



The Roberval Balance ***(or Enigma)***

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The Roberval Balance was invented in 1669 by French mathematician Gilles Personne de Roberval

The mechanism is a parallelogram that is constantly in a state of equilibrium regardless of position of equal weights

Better known as Roberval's Enigma



Gilles Personne de Roberval

- Born 1602, he attended college in Paris and in 1631 he was appointed the philosophy chair at Gervais College, Paris. Two years after that, in 1633, he was also made the chair of mathematics at the Royal College of France. He was a co-founder of the French Academy of Sciences in 1666.
- A condition of tenure attached to this particular chair was that the holder (Roberval, in this case) would propose mathematical questions for solution, and should resign in favor of any person who solved them better than himself. Notwithstanding this, Roberval was able to keep the chair till his death in 1675.



Verification using FEM

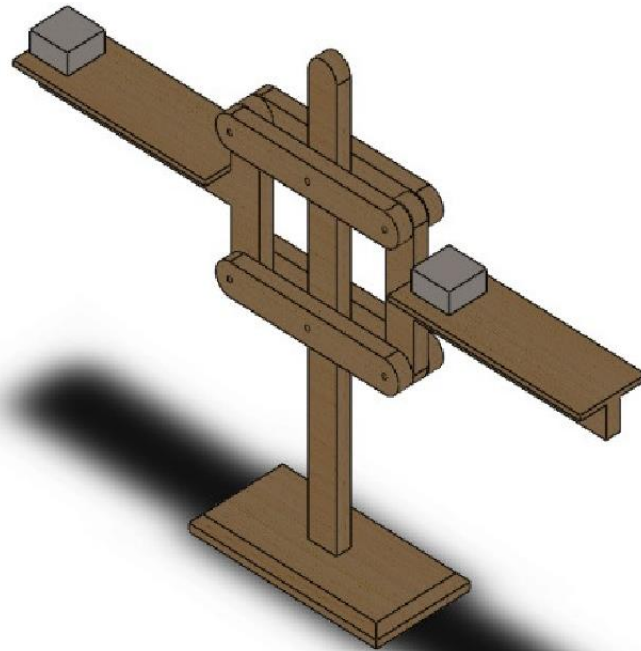
- Three FEM packages were examined
 - SolidWorks
 - Fusion 360
 - COMSOL
- Results were compared – all essentially the same

