatch"

- Gas Path
- HP Spool
- LP Spool



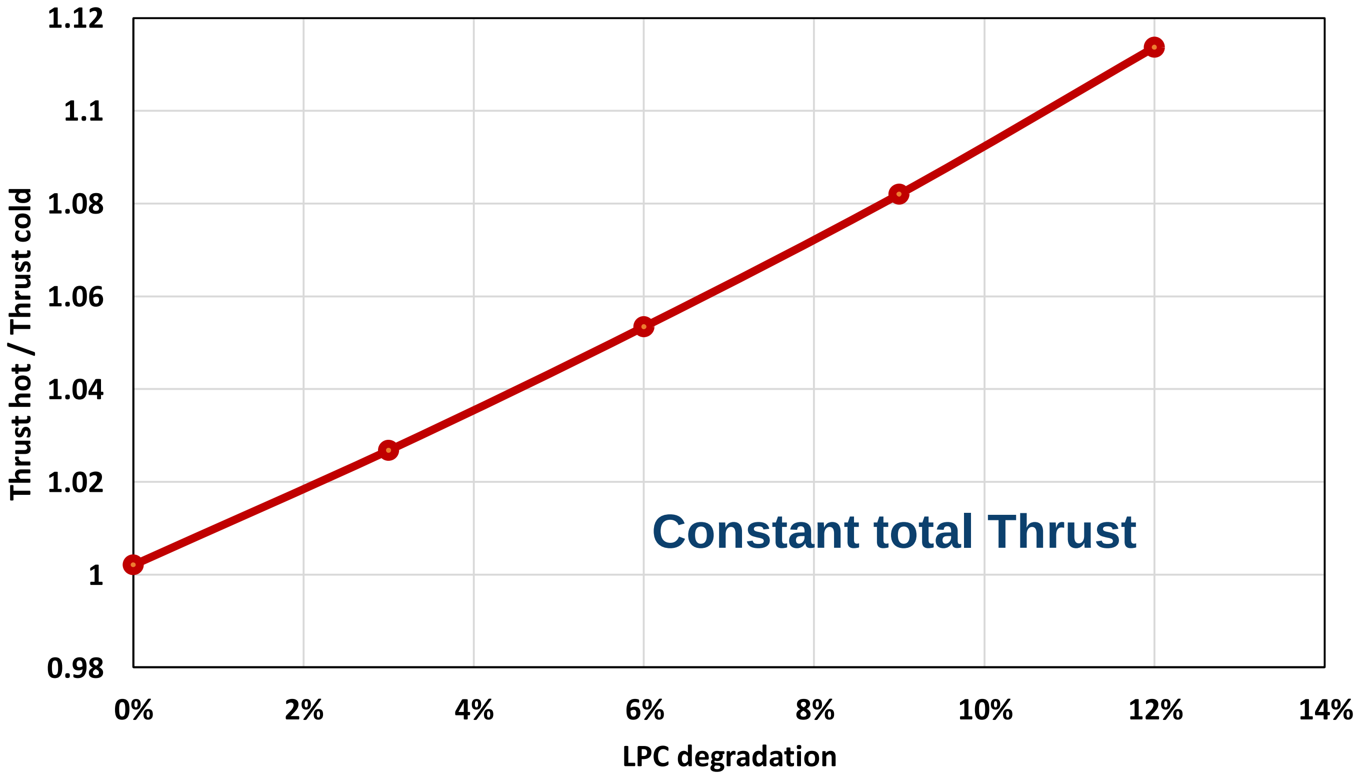
Thrust Vectoring- Scenarios

Case Study -1

- Engine performance with LPC degraded – Thrust Mismatch at constant overall thrust.
- Engine with thrust mismatch correction at constant overall thrust with bleed adjustment

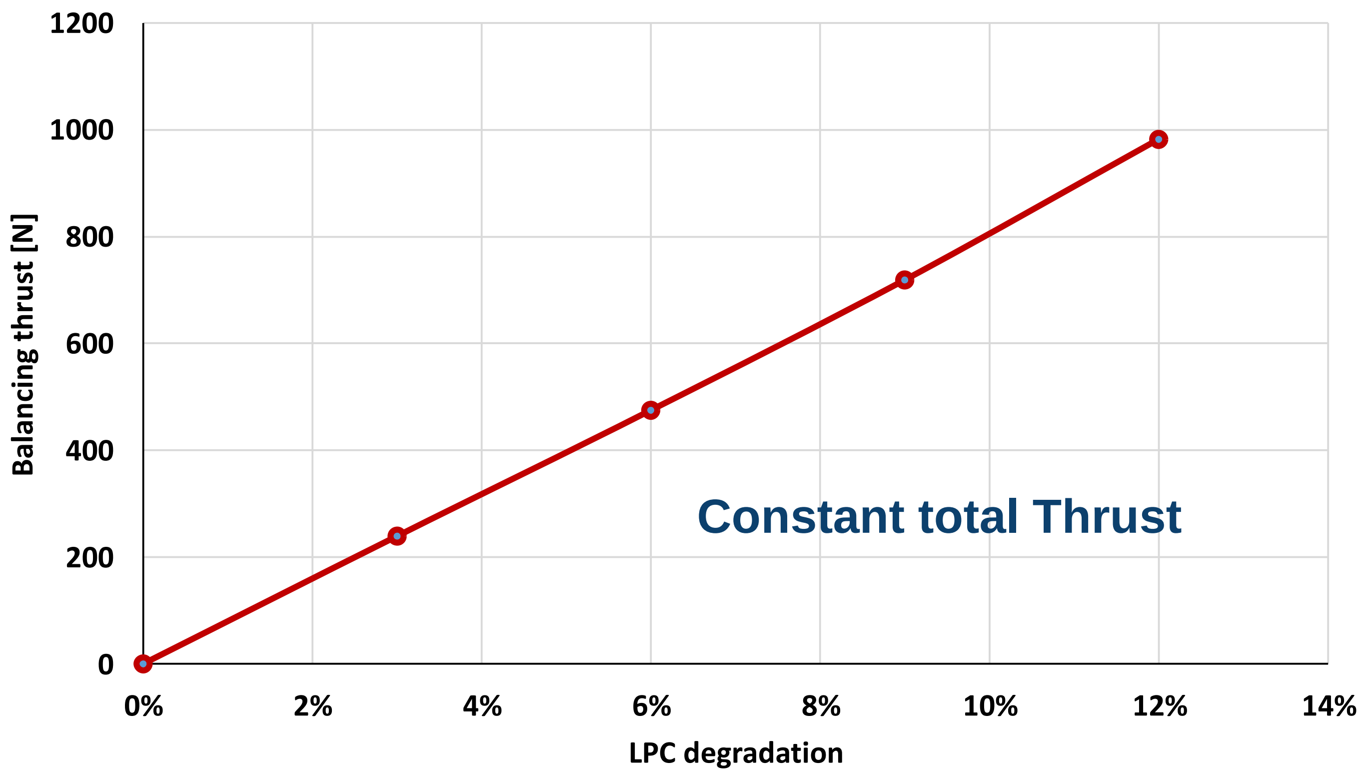
Thrust Vectoring- Mismatch in Thrust

Case 1 - Degradation of LPC (Unbalanced)



