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Multi-Disciplinary Optimisation Methodology for Aircraft Load Prediction

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***Abstract*—**The paper demonstrates a methodology that can be used at an early design stage of any conventional aircraft. This research activity assesses the feasibility derivation of methodology for aircraft loads estimation during the various phases of design for a transport category aircraft by utilizing potential of using commercial finite element analysis software, which may drive significant time saving. Early Design phase have limited data and quick changing configuration results in handling of large number of load cases. It is useful to idealize the aircraft as a connection of beams, which can be very accurately modelled using finite element analysis (beam elements). This research explores the correct approach towards idealizing an aircraft using beam elements. FEM Techniques like inertia relief were studied for implementation during course of work. The correct boundary condition technique envisaged for generation of shear force, bending moment and torque diagrams for the aircraft. The possible applications of this approach are the aircraft design process, which have been investigated.

***Keywords*—**Multi-disciplinary optimization, aircraft load, finite element analysis, Stick Model.

I. Introduction

In the modern era of Aircraft design, preliminary design strategy based on requirements of reduction in lead-time, configuration trade-off, and accurate modelling and simulation. Design and development of any product is primarily dependent on accurate load prediction as it is the most important part of the product design. For aerospace industry, the prediction of flight loads becomes more significant as it is more challenging, costly and more time-consuming product development as compared to other products. Accurate loads prediction in a minimum time allows aerospace companies to focus on more iterations as well as novel design concept application and a reduction in overall product cycle time with improved product quality.

Aircarft structural sizing depends on the aircraft flight loads (due to manoeuvres and gusts) and aircraft ground loads (e.g. landing, turning, and braking). Aircraft designers aim to achieve minimum structural weight, whilst ensuring minimal possibility of failures during entire service life of an aircraft's operation and in-service life due to excessive stresses or deflections. Prediction of aircraft loads in the entire flight envelope is important part of this requirement.

Traditional development processes are not contributing a value addition for new product design. Virtual platforms are only the viable solution to meet current demands of customers and developers for aerospace. Using multi-disciplinary methodology and application of Finite Element Analysis (FEA) software enables effective analysis and real-life performance optimization of aircraft.

> "*A European Industrial Doctoral (EID) network is proposed to improve the prediction, and also the efficiency in calculation, of aircraft loads. The loads experienced by an aircraft in-flight (due to manoeuvres and gusts) and on the ground (e.g. landing, turning, braking) are the key elements in determining the structural sizing and hence its weight. Although the structural design must ensure that structural failure cannot occur at any point of an aircraft's operation due to excessive stresses or deflections, the aircraft weight must be as small as possible. If it were possible to obtain more accurate loads predictions than at present at the edges of the flight envelope and other critical points, and also to consider uncertainties in the calculations, it would be feasible to produce lighter aircraft designs which are more efficient and more environment friendly. A further requirement is to be able to turn around all the many required loads calculations much faster, enabling a much more thorough search of the possible design space, particularly for the novel aircraft configurations that are likely to occur in the future*" [2].

DLR also developed a series of tools for Virtual Aircraft Design and Testing based on High-Fidelity Methods [3]. Cooper et al. investigated a methodology for flight load prediction using multibody simulation [4]. The research provides a methodology for the creation of a structural model and force application and produces results. Shear force and bending moment were captured quite well and compared with validated data. Although the study achieved its intended outcome, further improvements are required to utilise it as commercial aircraft design tool. Major areas for improvements are

- Due to approximations and assumptions made, further research has to be done to assess shear forces, bending moment and tip deflection results better and validated through available data.
- Inclusion of Pilot or ECFS (Electronic Flight Control System) command.
- Inclusion of aero elasticity to incorporate the effect of change in forces due to structural deformation.

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II. Methodology

A. Overview of Methodology

Mostafa et al proposed a methodology for accurate development of stick model for DLR F-6 wing from 3D finite element model [5]. Elliott et al presented framework for aircraft load prediction through MDO [6]. Using software platform ASTROS (Automated Structural Optimisation System) they presented for 100+ seater passenger aircraft as case study.

Gazaix et al. [7] investigated possibility of application of Multi-disciplinary optimisation in preliminary design of aircraft. Enabling such a concurrent engineering process, MDO should be an efficient decision support tool for the designer.

