Minimum weight design of a wing box subjected to bending



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Minimum weight design of a wing box subjected to bending Abstract: Aircraft wing is one of the best examples of an efficient structural design. A variety of structural arrangements are possible to satisfy design goals. The endeavour is always to arrive at a minimum weight of a wing structure for a given set of design conditions. The main load carrying structure of a wing is the torsion box formed by front spar, rear spar, and top spar & bottom skins. In the preliminary design stages an effect is made to arrive at an efficient design of this box –structure.

The load carrying capacity of this box structure is largely controlled by the buckling of the compression cover plate. In order to get a minimum weight design of such a box the compression cover skin and its support arrangements are to be selected so as to give highest buckling stress. In this project an ideal box beam representative of a wing torsion box will be considered for a detailed analysis. The box beam subjected to a bending moment, various structural arrangements will be considering in order maximising the buckling stress.

An analytical formulation is developed to obtain the minimum weight of the box design charts will be developed based on this formulation. A FEM & FEA route will be employed to correlate with the analytical predictions. Introduction Aircraft structure is one of the finest examples of optimum structural design. Beginning with Wright brothers first flight the covering was of fabric material for the aircraft. With the advancement of our structural concepts fabrics gave way to stressed skin design which continues even today. Airframe is essentially a semi-monologue structure: a thin skin of orthogonally stiffened to resist the externally applied load by developing internal stresses distributed uniformly over large areas. These skins are very efficient in carrying in plane tensile loads. But they are relatively weak in carrying compression and shear loading thin skin structures are prone to the phenomenon of buckling. This practically restricts their ultimate load carrying capacity. Aircraft wings, fuselage and control surfaces primarily resist externally applied load by beam action.

In flight the wing top surface too is subjected to compression. In fact the static design limiting consideration is the buckling and subsequent failure of stiffened skins of the airframe. In a multiple load path compressive load carrying structural component, once buckling initiates in any one of the elements, other elements are not develop their full load carrying potential. There for an efficient and minimum weight design, a multiple load path structure must be designed to fail simultaneously at the design ultimate load.

For an efficient design of a transport aircraft wing to have a minimum weight for a given design ultimate bending moment the wing top skin must be sized to have the highest buckling stress possible. A uniformly thick skin without any lateral support cannot develop high buckling stress. A number of support arrangements are utilized to maximize the buckling stress. Typically in a transport aircraft wing, transverse supports are provided by the ribs and this enhances the buckling stress of the wing top skin. A typical longitudinal section of a wing is shown below the rear spur and the top and bottom skin covers.

A rear aircraft wing buckling analysis will require a numerical solution approach through a FEM and FEA route. On the other hand closed form analytical solution is possible only for simplified geometry and simple loading condition. These closed form solution are extremely important to develop our understanding of the structural response of the wing structure. With this view in focus, we will consider only the torsion box of the wing structure to be carrying the entire wing loading. This is the box formed by the front spur,

In an actual wing this box is of variable cross section designed to carry varying bending moment along the span however in our simplified model we will assume the torsion box to be a box beam of constant cross section. In addition are further assuming that this box beam is subjected to a constant bending moment. Our aim is to develop a multiple rib support system in order to arrive at a minimum weight design of this multi-rib box beam for a given design bending moment. A longitudinal section of this idealized multirib box beam is shown here

The box beam has a length L, width W and height h. It is subjected to a design ultimate bending moment M. Assuming that the bending moment is resisted by the top and bottom skin of the box, the uniform axial load per unit width is given by N = M/hW. There are four geometrical variables; 1) ts, the thickness of the compression cover, 2) tt, the thickness of torsion cover, 3) tr, the thickness of the rib and 4) Lt, the rib spacing which have to be sized such that the box develops the highest buckling stress at the applied stress level and fails. Scope of the present investigation

The aim of this investigation is to explore various design options in sizing a multi-rib box beam subjected to a constant bending moment. Two approaches will be followed for this the first one is an analytical study where in closed form solutions will be derived for the minimum weight design for a given design condition (M, h and w) for the box beam. The suitability of design options will be evaluated as a function of a non-dimensional loading parameter (M/Eh2w). In the second approach, buckling analysis will be carried out via a finite element route in order to validate the analytical predictions from the first approach.