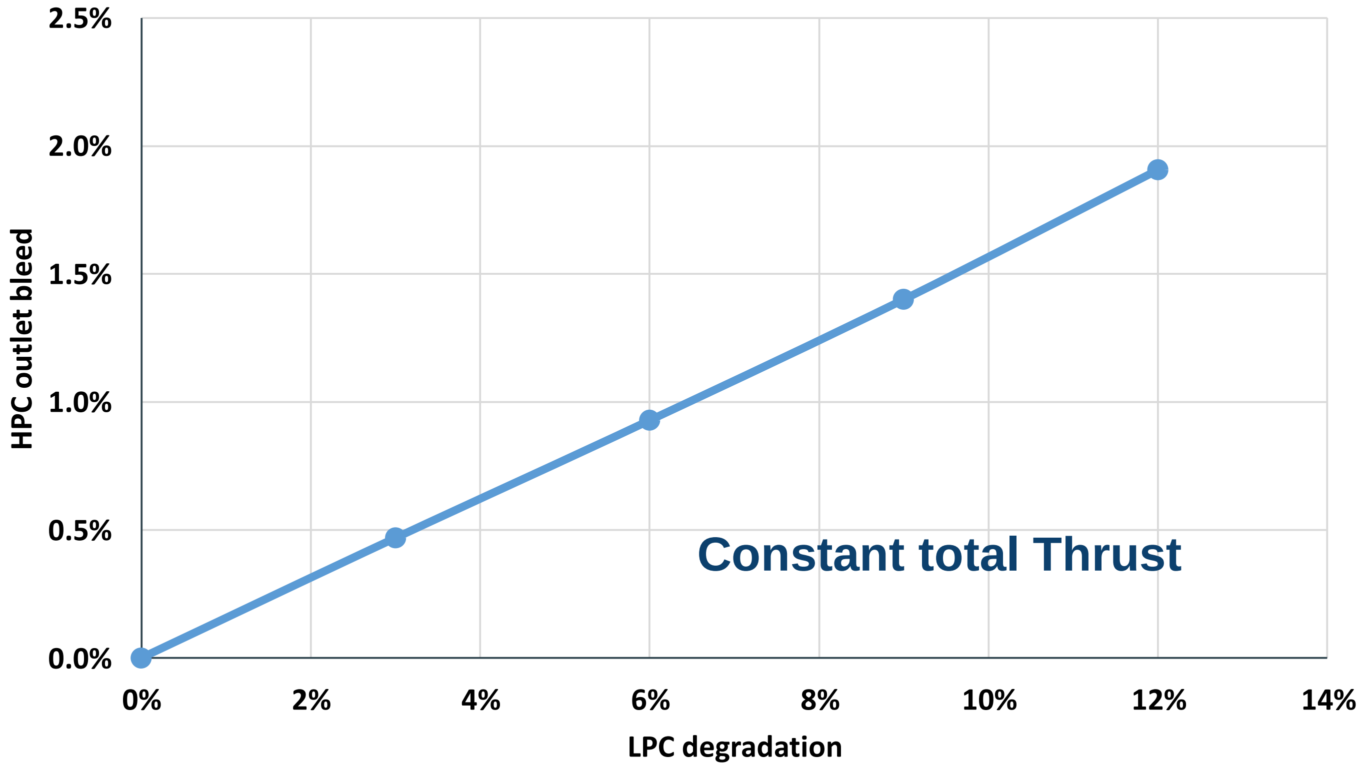
Thrust Vectoring: Thrust Balancing

Case 1 – HPC Bleed balance



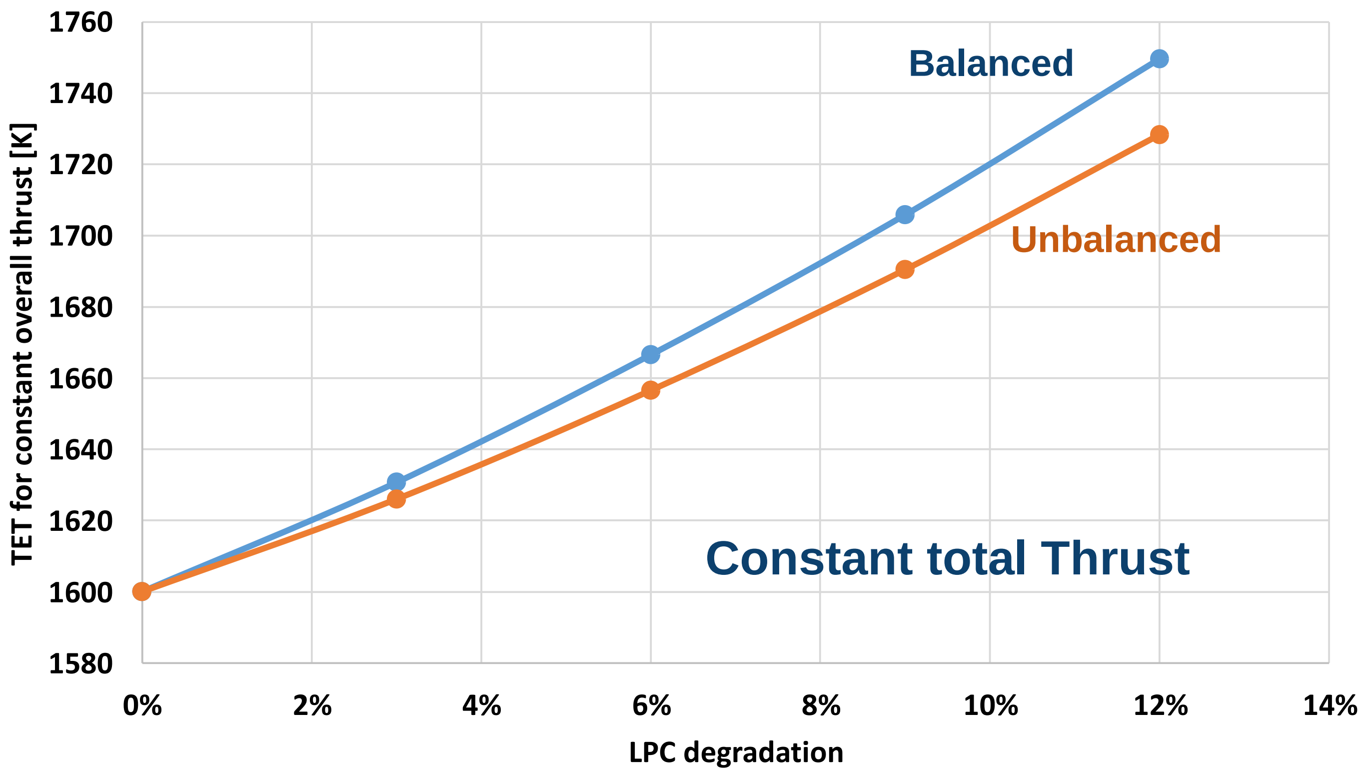
Thrust Vectoring: Thrust Balancing

Engine model – case 1 – HPC bleed Balance



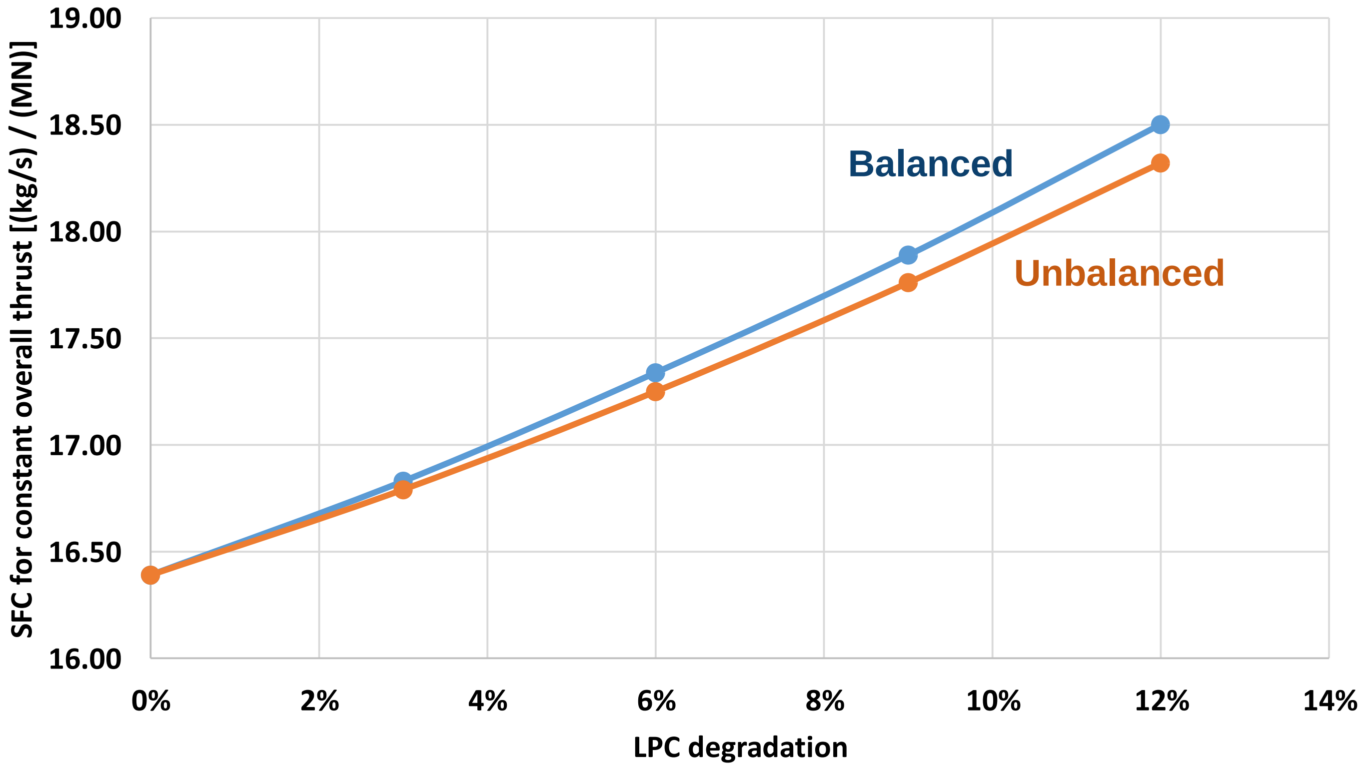
Performance deviation due to Degradation