This methodology uses commercial finite element analysis software applications in the context of flight loads prediction during the early phases of design for freighter/commercial aircraft. The methodology offers significant saving in lead time which results in more iterations and delivery of improved quality of product. In initial design phase, limited inputs are available for designers and the main challenge is to analyse large number of load cases with accuracy as well as analyse the effect of changes of various configuration and parameters. Techniques such as inertia relief have been studied and implemented as well as a thorough treatment of boundary conditions with an aim of producing representative shear force, bending moment and torque diagrams for the aircraft [8], [9].

This research is concerned with methodology but also move towards automation. The tool can be used to model an entire aircraft using beam elements with following features:

- Automatic generation of the aircraft beam model allowing for control of structural member's connection,
- Intuitive means to distribute the mass of the aircraft for different loading scenarios,
- Ability to apply loads to the beam elements in such a way that appropriate pitching moments are taken into account,
- Management of a large number of load cases,
- Generation of envelopes,
- Generation of reports describing assumptions, boundary conditions and results.

The methodology and its implementation have challenges in order to make the tool suitable for practical use of industries. During process of development, major challenges have been identified and most feasible solution obtained. Fig. 4 shows major challenges identified and their solution.

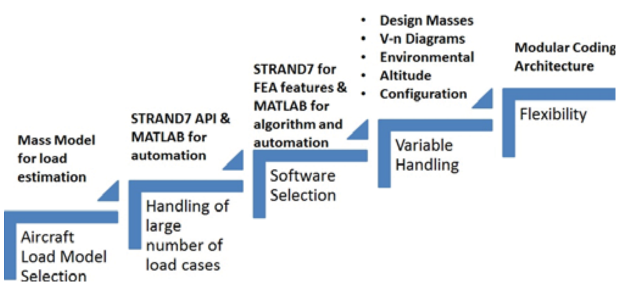

Fig. 1 Challenges and solution for implementation of methodology

B. Aircraft Mass Model Idealisation

Aircraft mass model [10] was idealised in form of nodes created at station. For fuselage nodes were created longitudinally at mass CG in equal intervals. The mass distribution was as per graphs derived from conceptual design [1]. The mass was distributed for different combinations as per conceptual design data. A comparison of mass distribution estimated from conceptual design and idealized aircraft was done for error proofing of mass distribution.

C. Air Load Prediction, Automation, and Validation

Since for initial design of structure, large amount of data is generated and handling of these data is very tedious task. To satisfy Airworthiness requirement and to ensure aircraft safe operation all possible combinations of mass, cg, altitude, configuration, and velocities need to be considered. Approximately 6000 load cases are generated for an aircraft. Manual creation of these load case is time consuming and difficult task. In order to minimize time, a MATLAB script was written which could generate possible load cases and calculate total air loads for steady level flight and manoeuvre flights as well as for atmospheric turbulence based on parameters like mass, cg, velocity, configuration, altitude etc.

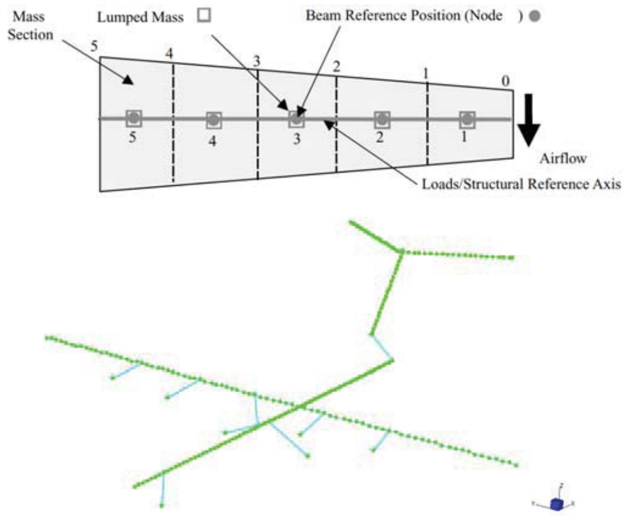

Fig. 2 Aircraft Mass Model Idealisation

D. Steady Level Flight: Case Study

Total 336 cases generated for steady level flight and loads were calculated through MATLAB program. MATLAB program output and F-14 load estimation through conventional method and formulation compared for sample load cases.

III. Result Validation

Figs. 6 and 7 represent comparison of shear force and bending moment distribution of wing over semi-span calculated from traditional method vs proposed methodology. The program shows that two of the three main quantities for flight loads, namely shear force and bending moment were captured quite well when compared to other validated data.