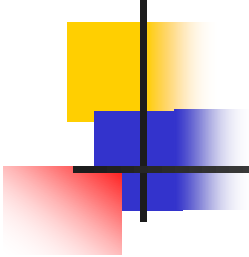


Problem setup

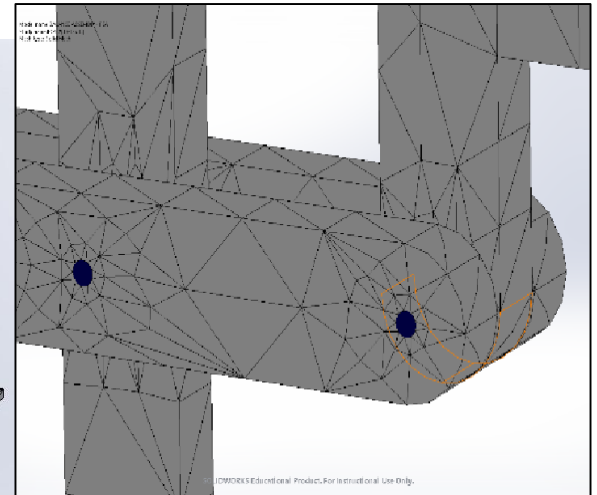
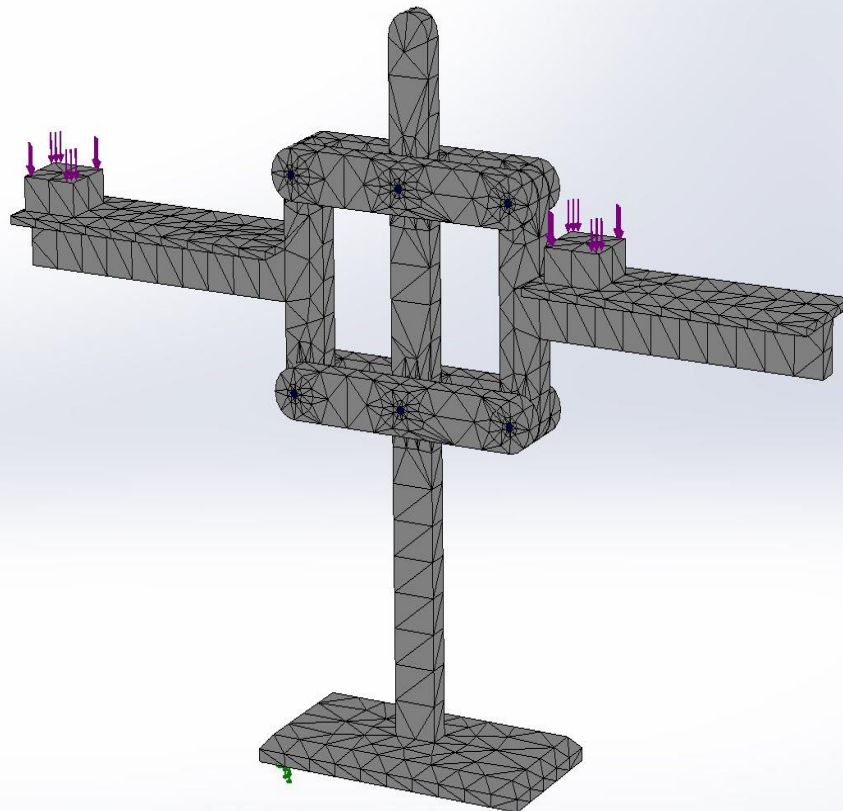
Mesh Type	Solid Mesh
Total Nodes	14530
Total Elements	7677
Max Aspect Ratio	17.156
Mesh Quality	High

