Space structures

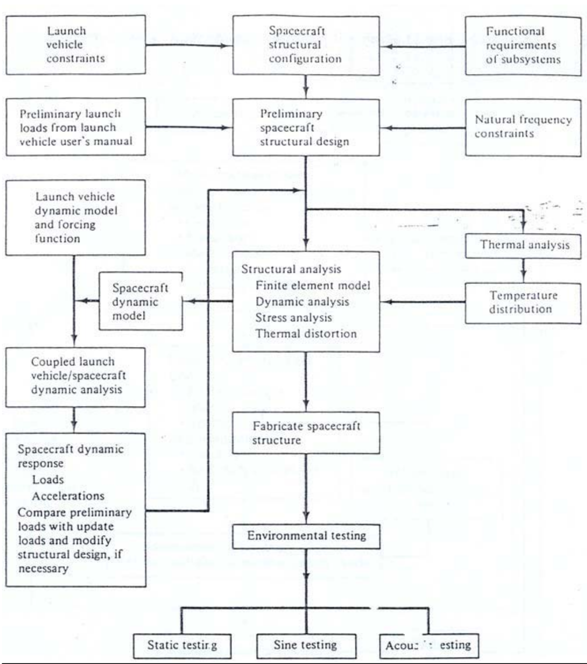
4. Structural analysis: the fundamental physics and the relevant mathematical assumptions of the models of solids and structures

Prof. P. Gaudenzi

Università di Roma La Sapienza, Rome Italy

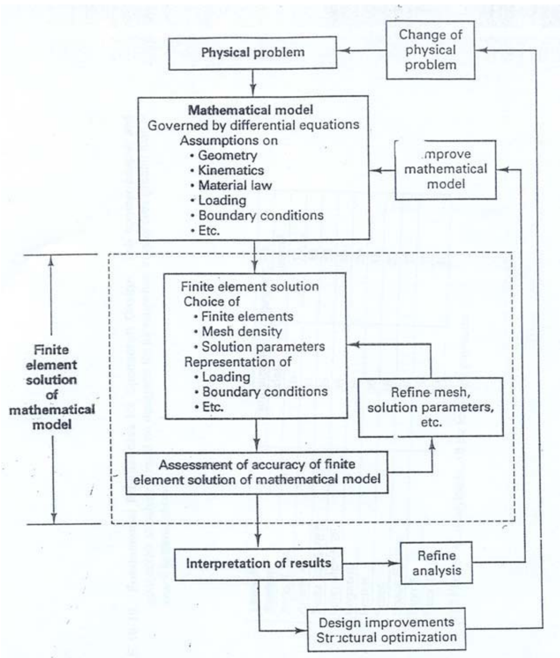
paolo.gaudenzi@uniroma1.it

STRUCTURAL ANALYSIS IN THE PROCESS OF SPACE STRUCTURE DESIGN



In the flow chart aside structural analysis is included in a possible design and realisation flow chart of a spacecraft. It is clear how basic requirements are coming from the general configuration of the spacecraft, the launch system, the subsystems. Then a preliminary structural design is performed based on which the analyses are performed. Also it is clear that stress analysis, dynamic analysis, thermoelasticity analysis are performed in iteration and concluded by a positive conclusion of verification by analysis. The verification by test is also always necessary.

MODELLING REALITY



Reality is infinitely complex and still mostly unknown. In an engineering process the effort of modelling the evolution of a physical problem, occuring to a natural or artificial system, is based on the knowledge of the physics. A mathematical model represents the physical behaviour assumed for the part of the reality that we are interested in. If we just limit our evaluation to the structural problem (a very narrow perspective as compared to all the others), simplifying assumptions on geometry, kinematics, material low, loadings, boundary conditions are necessary. A representing error is then necesserily generated.