IV. Conclusion and Recommendations

The methodology has been developed and validated during research work. Aircraft beam model has been generated and mass of the aircraft for different loading scenarios has been distributed. Loads have been applied to the beam elements in such a way that appropriate pitching moments are taken into account. The research shows that methodology is capable of managing a large number of load cases. The methodology provides a tool for quick estimation of aircraft structural load. Time saving for overall cycle is major achievement of the methodology. In addition to this, the designer can generate the load spectrum and identify critical cases for structural design.

The simulation results of the model created have shown very promising results as shown.

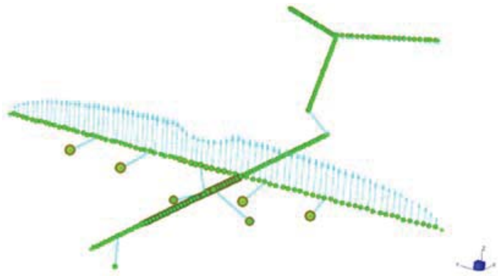

Fig. 3 F-14 Stick Model with Forces Applied

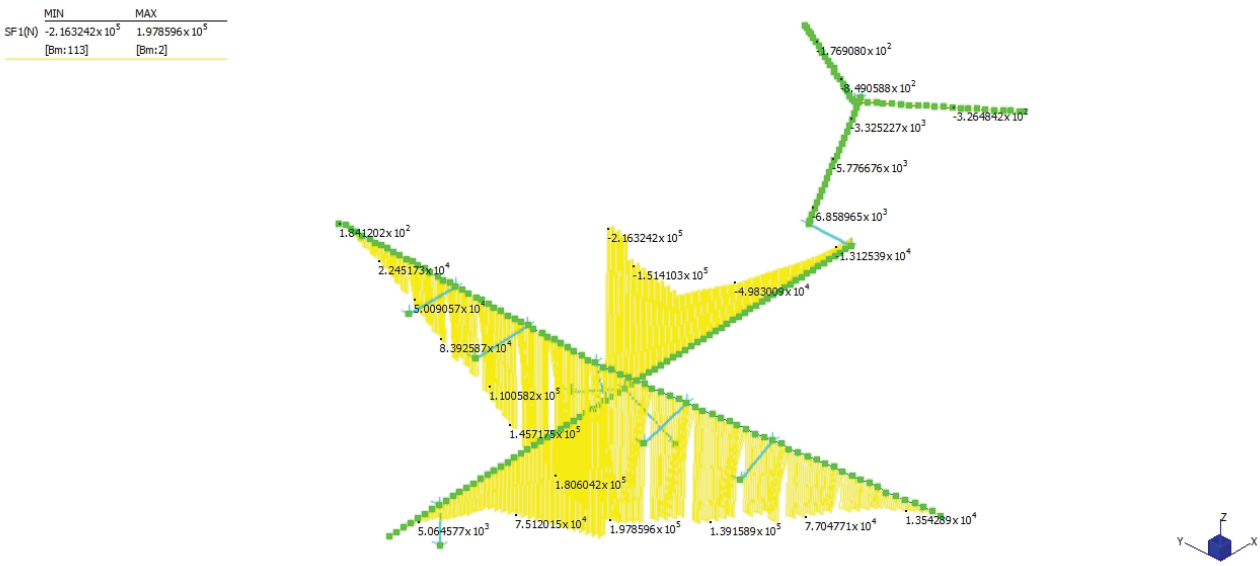

Fig. 4 Shear Force Diagram for Load case 1

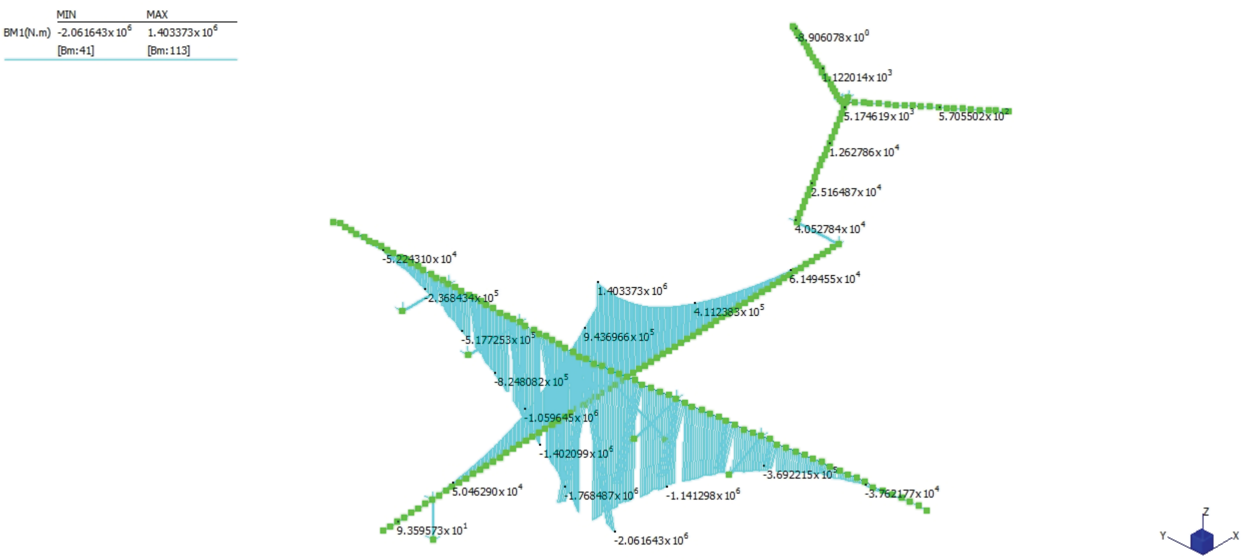

Fig. 5 Bending Moment Diagram for Load case 1

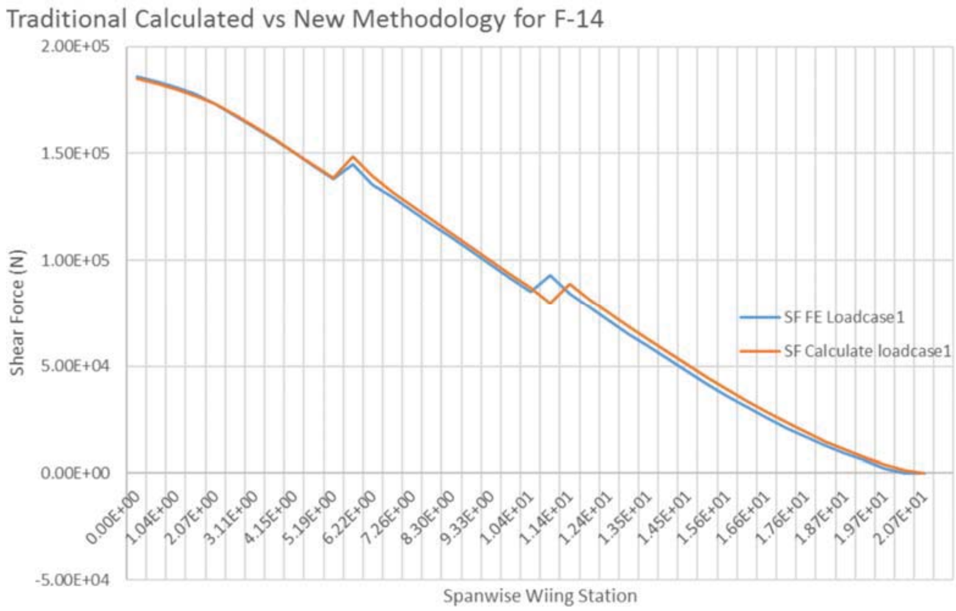

Fig. 6 Comparison of Shear force distribution over wing for same Wing Body Lift (Load case 1)

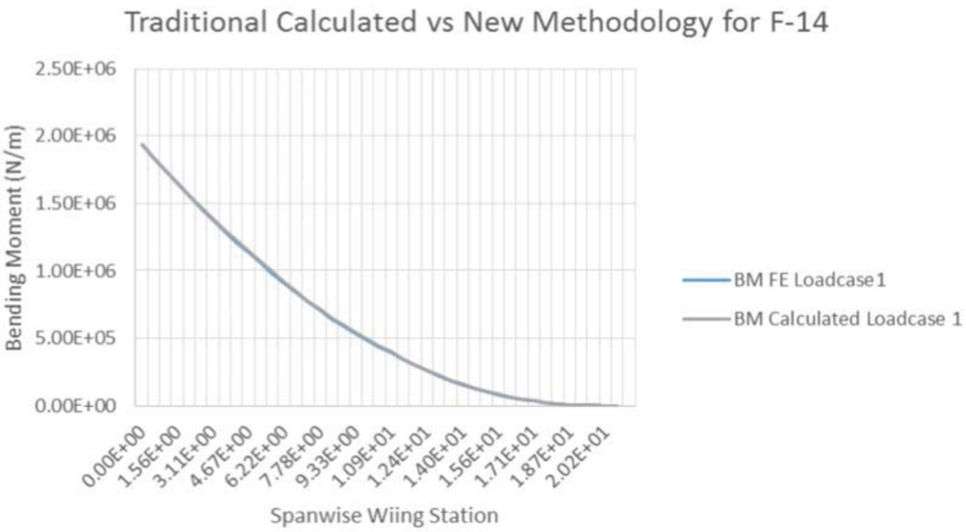

Fig. 7 Comparison of Bending Moment distribution over wing for same Wing Body Lift (Load case 1)