Change in TET due to Bleed Balance



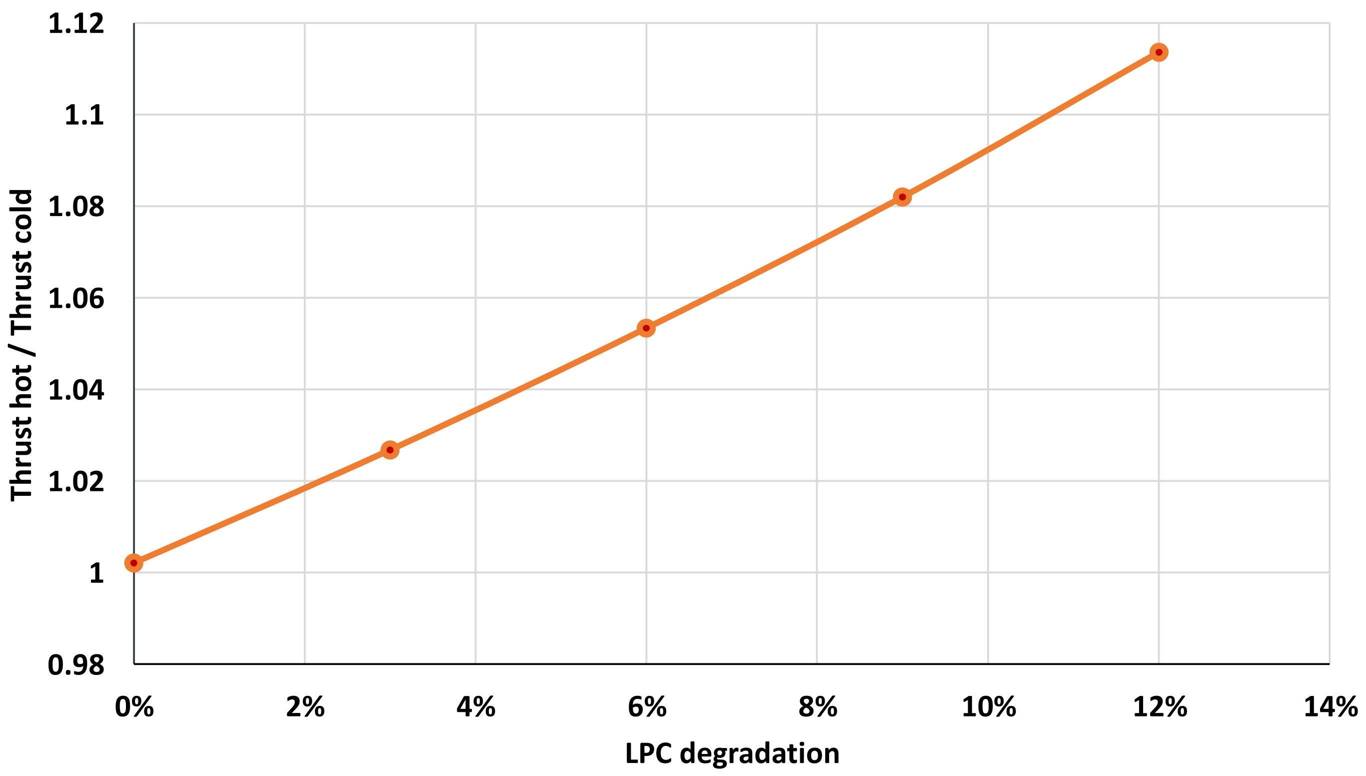
Performance deviation due to Degradation

