RECYCLING OLD WEIGHT ASSESSMENT METHODS AND GIVING THEM NEW LIFE IN AIRCRAFT CONCEPTUAL DESIGN

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Abstract

Aircraft conceptual design is an iterative process, which favors the use of weight equations for initial weight assessment. Some weight equations can be found in handbooks while others are heavily guarded company secrets. Several weight equations are constrained or limited in use to either military or civil applications or to certain weight classes, layouts etc. This might cause trouble if the designer is less observant about the validity of constraints in used weight equations.

In the best of all worlds the aircraft designer would like to possess a tool which incorporates a logically built up weight assessment process for structures and which apart from being iterative, should be adaptable to the design, needs and layout of the specific aircraft on the drawing board.

This approach essentially means backing off from weight equation dependence, but is this really possible to do?

This paper aims to find out.

1 Introduction

Sweden continuously runs aircraft research programs, so-called NFFP programs. NFFP is a Swedish abbreviation for national aircraft research projects, each typically running between two to four years. The research programs involve industry as well as universities. The state finances 50% of the cost, while industry has to come up with rest. The industries involved are Saab Aeronautics and Volvo Aero. Four research programs have been covered so far with the fifth program currently running. Saab Aeronautics and Linköping University have cooperated in all of them. In the current NFFP5 project "Concept Methods for Deriving Air Vehicles", Saab and Linköping University are working closely together developing aircraft conceptual design tools for Saab Aeronautics in the future. The current project involves three major work packages:

- Develop better weight assessment methods for structures and systems.
- Develop a generic and parametric aircraft conceptual design model in CATIA
- Develop conceptual design programs and parametric CATIA models for basic aircraft systems

This paper concentrates on the first of these work packages, i.e. weight assessment methods for structures.

1.1 Background

The structural weight assessment problem surfaced at Saab Aeronautics some years ago when Saab studied a small jet powered air ambulance aircraft. The aircraft was designed in accordance with FAR 23/EASA CS23 rules, i.e. limited to approx. 5600kg in Max Take-Off Weight (MTOW). The aircraft was designed for comparably short take-offs and landings and had three basic roles: air ambulance (main role), carry passengers (up to nine) or being a small package freighter.

Market research showed that the biggest challenge in designing air ambulance aircraft is ergonomics, i.e. how to avoid people hurting their backs while loading and unloading patients. Existing air ambulance aircraft are usually not purpose built. They are refurbished smaller sized passenger aircraft, usually designed with small cross-sections and side placed doors. This design is of no help when loading and unloading patients because the design basically means lots of twisting and turning when doing so.

Therefore there was a profound interest from the market side when the idea of a rear placed belly door was proposed. Sufficient cabin space as well as a pressurized cabin (higher pressure than usual, for patient safety) and good seating arrangement (placement relative to the litters for ease of medical care) was on the list of requirements as well.

Design work started and different concepts were evaluated. Very soon work focused on fuselage structural design, door placement and which door configuration to use. We wanted to be able to evaluate the weight differences between various door arrangements and placements, since it was commonly felt that all up weight would be a close call in some cases.

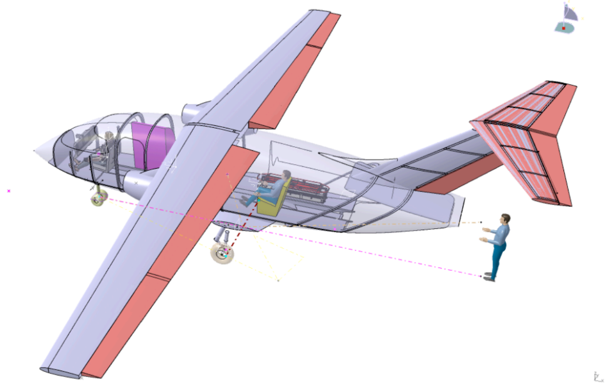

Fig. 1. Aircraft general layout

The problem was that Saab lacked good methods for evaluating fuselage structural weight in such detail. It's not common to use detailed structural weight analysis in conceptual design; such methods are used in later phases.