MODELLING REALITY (2)

The capability of mathematical model of representing the physical problem under concern is the basic initial step of every analysis. Once the problem is well established from its physics and its mathematical model in analytical terms (integral or differential equations), there is no guarantee, generally speaking, on the deduction of an exact – meaning identically satisfying the equations of the problem - solution. In general it is not even known if the solution even exist and if it is unique. For this reason fundamental theorems of linear theory of elasticity created the basis of a very powerful analytical tool for structural design.

Also the theory of elasticity, the most effective theory for structural behaviour, is not able to provide analytical solutions in most practical problems. A tremendous help in this effort is provided by the theory of structures (beams, plates, shells) that provided a much wider spectrum of closed form solutions due to some restricting representation capability of the variables used for describing the mechanical system.

MODELLING REALITY (3)

Simplified analytical models should always be used whenever possible as a support to design especially in the preliminary phases. The basic analytical relations among the fundamental physical quantities descibed by the analytical solution of the problem should always be understood by the designer.

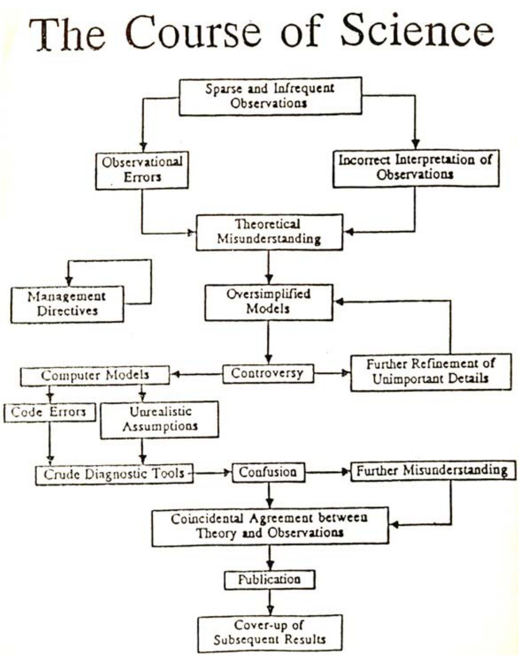
In real practical cases, whenever a detailed analysis is needed, the search for a closed form solution is hopeless, mostly due to the impossibility of solving differential equation systems. Numerical approximate solutions need to be sought. The finite element method is the most popular numerical approach for this purpose in solid and structural mechanics. The method requires to set the degree of representation of the problem (essentially established by the shape functions of the element and by the mesh refinement) and the process on how convergence to closed form solution can be reached.

MODELLING REALITY (4)

The possibility of finding a solution is due to the transformation of the problem from a system of differential equation to a linear algebraic system of equations, a mathematical problem that a modern computer is able to solve for many millions of algebraic variables. In case of eigenvalue problems (dynamics, buckling analysis) still major problems exist for finding a solution.

The convergence of a numerical procedure can be reached only in the frame of the initial mathematical assumptions. The assessment of the accuracy of the procedure aims at reaching reliable approximate results. In this process both truncation errors (due to finite element modeling) and round off errors (due to the numerical solution of the final system of algebraic equations) will occur and need to be taken under control.

A NICE LOGIC FLOW PROCESS



A look of what should not be done could also be important.
The flow chart aside, quite popular among universities and research centres, is indicative of some behavioural mistakes one should avoid.

MODELLING EFFORT

- Modelling the material behaviour (failure modes)

- Modelling the structural behaviour: material + geometry (imperfections) - (membrane, plate/shell, beam, 3D)

- Modelling of loads and boundary conditions (connections)

-Establish the analysis to be conducted (static and dynamic response, stability and buckling) – LINEAR OR NON LINEAR RESPONSE

-Evaluate results and correlate them with test

- Establish the level of detail needed in step and always use the simplest model available for the purpose, better if closed form solutions are available

- Respect the physics

- Respect the facts

CONCLUDING REMARKS

Modelling the structural behaviour

Modelling reality: limits and assumptions

Different nature (analytical and numerical) of modelling tools