Change in Fuel Consumption due to Balancing



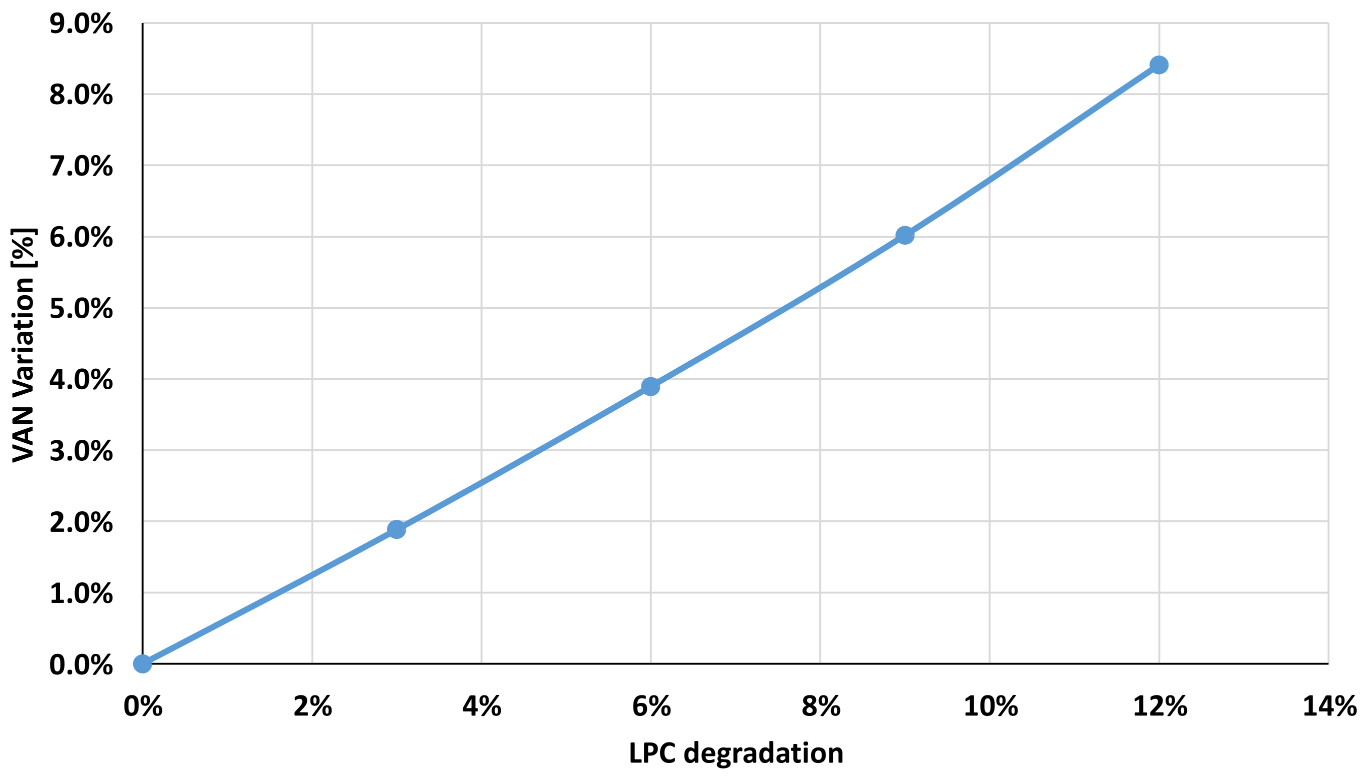
Thrust Vectoring: Mismatch

Thrust Unbalance



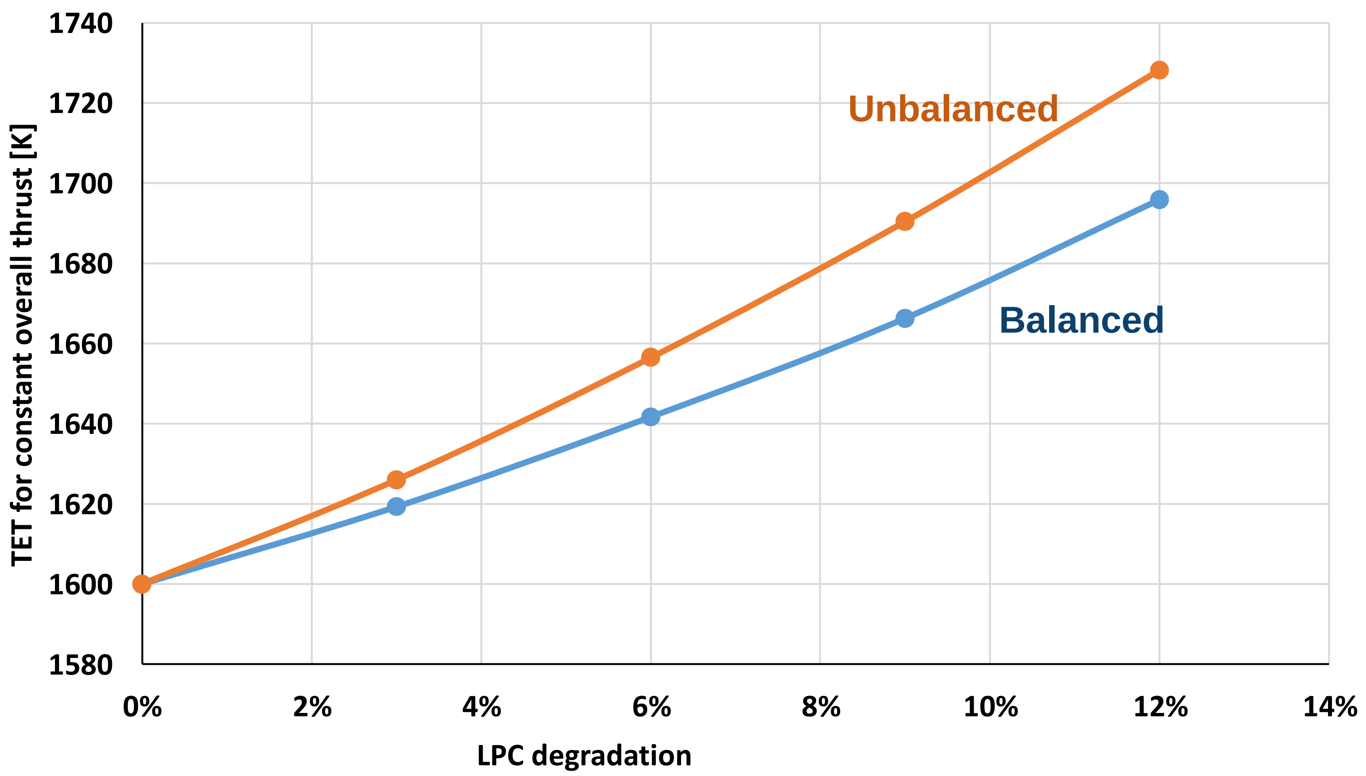
Thrust Vectoring: a Performance Perspective

Thrust Balance using Variable Area Nozzle



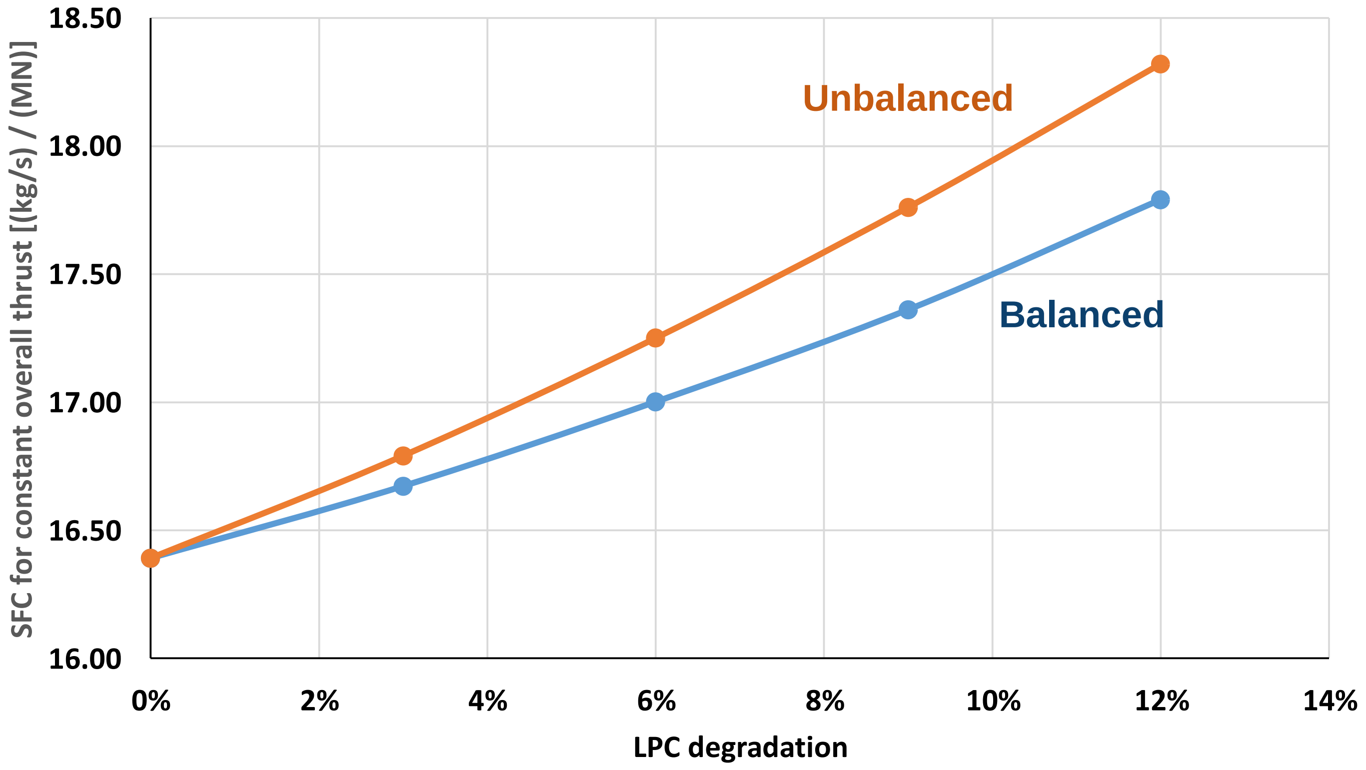
Performance deviation due to Degradation

