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Procedia Engineering 144 (2016) 3 – 25

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Advances in Aero Structures

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Abstract

With the advent of high performance computing the approximate engineering approach of 20th century has given way to Science to Engineering approach directly from 17th century to 21st century. The concept of simultaneous design and optimization that began with Science Revolution with Brachistochrone Problem has helped in achieving optimum designs from the concept particularly in complex aeronautical structures. This paper describes through some examples the way in which aircraft structural designs can be produced in a short period of time using SBES approach through HPC.
Concept design of an aircraft wing given the loads and the airfoil shape from CFD
Achieving a composite structure through optimization principles
Impact analysis from bird hits
Fluid Structure Interaction and flutter analysis
Engine-Wing integrated structure analysis attempts

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: Tuned mass damper, Piezoelectric actuator, Method of multiple scales, Fixed point theory.

1. Introduction

Geometry (Shape) played an important role in ancient civilizations and optimization problems had their roots in Greek science. Euclid (323-285 B.C.) is a great Greek mathematician best known for his treatise on geometry, which influenced the development of Western mathematics for over 2000 years, see Rao (1992). With modern design practices of globally elastic and locally plastic structures, it is once again the shape of mechanical components that is playing a significant role in optimizing weight, maximizing life etc.

In Euclid's book III of the Elements, see Heath (1956), the basic ideas of optimization are embedded; there is a discussion of the greatest and least straight lines that can be drawn from a point to the circumference of a circle. Also in book VI, it is discussed about the parallelogram of greatest area with a given parameter.

Archimedes (287-212 BC) of Syracuse in Sicily is believed by many to be the first mathematical genius the world has so far produced. He is also believed by many to put his accomplishments into written form, see Heath (1897) and Crombie (1979). In his work on division of a sphere in two parts so that the volume ratio of these parts is equal to a given ratio, Archimedes solves the problem of finding the maximum of $f(x)=x^2(x-a)$. Amongst the Alexandrian school of engineers is undoubtedly Hero who lived sometime during the second century BC. He proved that light travels between two points through the path with shortest length when reflecting from a mirror see Pederson (1993).

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Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.05.002

The event which most historians of science call the scientific revolution can be dated roughly as having begun in 1543, the year in which Nicolaus Copernicus published his *De revolutionibus orbium coelestium*, see Rao (2011). Scientific revolution made rapid strides beginning with Isaac Newton (1786) and Gottfried Leibniz (1684) that developed fundamentals of calculus and calculus of variations.

Euclid's influence is so profound that it is said that Newton in 1663, when he was just 20 years old, bought a book on astrology out of a curiosity to see what is there in it. When he could not understand an illustration in this book, he bought a book on Trigonometry, and to follow the geometry in this book in turn, he bought the book of Euclid's elements of geometry. Armed with these books, he discovered in 1665, the subject of differential calculus, while he was still an undergraduate student at Cambridge.

It is worth noting the way in which Calculus of Variations was invented by Newton. Johann Bernoulli challenged fellow mathematicians at that time to solve an unresolved issue called Brachistochrone problem, see Rickey (1996), specifying the curve connecting two points displaced from each other laterally, along which a body, acted upon only by gravity, would fall in the shortest time. From Greek, βράχιστος, *brachistos* means *the shortest*, χρόνος, *chronos - time* giving the name Brachistochrone. He set a dead line of six months originally and extended it to a year and a half at the request of another fellow mathematician. It is said that the challenge was delivered to Newton at 4.00 PM on January 29, 1697. Newton before leaving for work next morning invented calculus of variations to solve this problem. The subject of calculus of variations plays an important role in the theory of optimization and analysis that will be discussed in this paper.

2. Brachistochrone – The First Optimization Problem

The Brachistochrone problem is specifying the curve connecting two points displaced from each other laterally, along which a body, acted upon only by gravity, would fall in the shortest time. Newton showed that the required solution is a cycloid by discovering calculus of variations. Rao (2012) treated this as analysis problem or design problem. Exact solution using classical optimization and Galerkin solution with a one term approximation (analysis) are given in Fig. 1 along with a straight line path for a comparison. Table 1 gives the time taken on Cycloid

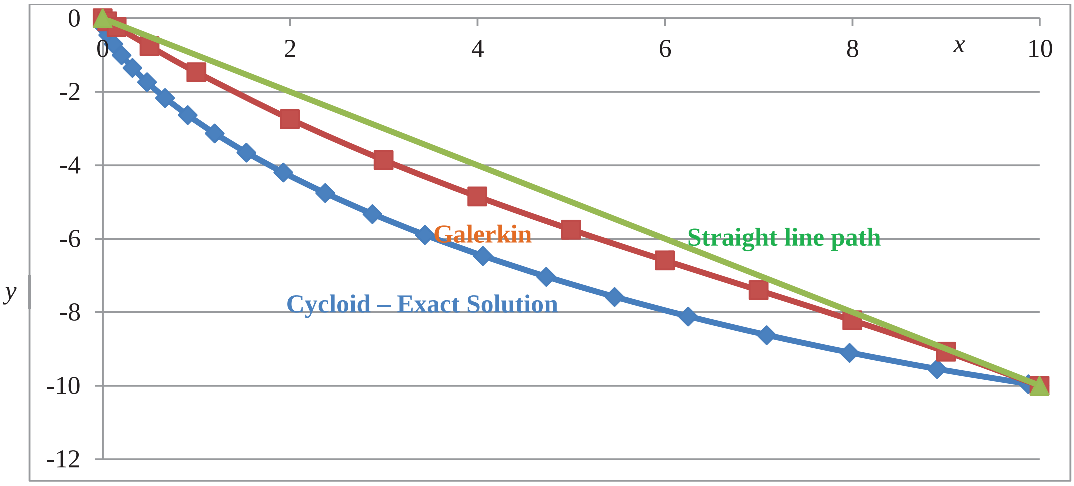

Fig. 1 Brachistocrone Solution

This time 1.512 sec is the least time for travel between points (1) and (2), considerably less than straight line path time 2.016 sec and slightly more than the vertical fall 1.426 sec.

We conclude from the above that the optimization problem posed by Johann Bernoulli is also analysis problem through Variational Calculus; the reason for bringing out this point is that all analysis methods essentially are approximate methods and today the design exercises for structures are carried out by using finite element methods which also are approximate methods from Calculus of Variations. Therefore the design and optimization procedures