After some research a useable method was found in: The Fuselage Weight Penalty Method, as proposed by Torenbeek [1] for civil applications.

2 Weight Assessment Methods

2.1 The Fuselage Weight Penalty Method

The Fuselage Weight Penalty Method calculates a so-called fuselage gross shell weight in the first step. This is the weight of an ideal fuselage in ultimate bending. Ideal in this case means a fuselage without holes and cutouts (every hole and cutout being smoothly covered). Next step is to add penalties created by cutouts such as doors, windows, wing attachments, landing gear wells etc. These weight penalties include weight assessment for reinforcements around cutouts as well as weights for doors and windows.

The Fuselage Weight Penalty Method turned out to be of great help in evaluating the different door arrangements in the air ambulance aircraft

2.2 SAWE Methods

The Society of Allied Weight Engineers (SAWE) is an organization for weight engineers and aircraft weight engineers in particular. SAWE has existed for a long time and over the years built up a large and very comprehensive database.

The main target for SAWE methods is the preliminary design phase, i.e. the phase, which immediately follows the conceptual design phase. In the preliminary design phase the design is progressively getting more detailed as it matures and thus requires more people to be involved. Weight engineers are heavily involved in preliminary- and detail design, but not in conceptual design. Why is that?

In conceptual design few people are involved and the designers are using iterative design programs. At this stage weight calculations have to be automotive and rapid, which explains the popularity of weight equations.

Today the two phases, conceptual- and preliminary design are more or less merged. Thanks to the evolution in tools, this situation is still possible to handle.

One such useful tool is CATIA, which is a 3D CAD program used extensively in all phases of design. Its parametric approach has made seamless design possible. We can use the same conceptual design model in all phases of design and analysis. Never thought possible before, but now the real thing, saving time and costs in all phases.

Consequently time seems right to bring in a preliminary design tool for weight calculations into conceptual design. This will be a challenging task but by no means impossible.

3 How the Proposed Method Works

3.1 The Basic Idea

Research into the SAWE database revealed some useful methods, especially the method presented by Hammitt [2]. The method primarily deals with military aircraft structures, but as quoted in the paper: “does not exclude other applications as well”.

The method analyses both fuselage and wing structural weight. It follows the same procedure as in Torenbeek [1], i.e. first step: calculate fuselage/wing gross weight, second step: add penalties for cutouts.

So the idea came up to combine the two methods. Both methods will have to be used partly separately when applying weight penalties, but when calculating the initial fuselage/wing gross shell weight, a similar approach can be taken in both civil and military applications.

The reason for the approach is due to the fact that civil and military aircraft differ in their structural build up. For instance doors in civil aircraft are openings used to embark or disembark passengers or cargo. So the structural load path has to be carried around the door with the help of surrounding reinforcements.

In military applications internal weapon bays are similar in design and build up as cutouts for landing gears. Structural stiffness is lost when the cutout is made, but stiffness is regained by surrounding it with load carrying structures. In other words a structural pocket is being created. A door finally closes the pocket and keeps up the aerodynamic shape.

So in conclusion, the difference is in how a door is being used, i.e. either to cover a structural pocket or one which you can pass through. This decides the way the reinforcement has to be made and hence also which weight penalty to pay.

3.2 First Step: Calculating Fuselage Gross Shell Weight

The Fuselage gross shell weight calculation is based on the load being applied. The designing case for both military and civil aircraft is a pull up maneuver. The ultimate load case is considered only. For military aircraft that translates into design weight times an ultimate load factor. In the civil world, design weight equals Max Zero Fuel Weight (MZFW) times an ultimate load factor, the latter being decided by regulations, maneuvering or gust.

The fuselage can be treated as a bending beam resting on two supports. The first support is positioned at the forward wing attachment and the second at the rear attachment. In civil aircraft the position of the attachments coincides with the positions of the front and rear spars, i.e. where the spars pass the fuselage longitudinally. In a military aircraft there could be several spars and attachments in a wing. The beam model needs two. It’s not that easy to know which two to choose and where to position them.