Change in TET due to Nozzle Area Adjustment



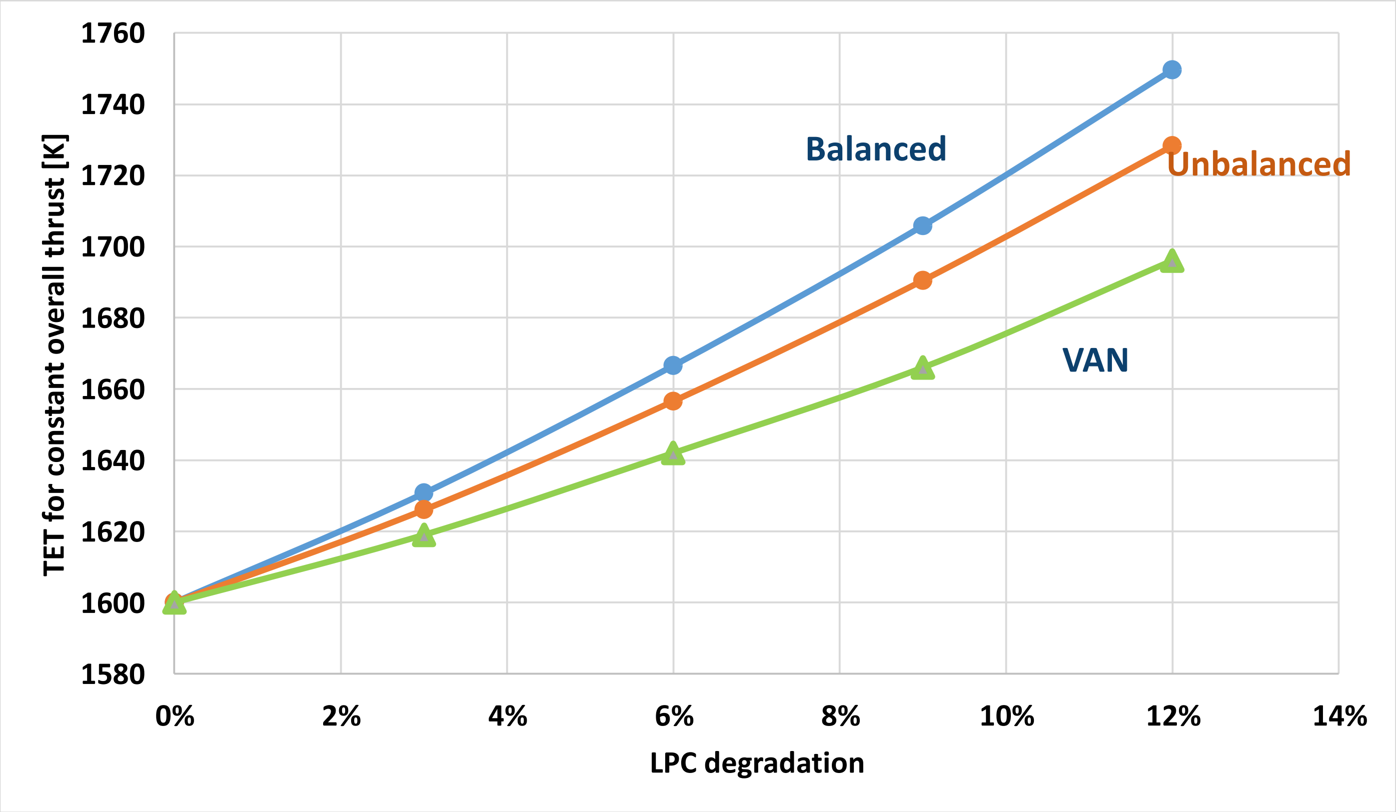
Performance deviation due to Degradation

Change in Fuel Consumption- Balancing by VAN

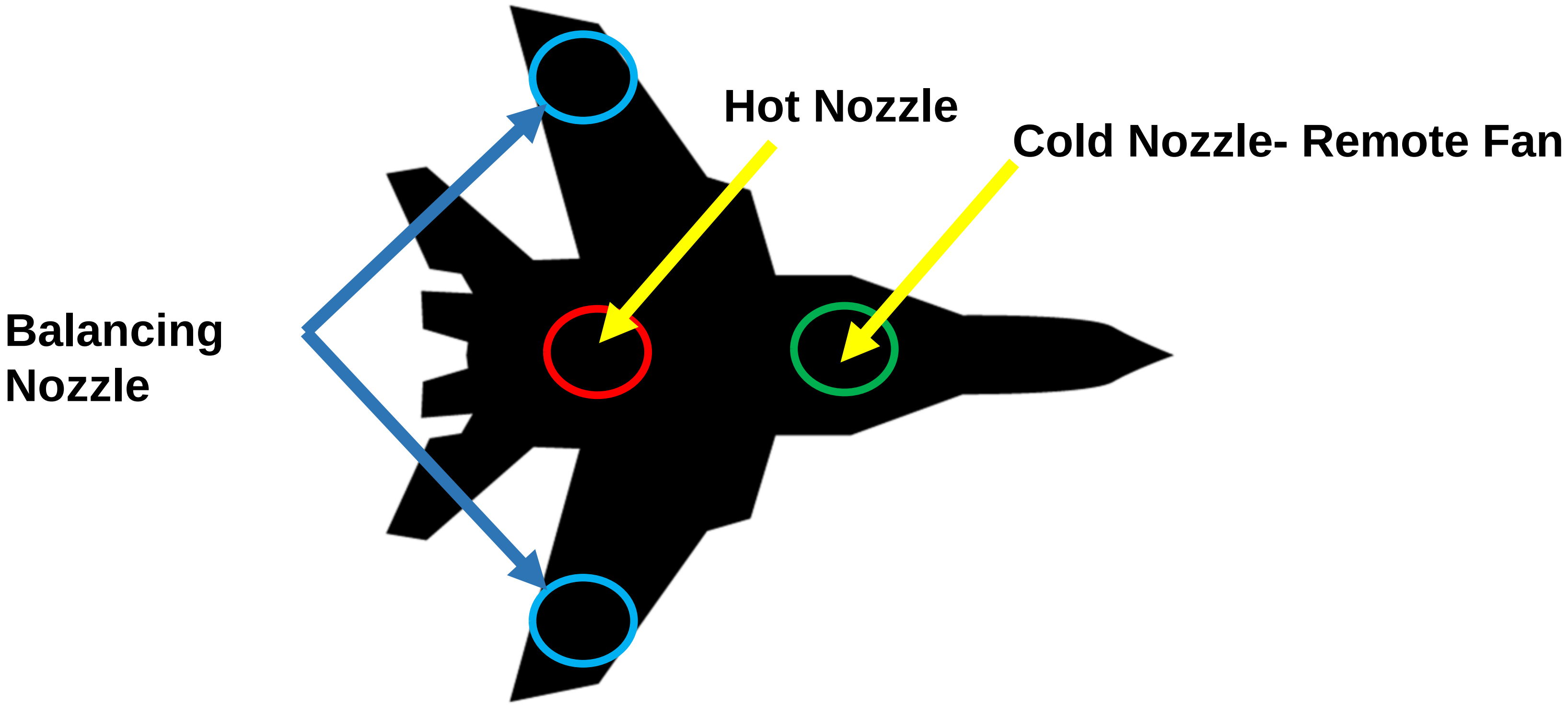


Thrust Vectoring: Performance

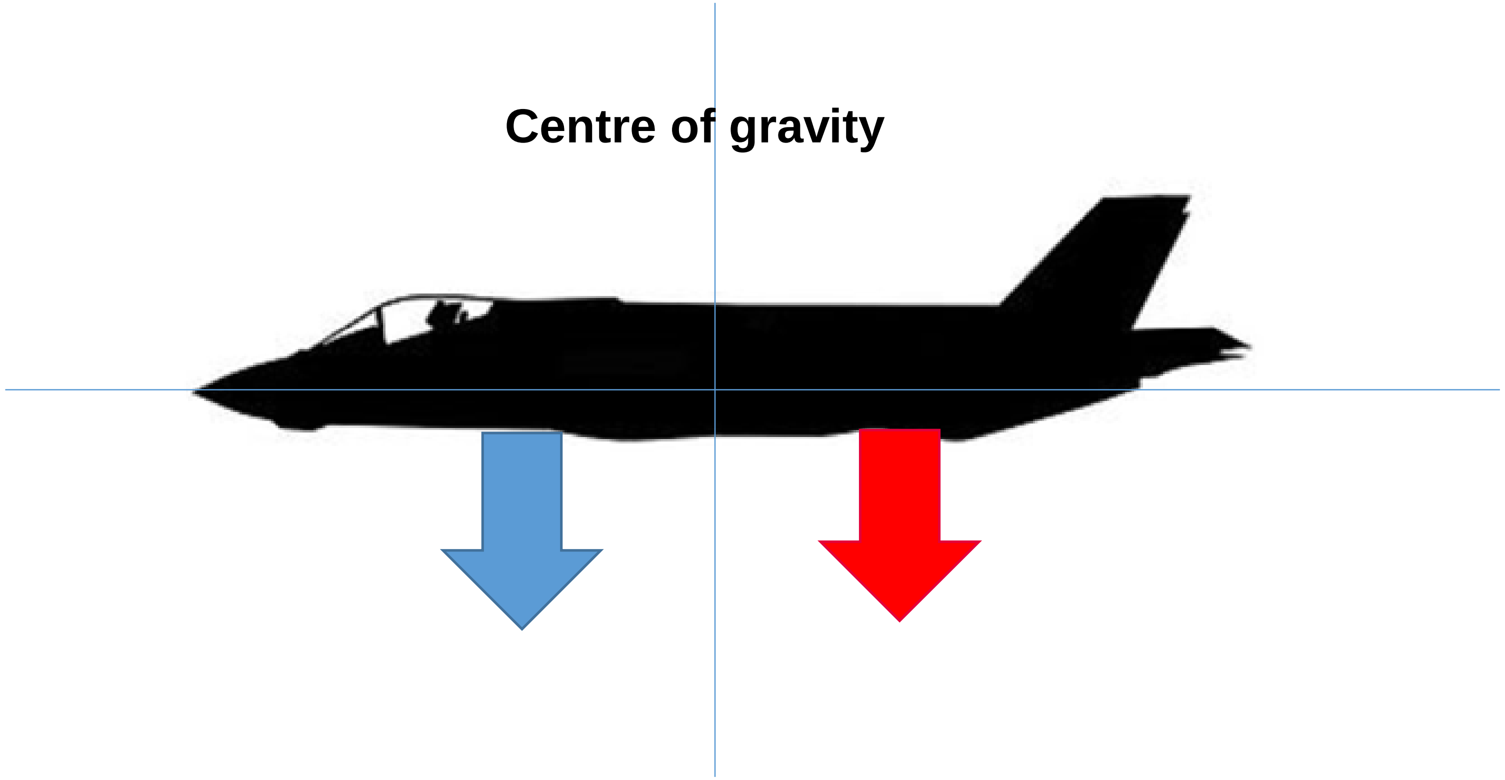
Comparison of both Methods – Constant Thrust