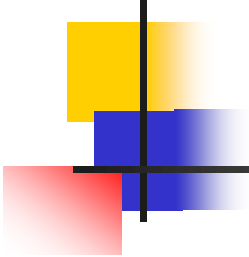
The balance



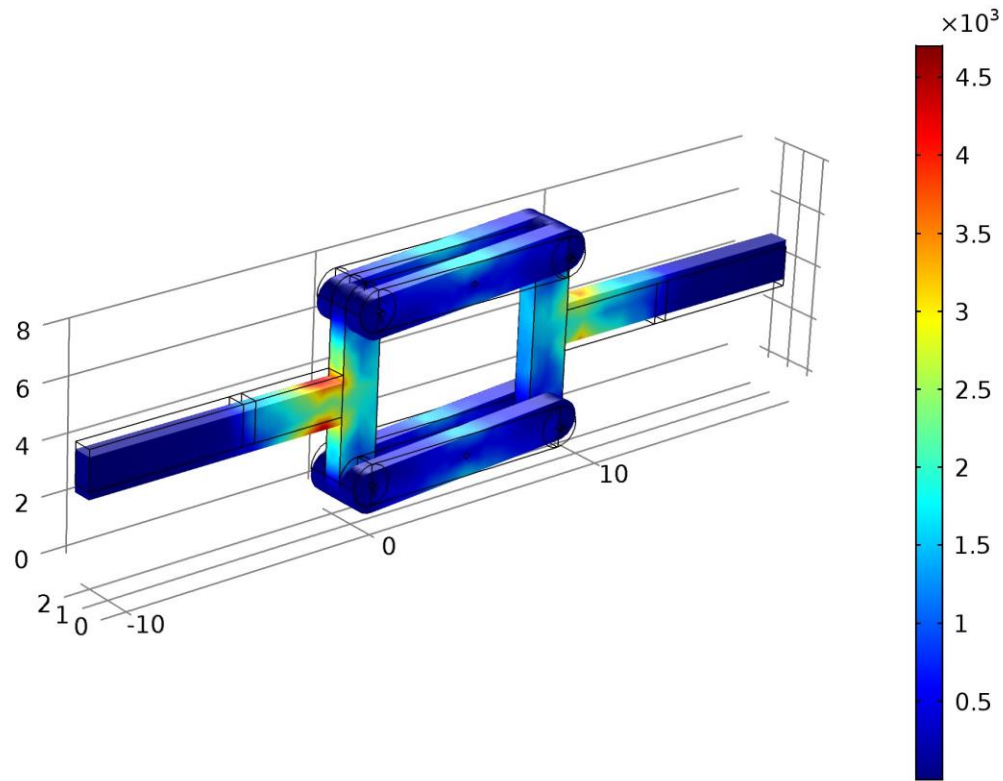


Model name: BALANCE ASSEMBLY - FEA
Study name: POS 2 (Default)
Mesh type: Solid Mesh