After this validation, more realistic wing boxes will be analyzed numerically in this route in order to understand the importance of idealization followed in the first approach. The first approach requires a thorough understanding of the buckling phenomenon. The top cover of a wing box beam is a long and wide plate. For all practical purposes it will buckle as a wide column where the critical buckling stress is given by the Euler's buckling formula This will be an unacceptably low value. In order to increase the buckling stress, ribs are employed with provide lateral support to the compression cover plate along their lines of attachment.

Various possible buckling modes can occur which are briefly discussed below If the flexural rigidity of the tension cover is very low, the box can buckle as a whole. If the tension cove is flexural very stiff and the ribs are very weak then the buckling pattern will be as shown here As the deflection stiffness of the ribs increase the buckling pattern changes forming more than one half sine waves over the length of the box as shown in the next figure Here the

ribs are represented as deflectional springs and the buckled wave form is https://assignbuster.com/minimum-weight-design-of-a-wing-box-subjectedto-bending/ very much exaggerated. The idea here is that the ribs are not stiff enough to provide nodes at their location.

This is illustrated in the next figure The ribs are just stiff enough to enforce nodes along their lines of attachment with the skin. The effective length of buckling = rib spacing and the buckling stress is the highest. Even if we increase the rib stiffness higher than this value, the buckling stress cannot increase any more as the effective length cannot be less than the rib spacing. Therefore for a minimum weight design of a multi-rib box beam it is necessary to provide just the right stiffness to the ribs such that they perform as effectively rigid supports to enforce nodes at their locations this is easily said than done.

For a given multi-rib box beam of height h and width w and length L subjected to a design ultimate bending moment m, a minimum weight design can be achieved by 1) Selecting the rib thickness tr such that it behaves as an effectively rigid support to enforce nodes at its location making the effective column length spacing, Lt 2) Selecting the skin thickness such that buckling stress is a maximum. 3) Making the buckling stress equal to the applied stress corresponding to M and all of those depend on the flexural rigidities De and Dt of the compression and tension cover plates.

In order to achieve this scope of this investigation will be as follows The ribs are represented as linear springs with a spring constant K. a column of length Lc as considered with a large number of springs equally spaced Lt Inches apart within Lcr. The discrete spring reactions are converted to distributed elastic reactions q (lb/inch) so that the problem reduces to a column under distributed lateral support as shown here For the column under elastic support the buckling problem is solved in a closed form where the load p is expressed as a function of k, Lt, and Lcr.

For a given values of k and Lt this expression for p can be minimized with respect to Lcr to determine the critical buckling load Pcr. This critical load becomes a maximum by selecting the value of k and Lt such that Lcr becomes equal to Lt. It is then possible to derive explicit expressions for ts, tr and Lt in terms of m, h and w which gives a minimum weight design. This completes the phase of the investigation. In the second phase a finite element model of the box beam will be developed and buckling analysis will be carried out to validate the analytical solutions.

Literature survey Multidisciplinary Design Optimization (MDO) techniques were successfully applied in sizing the wing boxes of the newly developed Fairchild Dornier regional jet family. A common finite element model for the whole aircraft was used for the static and aero elastic optimization and analysis purposes. A detailed design model in the order of thousands of design variables was constructed. All relevant sizing requirements for structural strength, aero elastic behaviour and manufacturing, resulting in over 800, 000 constraints, were applied under all loading conditions.

Many auxiliary tools for automating the process of preparing the huge amount of required input data, as well as the rapid assessment of results, were developed. Most of these tools were developed in close coordination with the MSC Software GmbH, since the MDO implementation process is

cantered around the optimization procedure in MSC. Nastran SOL 200. A new MSC. Nastran feature called External Server was utilized to integrate company specific wing buckling constraints into the Nastran optimization loop.

An independent and comprehensive analysis of the conceived wing box's structural sizes confirmed the validity of the results. A method of estimating the load-bearing fuselage weight and wing weight of transport aircraft based on fundamental structural principles has been developed. This method of weight estimation represents a compromise between the rapid assessment of component weight using empirical methods based on actual weights of existing aircraft, and detailed, but time-consuming, analysis using the finite element method. The method was applied to eight xisting subsonic transports for validation and correlation. Integration of the resulting computer program, PDCYL, has been made into the weights-calculating module of the Aircraft Synthesis (ACSYNT) computer program. ACSYNT has traditionally used only empirical weight estimation methods; PDCYL adds to ACSYNT a rapid, accurate means of assessing the fuselage and wing weights of unconventional aircraft. PDCYL also allows Flexibility in the choice of structural concept, as well as a direct means of determining the impact of advanced materials on structural weight.