Thrust Vectoring - Remote Fan Configuration



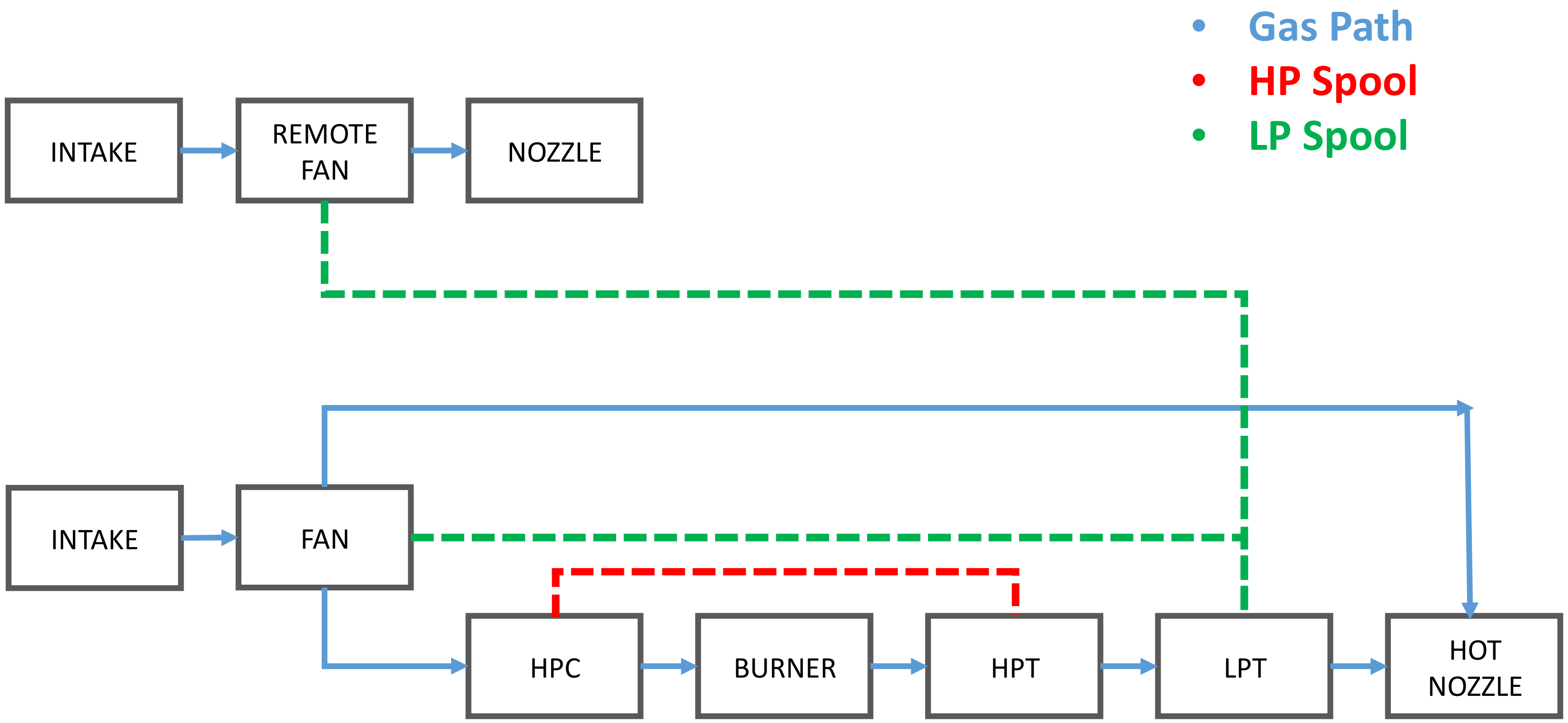
Thrust Vectoring - Remote Fan Configuration