The authors suggest the following procedure:

- Position the Mean Aerodynamic Chord (MAC). Then centre of lift will be close to 25% of MAC at low subsonic speed, gradually moving back to 40-50% at supersonic speeds.
- Position the resulting lift force as point loads in both these MAC points.
- Position your bending spars where the wing section is as thickest chord wise.
- Figure out which two of the spars, which will be the most heavily loaded by eyeballing.

Those two spar positions are then chosen as the forward- and rearward attachments to be used in your bending beam model.

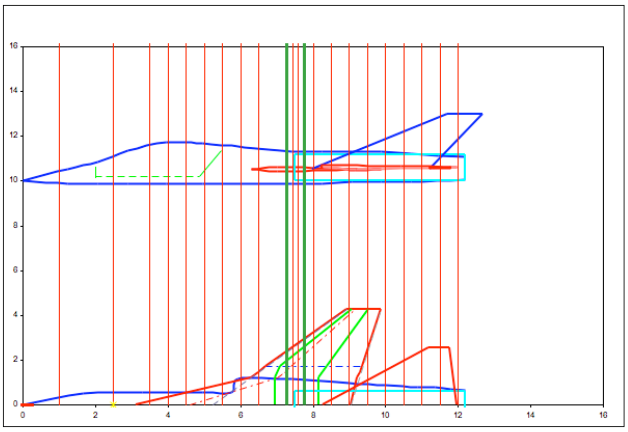

Fig. 2. General view of an example a/c with lengthwise divisions into stations and zones

The fuselage is divided into several stations along the fuselage, almost equally spaced forward and aft of the wing attachments (supports).

The distance between two neighboring stations makes up a zone. The zone´s main function will be explained later. The individual loads are either considered as point loads, distributed loads or partly distributed loads, positioned at appropriate places along the fuselage. The effect in shear and bending is thus taken into account at every station and summed up

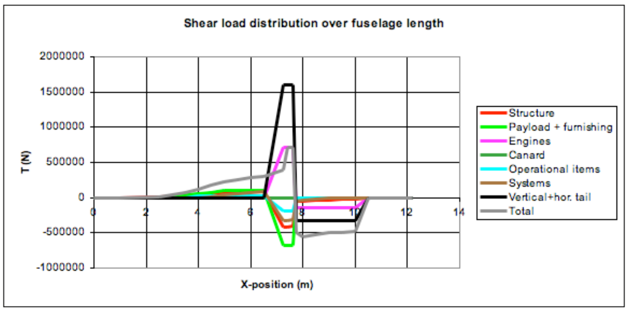

Fig. 3. Shear load distribution over fuselage length

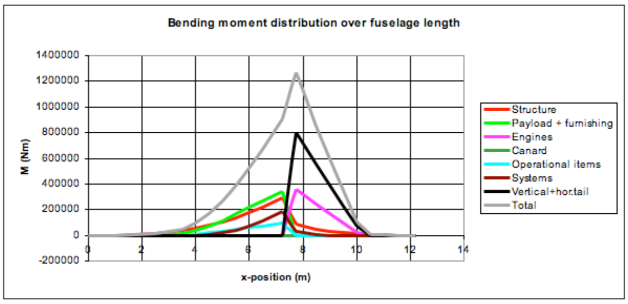

Fig. 4 Bending load distribution over fuselage length

Using Hammitt [2] the bending and shear load distribution sizes the skin of the fuselage. The skin is a smeared out, into an equivalent skin thickness comprising bending or shear material and distributed over the fuselage length. The equivalent skin has a minimum thickness, which then is sized up towards the attachments in accordance with the load distribution over the fuselage.

The result is a weight distribution in kg/m over the fuselage length, which then is summed up and results in the final fuselage gross shell weight. As mentioned this is the weight of an idealized fuselage since it assumes all cutouts being smoothed over.

3.3 Second Step: Calculating Fuselage Weight Penalties

In the second step it is vital to know where the different cutouts are being positioned lengthwise. For example a cutout for the nose gear wheel well, positioned in the nose will be less demanding weight wise compared to a cutout for the main gear positioned closer to the middle of the fuselage. So the position of the cutout lengthwise is important and has a major influence on how large the weight penalty will be. The user has to identify in which zone(s) (calculated from the nose in Fig.2) the cutout is placed to be able to calculate the weight penalty.