There is a lot of potential to use it in the context of flight loads. Further research could be done to assess the quality and accuracy on the basis of such requirements. As an improvement in future the author considers following recommendations:

1. The project delivers a methodology for finite element analysis beam model application for aircraft load prediction. The research shows that the mass model is sufficient to analyze structural loads for aircraft. For further study, the model can be converted into a stiffness model with accurate structural inertia properties. The correct idealisation of the structural properties gives a distribution of mass due to structure. The remaining mass like payload and fuel can be distributed and attached to structural nodes as lumped masses. This type of model can be used for aeroelasticity study and to estimate structural deflection.
2. The beam model is very useful for predicting structural loads during preliminary design to evaluate the merit of the design. As the mass distribution is dependent on wing, tailplane, fin sweepback, dihedral, etc., it can be used to study effect of these parameters on structural design.
3. Modular architecture programming provides scope for further expansion of this load prediction module. The output of the load prediction module can be used as input for the initial sizing of structural members. Modular architecture also provides flexibility for the user to integrate the program with other third party software. For example, aircraft load and wing lift distribution and

tailplane lift distribution generated from wind tunnel data or CFD analysis can be taken directly as input for the generation of the load spectrum.

4. The program developed is using the Strand7 application which is currently running on 32-bit environment. Hence it is compatible with 32bit MATLAB environment only. Also, the computing power of computers is one of main area of improvement. Strand7 API is not available for multithreading hence for running the total number of load cases, it requires a considerable amount of time. This time can be shortened with parallel computing method which currently Strand7 does not support.
5. The loading module is working for rigid airplane motion. The methodology can be used for flexible aircraft model generation. Currently loading is done with steady aerodynamics principle. Unsteady aerodynamics can be introduced in the model for aeroelastic study.
6. The methodology establishes and validates for major aircraft components such as wing, fuselage, tailplane, and fin. Control surfaces are not considered during methodology implementation and can be added further. The author tried to develop a methodology for loads prediction. In addition to that, MATLAB coding enables the automation of the process. There is further scope for improvements in the code.

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REFERENCES

[1] Prof Howard Smith, "Civil Multi-Purpose Air Freighter F-14 Project Specification," Cranfield university, 2014.
[2] CORDIS, "CORDIS Project summary Report, Project reference: 607911," 2013.
[3] J. Scherer, D. Kohlgrüber, F. Dorbath, and M. Sorour, "A Finite Element Based Tool Chain for Structural Sizing of Transport Aircraft in Preliminary Aircraft Design," Dtsch. Luft- und Raumfahrtkongress, pp. 1–11, 2013.
[4] Y. C. J. Lemmens, J. De Boer, M. Calvo-blanco, and J. Cooper, "Investigation of Flight Loads Prediction using Multi-Body Simulation," no. Vlm, 2014.
[5] M. S. Elsayed A., R. Sedaghati, and M. Abdo, "Accurate Stick Model Development for Static Analysis of Complex Aircraft Wing-Box Structures," AIAA J., vol. 47, no. 9, pp. 2063–2075, 2009.
[6] W. G. Elliott and B. R. Leigh, "Aircraft Loads Methodology for MDO Structural Dynamics and Materials Conference and Exhibit Seattle, Washington," Aerospace, no. April, 2001.
[7] A. Gazaix, P. Gendre, E. Chaput, C. Blondeau, G. Carrier, P. Schmollgruber, J. Brezillon, and T. Kier, "Investigation of Multi-Disciplinary Optimisation for Aircraft Preliminary Design," 2011.
[8] L. Liao, "A Study of Inertia Relief Analysis," in 52nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference Denver Colorado, 2011, no. 4–7 April 2011, pp. 1–10.
[9] M. A. Gockel, "Technical Application Note: Inertia Relief Analysis Using an Automated Support System, TAN 4002,".
[10] Wright Jan R and Cooper Jonathan E, Introduction to Aircraft Aeroelasticity and loads. England: John Wiley & Sons Ltd., 2007.