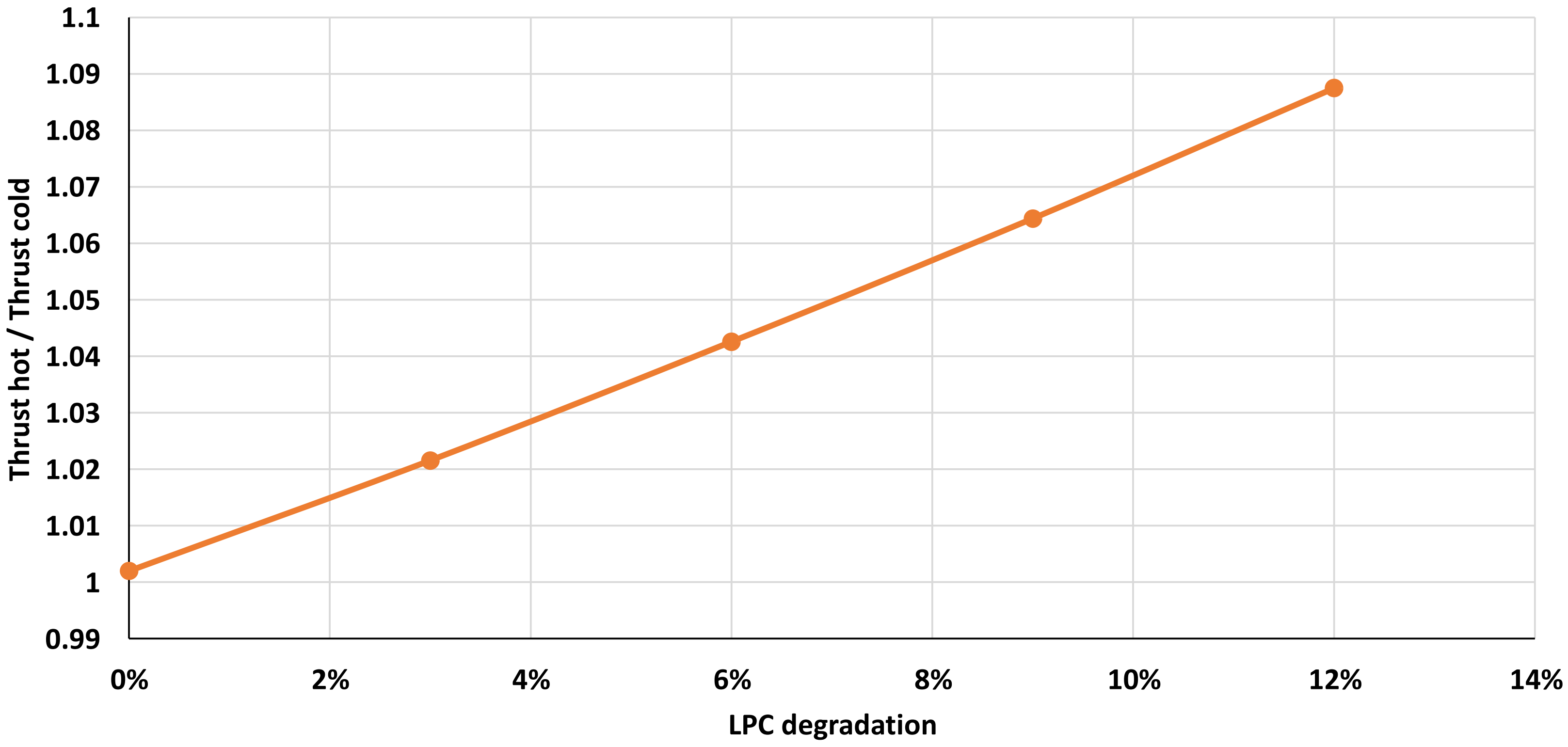
Thrust Balancing by Nozzle

Thrust Vectoring: Remote Fan Modelling

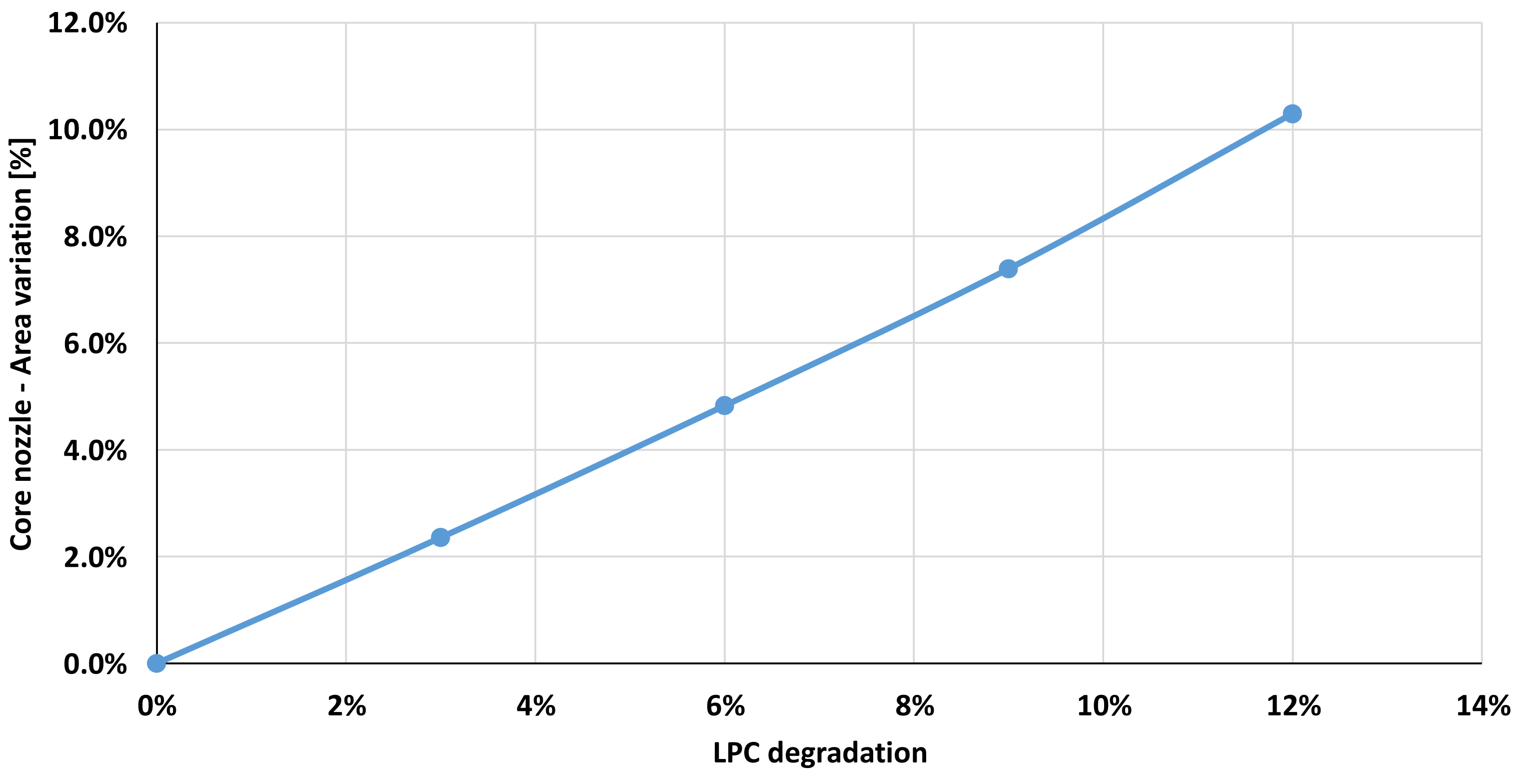
Engine Model – Case 2



Engine model – Case 2 – VAN Constant

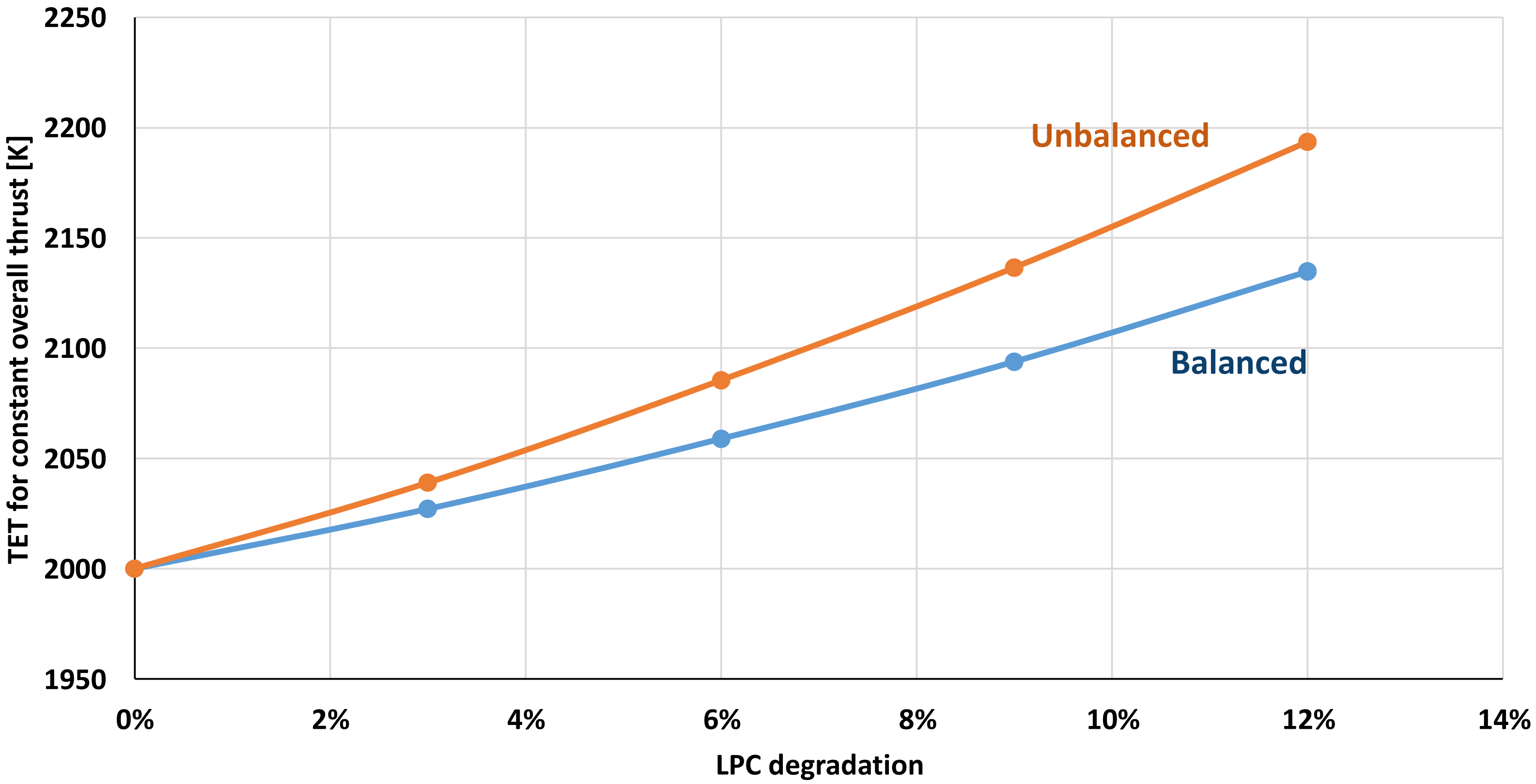


Engine model – Case 2 – VAN Balancing



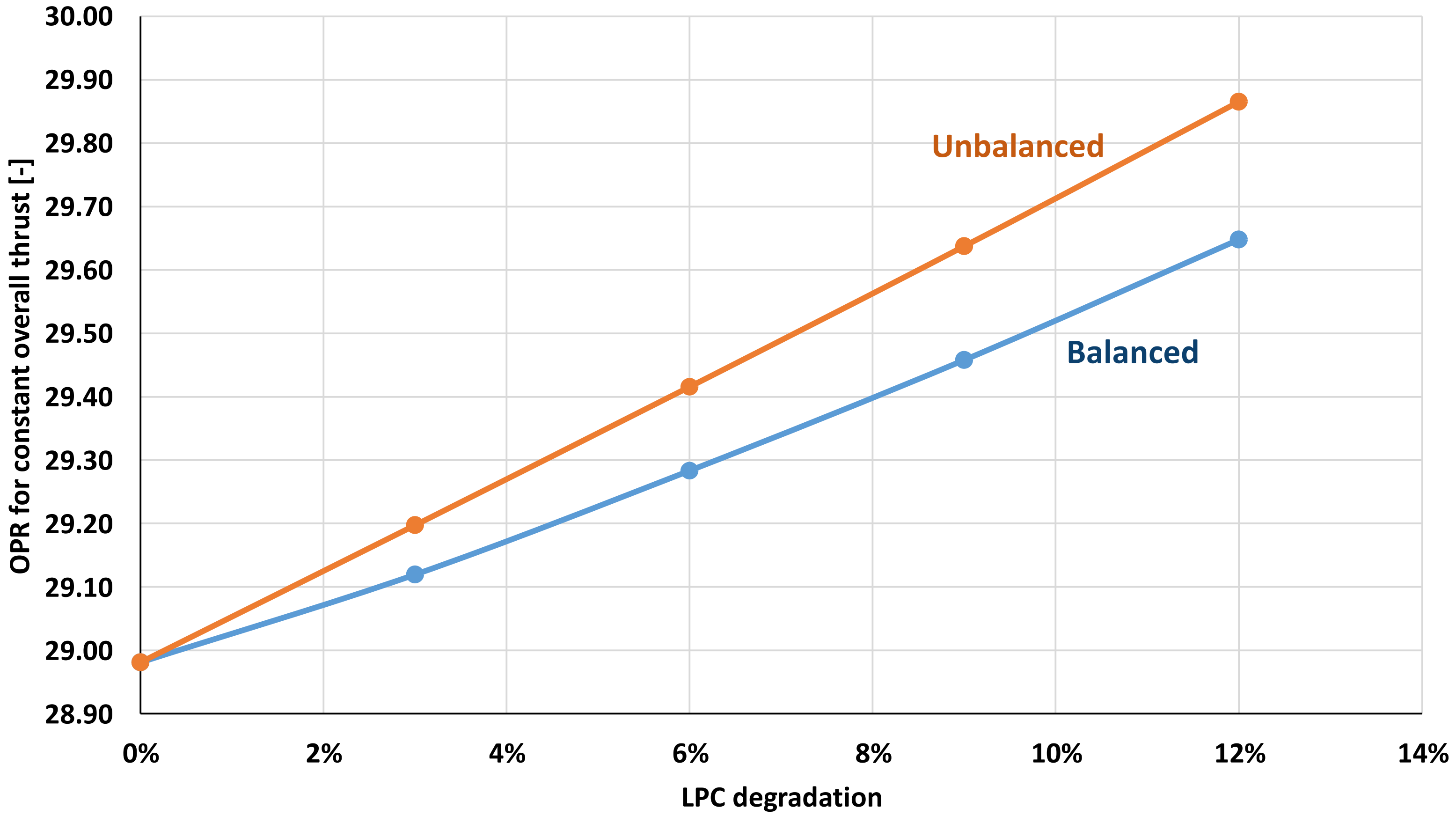
Thrust Vectoring: a Performance Perspective

Effect on TET- VAN Balancing



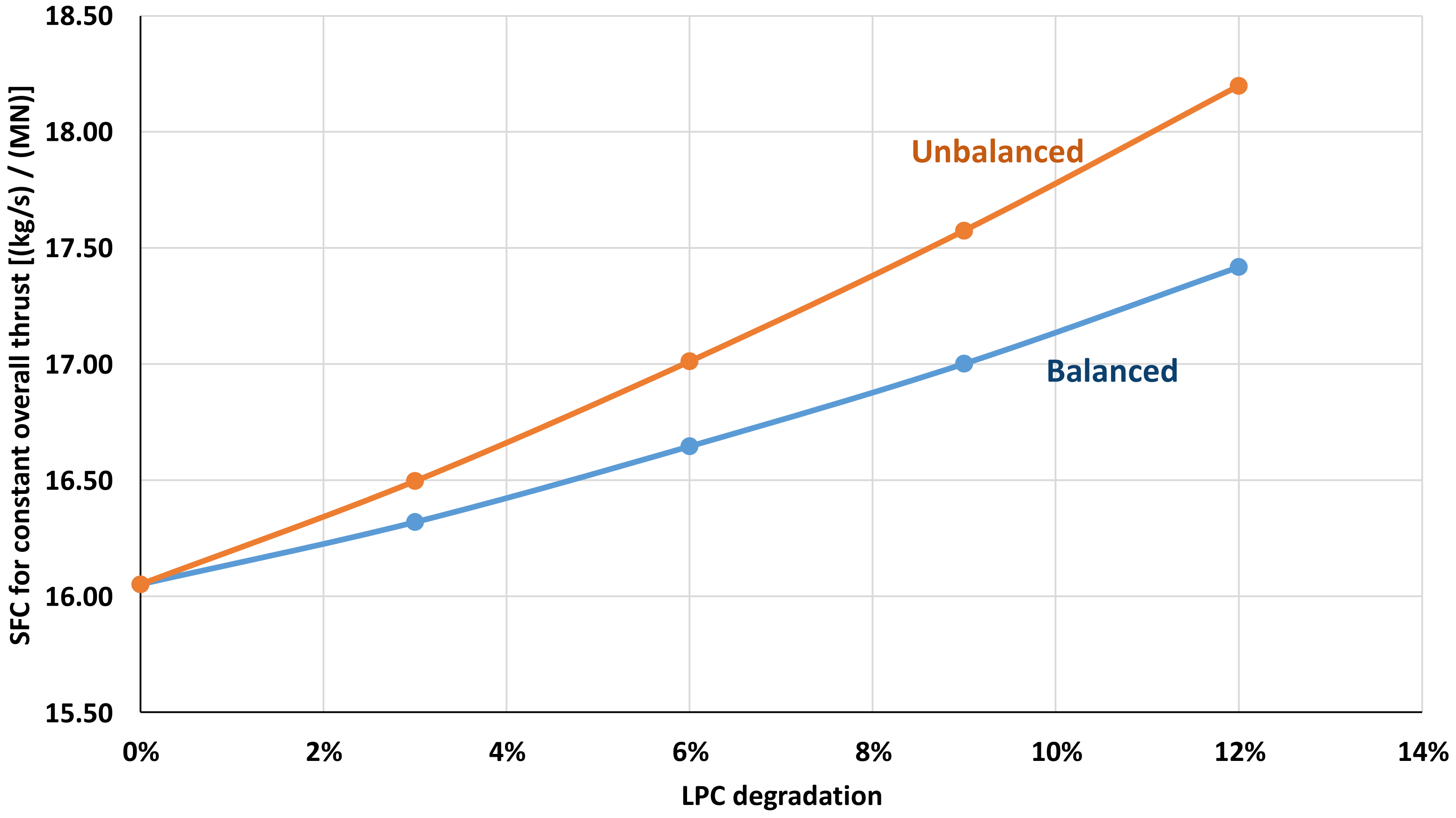
Thrust Vectoring: a Performance Perspective

Engine model – Case 2 – VAN Balancing



Thrust Vectoring: a Performance Perspective

Engine model – Case 2 – VAN Balancing



Conclusion

- Understanding engine performance change due to engine degradation in context of thrust vectoring
- Usefulness of performance simulation
- Effect of degradation on the creep life of the components
- Methods to mitigate the effect of high temperature creep
- Important for designers, operators and maintainers

Thank You