Total weight penalties are then calculated by following the procedure in Hammitt [2].

Now this may be true for military aircraft, but regarding civil aircraft the approach differs slightly. In this case the method of Torenbeek [1] is combined with the method of Hammitt [2].

In both cases the end result is the sums of fuselage gross shell weight in step 1 and the resulting weight penalties in step 2.

One thing to notice is that the method of Hammitt [2] lacks weight assessments for the inlet and engine ducting. The weight penalties of these items have to be added to complete fuselage weight calculations for military aircraft.

3.4 Third Step: Calculating Wing Gross Shell Weight

The wing is calculated as a bending beam in a similar way as the fuselage, with the supports being placed at the fuselage sides. The same load case is used as in the calculations for the fuselage. All items placed inside or on the wing, such as wing structure, systems, engines, main gear etc. are treated as point loads, partly distributed loads or distributed loads. These loads combined with wing lift are summed up in a total shear- and bending load distribution for the wing.

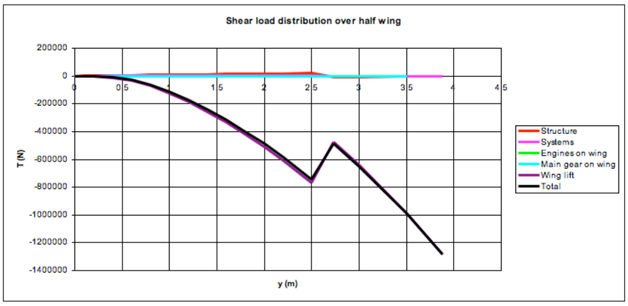

Fig. 5. Shear load distribution over half span

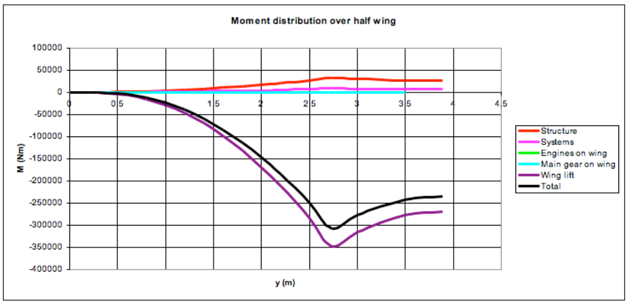

Fig. 6. Bending load distribution over half span

The procedure for calculating the gross shell weight follows Hammitt [2]. The gross shell weight of the wing is calculated for the structural part of the wing, i.e. the wing box only. The weights of the leading- and trailing edges are then added. The end result depends on the geometry of the wing box, wing sweep and the loads being applied.

3.5 Fourth Step: Calculating Wing Weight Penalties

The procedure for calculating wing weight penalties follows Hammitt [2], but has been complemented in some parts by Torenbeek [3], where Hammitt´s method is lacking.

4 Benchmarking

The proposed method currently works with metal fuselages as well as with metal or composite wings. The composite approach regarding the wing is made in accordance with Lewis [4].

The method has been used to calculate the fuselages and wings of the Saab 340, Saab 2000 and the Gripen 39C fighter for comparison with real structural weights. The results were encouraging, within 2% for each item.

5 Discussion

Are weight equations something of the past?

No not really. This method largely builds on Hammit´s method and that method incorporates a number of graphs (built on experience and tests), which the authors have translated into equations to make them work in an iterative environment. So we are still into weight equations, but let’s put it in another way: we don’t use weight equations globally, only locally.

6 Conclusions

The proposed method requires more preparations of the design from the point of view of the designer, thus requiring more input data, but the pay off is by far overshadowing the extra work needed. It's by far a more realistic approach; even minor changes can be introduced and traced. This increases the sensitivity in the process. The process is logical and is closely tied to the actual design and layout of the aircraft, which is exactly what we strived for. On top of that the benchmarking process shows encouraging results as well.

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