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# METHOD FOR WEIGHT REDUCTION IN THE DESIGN OF STATICALLY DETERMINATE TRUSSES FOR AEROSPACE STRUCTURES

**Abstract**. This paper explores strategies for minimizing the weight of aerospace structures through the optimization of both member sizing and the overall configuration of truss structures, as well as the selection of materials used in trusses. This article discusses how to decrease the weight of structure by optimization of member sizing and structural configuration of truss structures and material of truss aerospace. Designing aerospace structures involves numerous factors that complicate weight estimation. Given the intricate load distribution within a redundant structure and the various complex systems integrated into an aircraft, accurately forecasting weight becomes a challenging task. Although a weight engineer can calculate the weight of every component upon completion of detailed design drawings, this is not feasible in the initial phases of design, where detailed drawings may not yet exist. Hence, initial weight estimates often rely on simple statistical correlations. A notable observation is that the empty weight typically constitutes about 50% of the gross weight for most aircraft.

## Stress Analysis of Statically Determinate Trusses of aerospace structures.

Many aerospace structures can be effectively modeled as truss systems. For instance, the ribs of wings are commonly constructed as trusses. This trend is also evident in space applications, where trusses are favored for their simplicity and lightweight characteristics. This is clearly illustrated in Fig. 1, where it can be seen that the ribs in the wing are built up as a truss structure [5 - 7]. Also in space applications, trusses are widely used because of their simplicity and light-weightiness [1].

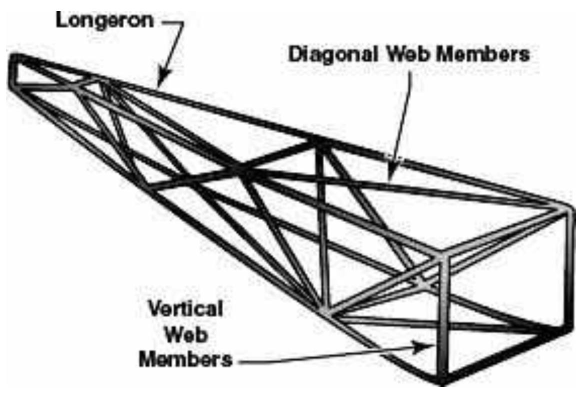


Figure 1. Rib truss structure example

**Truss Properties.** A truss consists of slender bars known as truss members, each with a specific cross-sectional area (A) and Young's modulus (E). In analyzing a truss, we operate under certain assumptions: the bar elements transfer loads solely through axial means (either tension or compression), and the joints are designed to transmit forces without transferring moments. If elements were welded or connected via plates, moments would also be transferred, which contradicts the axial load assumption. Additionally, loads can only be applied at the joints, and the weight of the bars themselves is often neglected during analysis.

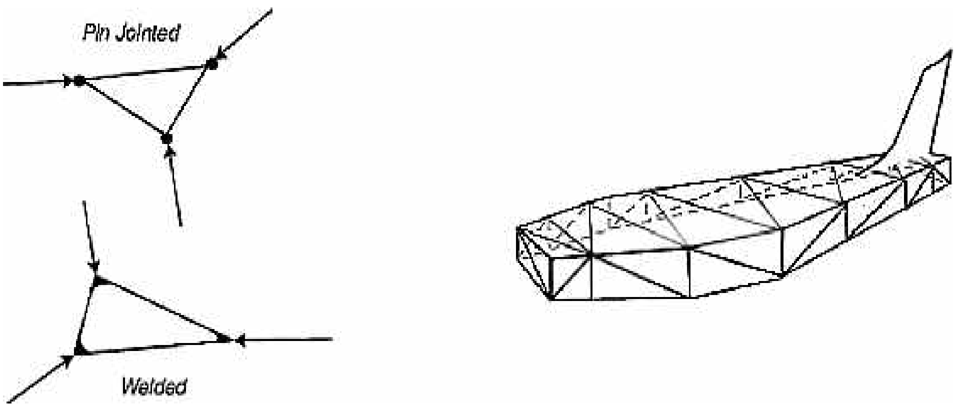


Figure 2. Typical simple truss structure

The following assumptions apply when analyzing a truss structure (Fig. 2). Bar elements can only transfer loads axially. These forces can be either tensile, tending to elongate the bar, or compressive, tending to shorten the bar. The bar elements are pin- joined together. This has as a consequence that the joints only transfer forces from one bar element to the other, and no moments [4]. If the bar elements were welded together, or attached with a plate, also moments would have been transferred, which is in contradiction with the earlier mentioning that bar elements are only suited to take axial loads, and no moments [3]. Loadings can only be applied at the joints of the truss. This inherently means that the weight of the bar, which would act at the midpoint of a uniform bar, is neglected.

**Stress Analysis and Design of Statically Determinate Trusses.** A truss is statically determinate if the numbers of unknowns is equal to the numbers of equations. Stress Analysis and Design of Statically Determinate Trusses [1] node, two forces in x and y direction act, that can be constructed for the problem. The unknowns are the truss member forces and the reaction forces at the truss supports. There are m truss member forces and r reaction forces.

So a necessary condition for static determinacy of a truss structure is

$$m+r=2n \quad (1).$$

If $m+r>2n$, the truss structure is indeterminate.