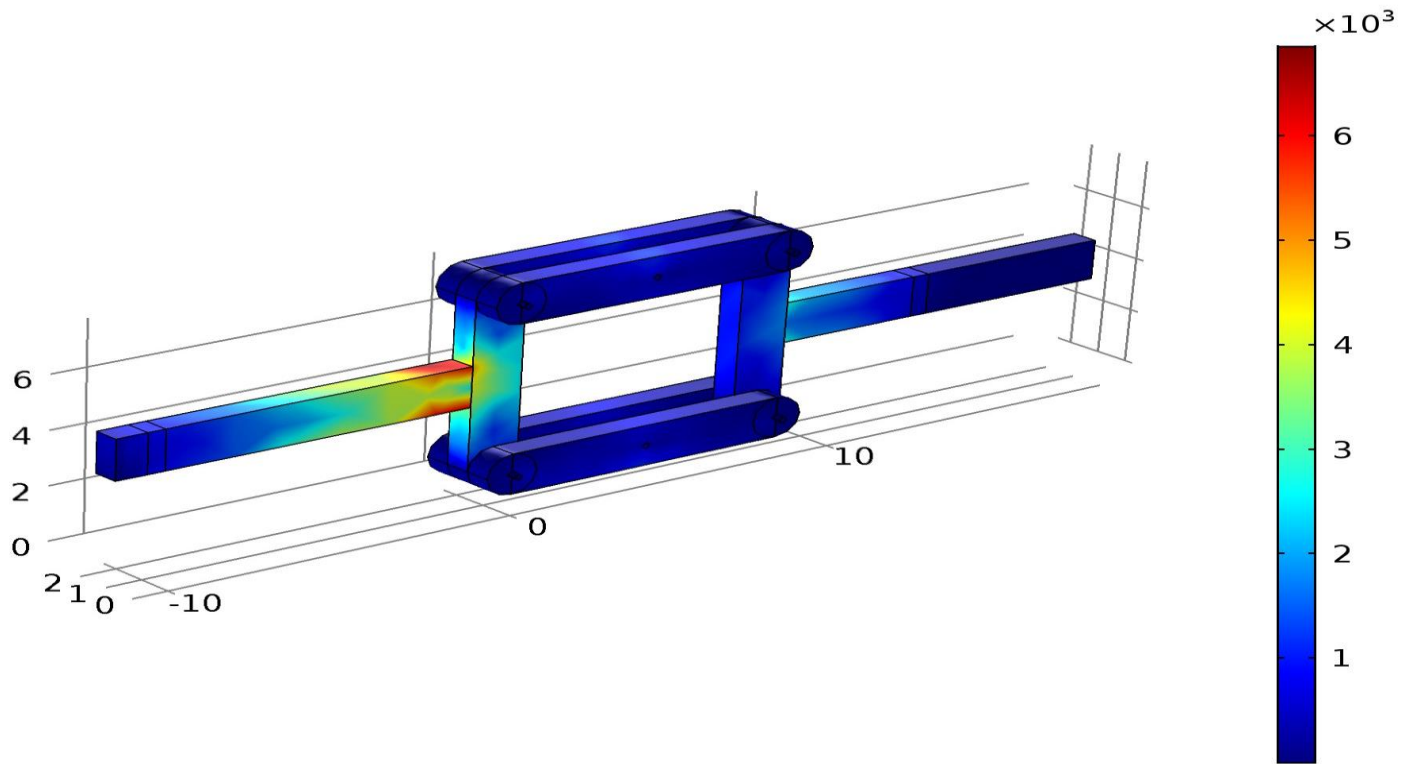


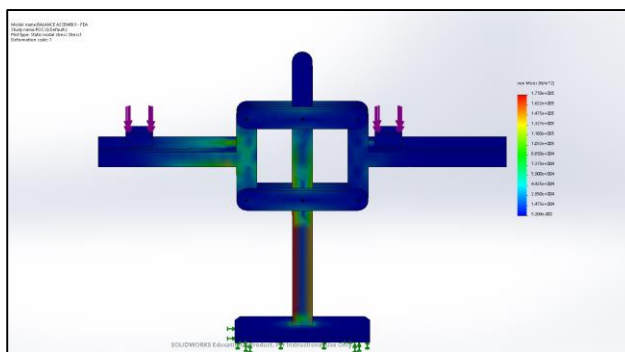
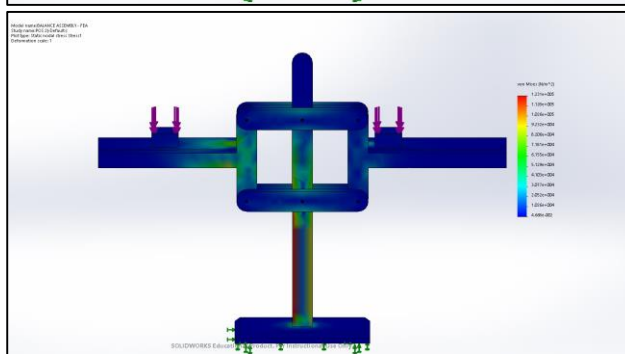
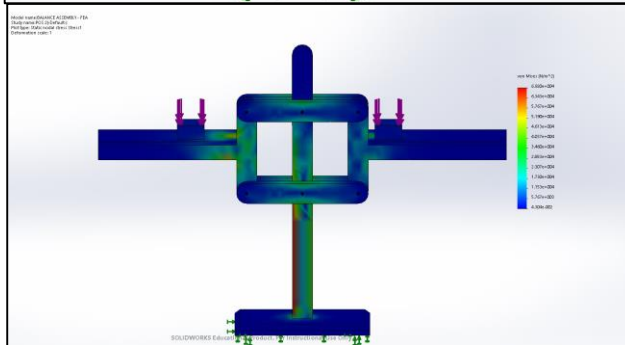
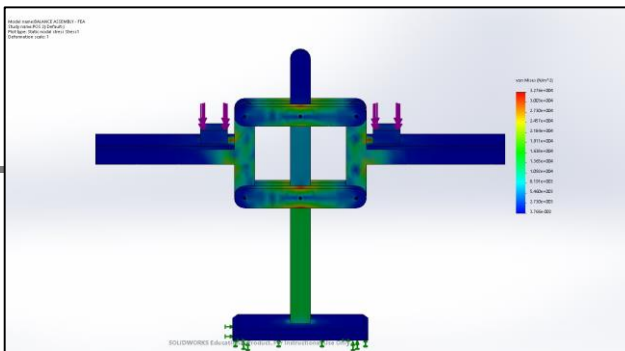