Using statistical analysis techniques, relations between the load-bearing fuselage and wing weights calculated by PDCYL and corresponding actual weights were determined. A User's Manual and two sample outputs, one for a typical transport and another for an advanced concept vehicle, are given in the appendices. Figure 3 shows the lower panel, the spars and the internal https://assignbuster.com/minimum-weight-design-of-a-wing-box-subjectedto-bending/

ribs of the outer wing box. The panels consist of a skin stiffened by rectangular stringers. The number of stringers decreases from inboard to outboard due to wing taper. Ribs are connected both to spars and panels.

The panels and spars carry global bending and torsional loads, whilst the primary function of ribs is to stabilize the whole structure and transfer the local air load into the wing box. Since the panels and the spars are machined from solids, the sizes of skin and stringers can change between each pocket surrounded by two stringers and two ribs. It is even possible to have a varying skin thickness or varying stringer height within a pocket to provide the locally required strength and stiffness with a minimum weight. This results in several thousands of independent parameters defining the whole wing box design.

The level of meshing detail of the wing model is shown in Fig. 4. This model is the same inite element model that is typically used for sizing by traditional methods. The wing box odel mainly consists of Shell and Beam elements representing skin and stringers/stiffeners, respectively. The whole wing model with its major substructures (centre, inner and outer wing) is given in Fig. 4. Combining wing box with fuselage and empennage FE models results in a WAM of approximately 250, 000 degrees of freedom. A finite element model common to the stress, aero elastics and the MDO group is used.

This FE model satisfies the requirements of all groups involved. Harmonization of the initially different FE models proved to be very important to allow rapid and efficient exchange of data between all groups within the MDO process. Wing Contents Providing lift is the main function of

the wings of an aircraft. The wings consist of two essential parts. The internal wing structure, consisting of spars, ribs and stringers, and the external wing, which is the skin. Ribs give the shape to the wing section, support the skin (prevent buckling) and act to prevent the fuel surging around as the aircraft manoeuvres.

They serve as attachment points for the control surfaces, flaps, undercarriage and engines. The ribs need to support the wing-panels, achieve the desired aerodynamic Shape and keep it, provide points for conducting large forces, add strength, prevent buckling, and separate the individual fuel tanks within the wing. There are many kinds of ribs. Form ribs consist of a sheet of metal, bent into shape. Plate-type ribs consist of sheetmetal, which has upturned edges and weight-saving holes cut out into it. These ribs are used in conditions of light to medium loading.

Truss ribs consist of profiles that are joined together. These ribs may be suitable for a wide range of load-types. Closed ribs are constructed from profiles and sheet-metal, and are suitable for closing off sections of the wing. This rib is also suitable for a variety of loading conditions. Forged ribs are manufactured using heavy press-machinery, and are used for sections where very high loads apply. Milled ribs are solid structures, manufactured by milling away excess material from a solid block of metal, and are also used where very high loads apply.

The stringers on the skin panels run in the length of the wing, and so usually need to bridge the ribs. There are several methods for dealing with this problem. The stringers and ribs can both be uninterrupted. The stringers now run over the rib, leaving a gape between rib and skin. Rib and skin are indirectly connected, resulting in a bad shear load transfer between rib and skin. The stringers can be interrupted at the rib. Interrupting the stringer in this way certainly weakens the structure, and therefore extra strengthening material, called a doubler, is usually added.

Naturally, the stringers can also interrupt the rib. The stringers now run through holes cut into the rib, which also causes inevitable weakening of the structure. The ribs also need to be supported, which is done by the spars. These are simple beams that usually have a cross-section similar to an Ibeam. The spars are the most heavily loaded parts of an aircraft. They carry much more force at its root, than at the tip. Since wings will bend upwards, spars usually carry shear forces and bending moments. Aerodynamic forces not only bend the wing, they also twist it.

To prevent this, the introduction of a second spar seems logical. Torsion now induces bending of the two spars, which is termed differential bending. Modern commercial aircrafts often use two-spar wings where the spars are joined by a strengthened section of skin, forming the so-called torsion-box structure. The skin in the torsion-box structure serves both as a spar-cap (to resist bending), as part of the torsion box (to resist torsion) and to transmit aerodynamic forces. Wing Functions and Attachments It is usually hard to attach the wing to the fuselage.