The reaction forces are due to the supports of the truss structure. The two support types that we use for truss structures are the pinned joint and the roller support. Both supports can be inspected in Fig. 3.

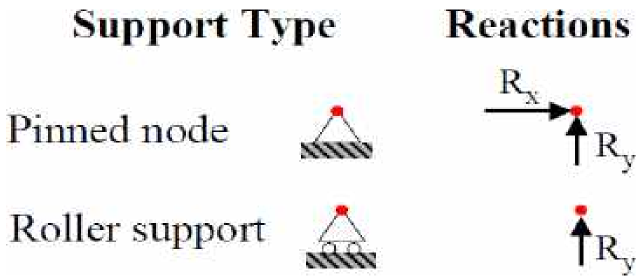


Figure 3. Truss support types

Two trusses are given in Fig. 4. One of them is statically determinate and one is indeterminate.

Figure out why they are determinate or indeterminate.

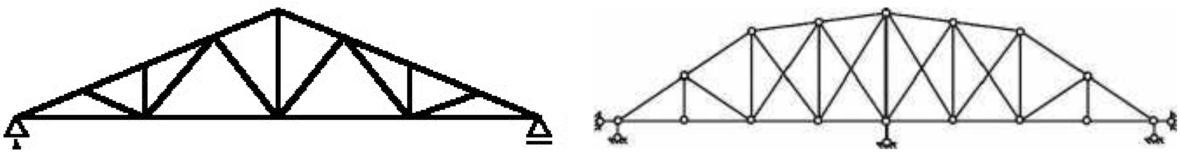

Figure 4. Statically determinate and indeterminate trusses

Truss Analysis. For each node within the truss, the sum of forces in both the x and y directions must equal zero. The method of joints is critical for understanding internal force distribution. The analysis procedure involves defining the truss structure, sketching each node with its associated member forces, applied forces, and reaction forces. It is essential to follow a consistent convention for force directions. By summing the forces at each node and setting them to zero, we can derive the unknown member and reaction forces. This step is crucial for verifying the overall equilibrium of the structure. Forces in either of the two directions at each node is equal to zero ($\sum Fx = 0$ and $\sum Fy = 0$). The method of joints is highlighted in Fig. 5.

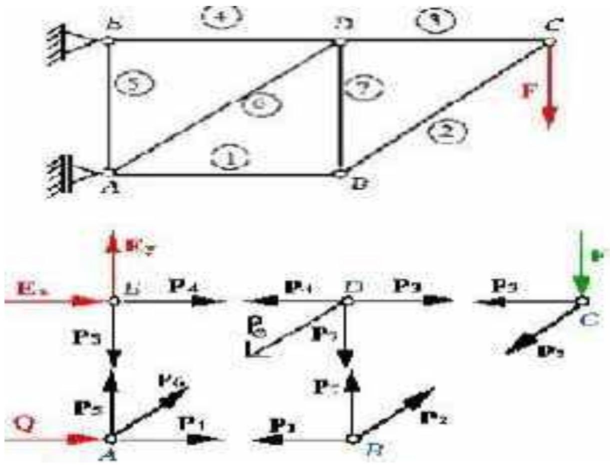

Figure 5. Internal force distribution inside a truss

Finally each node has its own applied force absence of the force. Pj , which can be zero. The procedure for analyzing a truss is as follows. Define the truss as described in the previous section. Draw each node separately including the member forces and if relevant, the applied forces and reaction forces on the node. By convention, we draw the direction of the member forces away from the node (see also Fig. 5). This does not mean that all forces are tensile. Compressive forces will come out negative. The reaction forces should be drawn in the positive axis directions and applied forces should remain in their original direction! Sum all the forces per node and per direction and equate them to zero for equilibrium. Solve the obtained equations from the previous item to get the unknown forces (notice that in case of a statically indeterminate truss, you would have too few equations!), both member and reaction forces. Check global equilibrium to see whether the reaction forces come out right. This gives additional confidence in the solution.

Notice that if the convention of drawing the unknown member forces away from the node is used, the compressive member forces come out negative automatically.

Now that the member forces are known, the member stresses using

can be retrieved

$$\sigma = \frac{P}{A} \tag{2}$$

Notice that only the cross-sectional area itself is needed for the calculation of the member stress, so the shape of the cross section, albeit a square or a circle, is irrelevant. Also notice that since a truss member can only take normal forces, only normal stress is calculated, so no shear stress is present in a truss member.

**Summary.** As the price of crude oil continues to soar, airlines are under increasing pressure to find innovative ways to minimize fuel costs, with the adoption of light weight aerospace structures interior materials a key focus for many operators [2].

Developers and manufacturers for the airplane interiors segment, said that nearly all carriers – even low-cost airlines – are looking for ways to run their operations more efficiently with

- out compromising their services in the ultra-competitive industry. ‘Fuel costs are spiraling for the entire industry, which is having a significant impact on many operators’ bottom lines. These rising operating costs are forcing airlines to get creative in their thinking and to examine new ways of reducing their fuel consumption or face extinction.”

Cabin weight reduction is one of the solutions, and something that is already being implemented. Airlines are pulling out all the stops to reduce their loads.

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