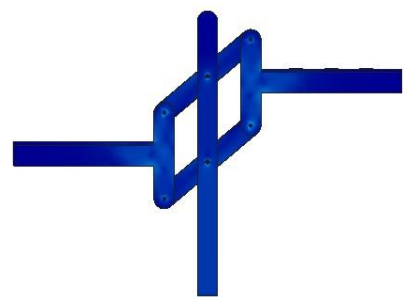
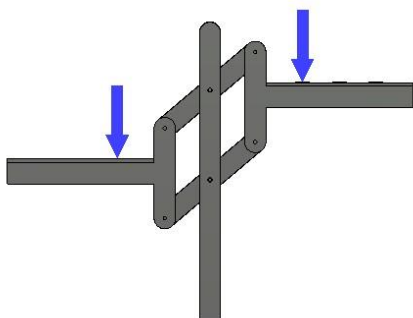
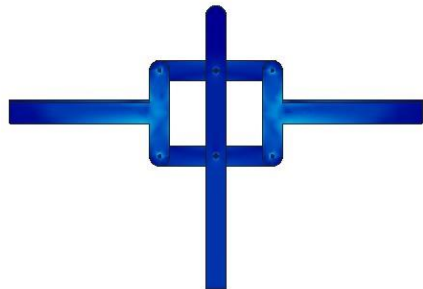
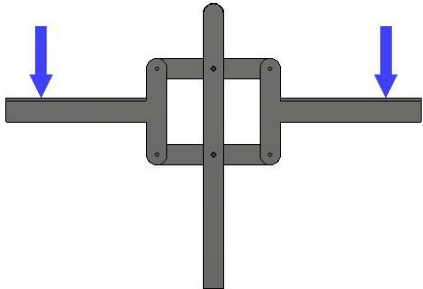
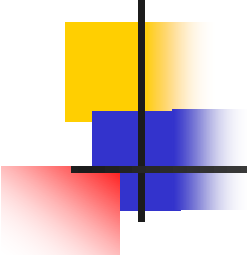
Time=1.5 s Volume: von Mises stress (N/m²)

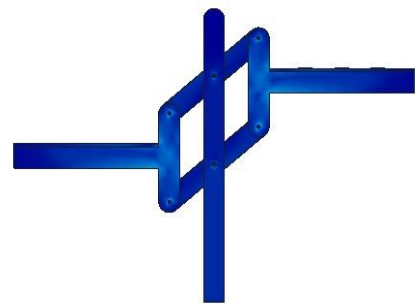
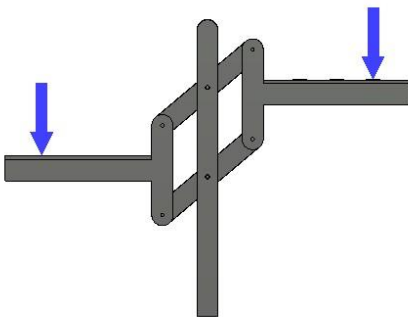
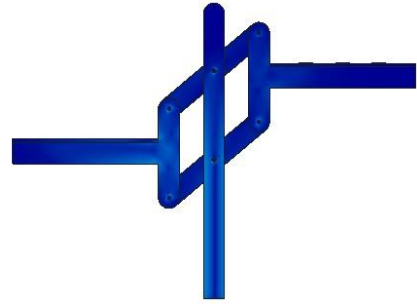
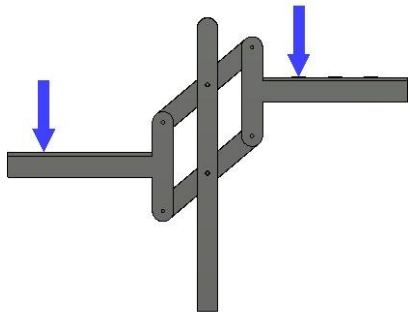
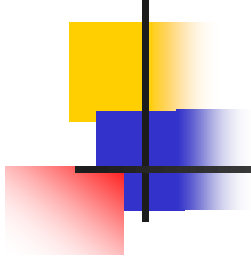


left_load(93)=9.3636 Time=0.76 s Volume: von Mises stress (N/m²)











Video



Conclusions

- The model will become unbalanced when two unequal forces are applied to the mechanism
- While in a state of equilibrium, the balance demonstrated the exact same stress field characteristics under a static stress as under a multi-body dynamics simulation



References

- S. B. Hanssen, Book of Scales, 2007
- J. T. Graham, Scales and Balances, Shire Publications, Aylesbury, 1981
- Z. J. Olsen, L. J. Olsen, M. Lewis, and M. Boswell, ME 704: Finite Element Analysis, Final Project Report – The Roberval Balance, UNLV, 2016



Thank you

Questions?