There is usually a third piece of wing contained within the fuselage. The connection of wings and fuselage are always by way of very strong and heavy bolts. The bolts that are used must be much stronger than necessary, thereby having sufficient lifetime. Stringers are attached to the wing skin, and run span-wise. Their job is to stiffen the skin so that it does not buckle when subjected to compression loads caused by wing bending and twisting, and by loads from the aerodynamic effects of lift and control-surface movement. In most aircraft, the wing skin performs several tasks.

It gives it the aerodynamic shape, it carries a share of the loads, it helps to carry torsional loads, it acts as fuel tanks and allows inspection and maintenance. Using the skin to carry part of the loads is called stressed skin. Almost all aircraft have their wing structure made entirely in metal, or a mixture of metal and composite. The skin may be fixed to the internal structure by rivets or bonding. The volume between the spars is often used for storing fuel. An alternative to attaching stringers to the skin for stiffness is a machined skin, in which the skin, stringers and spar flanges an be machined from a single piece of alloy, called a billet. Advantages are that less riveting is required, resulting in a smoother surface, lighter and stronger structures are possible, construction faults are less likely, less maintenance is required and easy inspection is possible. However, the costs are relatively high, and replacing parts is difficult. In commercial aircrafts usually around 25% of the aircraft's maximum operating weight is for fuel storage. Usually most or all of the fuel is stored in the wing, which is divided into several tanks, each one usually having its own pumps.

This allows fuel to be moved between tanks in flight, which changes the trim of the aircraft to minimize drag. Flaps are fitted at the trailing edges. Light aircraft usually have simple flaps or none at all. Larger aircraft have the

more complex split flap or Fowler flap. Most large transport aircraft have https://assignbuster.com/minimum-weight-design-of-a-wing-box-subjected-to-bending/

double-slotted Fowler flaps. Leading-edge flaps, called slats, may be added to increase lift even further. Flaps and slats increase both lift and drag, both being advantageous for landings. Spoilers are fitted to the top surface of the wing.

When operated, which is usually at touchdown, spoilers increase drag and reduce lift. Wing Loads and Other Loads A wing produces lift as a result of unequal pressures on its top and bottom surfaces. This reates a shear force and a bending moment, both of which are at their highest values at the point where the wing meets the fuselage. The structure at this point needs to be very strong, to resist the loads and moments, but also quite stiff, to reduce wing bending. The wing will be quite thick at this point, to give the maximum stiffness with minimum weight.

An advantage of wing-mounted engines is that their weight is close to the area in which the lift is produced. This reduces the total fuselage weight, reducing the shear force and bending moment at the wing root. A correct position of the fuel-load also results in a smaller moment at the wing root. Fuel load close to the tips reduces this moment. Therefore the order in which the tanks are emptied is from the root to the tip. The tailplane, rudder and ailerons also create lift, causing torsion in the fuselage. Since the fuselage is cylindrical, it can withstand torsion very effectively.

Also the landing gear can generate side loads causing torsion of the fuselage. But the main force caused by the landing gear is an upward shock during landing. For this, shock absorbers are present, absorbing the landing energy and thus reducing the force done on the structure. The extra work

generated during a hard landing results in a very large increase in the force on the structure. This is why the absorbers are designed with a safety margin by taking into account a vertical speed 1. 25 times higher than the maximum vertical speed during landing.

Work planned 1) Define the maximum weight design formulation of the multi-rib box beam. 2) Develop the idealized column models with distributed reaction forces 3) Solve this problem to get closed form solution for the critical buckling load 4) Derive expression for minimum weight of the box beam 5) Obtain expression for ts, tr and Lt 6) Generate design charts for the weight of the box as a function of loading parameter 7) Validation through finite element formulation 8) More realistic box beam analysis through FEA. References 1] Honlinger. H. G. (DLR), Krammer, J. (DASA), Stettner, M. (DASA): MDO Technology Needs in Aeroelastic Structural Design. AIAA-98-4731, 1998. [2] Ribour, F. : Analysis of Aeronautical Components from MSC/NASTRAN Integrated Finite Element Models Management to Specific Stressing. Paper No. 2001-145 of the Worldwide Aerospace Conference & Technology Showcase, Toulouse , April 8-10, 2002. [3] Hornlein, Herbert, Schittkowski, Klaus: Software Systems for Structural Optimization. Basel, Boston, Berlin: Birkhauser Verlag 1993.