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KNOWLEDGE-BASED INTEGRATED AIRCRAFT WINDSHIELD OPTIMIZATION

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Abstract

Innovation is the key to new technology. At the "Division of Fluid and Mechatronic Systems, Linköping University", a framework for aircraft conceptual design is continuously developed. RAPID (Robust Aircraft Parametric Interactive Design) and Tango are knowledge-based aircraft conceptual design tools implemented in CATIA® and Matlab® respectively. The work presented in this paper is a part of RAPID, explores the method, and proposes a framework for fuselage optimization with a parametric, reusable and automated windshield with a focus on the pilot visibility for conceptual design. The geometry is initially propagated from CAD (CATIA®) to CFD (Ansys®) using CADNexus. Initial optimization implemented on a 2D geometry to find an appropriate angle for the struct. An overall optimization to minimize the drag and maximize the load taken by windshield struts depending on pilot's eye position, floor height and cockpit length performed. Methodology to automatically mesh using Fine^{TM}/Open with OpenLabs and Ansys®, as the number of surfaces increases or decrease throughout the design automation is also proposed and used during the optimization.

1 Introduction

Windshield design is one of the challenging task involving both aerodynamics and structures to work together. Flat panels (example, Airbus A320) and curved panels (example, Boeing 787) are the most common forms used for windshield and a combination of both (example, Boeing 747) can be seen. In this work, Flat panel Windshield optimization is performed. The flat panels, visibility pattern, frames, and windows encapsulated as templates, this information know-how stored in templates known as knowledge template. Through automation scripts, by the use of *"Engineering Knowledge language"*, these templates are called frequently until the desired result is achieved.

The framework provides an edge to the conceptual design phase. The design processes along with knowledge based templates and automation provide a fast graphical representation to the user/designer. The end result of this framework can intensify the project processes and scale back the time spent on redesigning the entire work or ever-changing present work. The user need not be skillful with CAD (RAPID [1, 2]); however, understanding the parameters and the way to attain the specific style would be enough. Fine^{TM}/Open with OpenLabs and Ansys® are utilized for creating two different approaches for the automatic meshing of the design automated geometry. The optimization framework involving design automation, aerodynamic analysis, and structural analysis will further enhance the design process.

2 Knowledge Based Engineering and System

Knowledge Based Engineering, interpreted as a reusable information that exists in a defined method/form; this knowledge is reused either manually or automatically and the whole process of using existing knowledge such that it adapts to the new environment known as Knowledge Based System[3]. The automation performed in CATIA [4] using Engineering Knowledge Language (EKL); Knowledge Pattern enables to perform the automation in CATIA.

Templates of the objects (flat panels, visibility pattern, frames, and windows) created by encapsulating information regarding the objects needed to build the windshield, thus known as Knowledge template or User Defined Feature (UDF). A Catalog stores the location of the UDF. The Knowledge Pattern Algorithm script written using the EKL to control the UDF. Knowledge/templates utilized repeatedly to obtain the desired configuration, furthermore, can be updated depending on the necessity and used accordingly.

3 Methodology

The following sections present the methodology created to apply the design automated windshield geometry for automatic meshing and overview of windshield methodology.

3.1 Windshield Design Methodology

The initial design methodology is explained and presented [5] and the visibility pattern [6, 7, 8, 9] rules implemented in the windshield design. The design uses Knowledge pattern templates to store knowledge regarding windshield design and later automated using EKL.

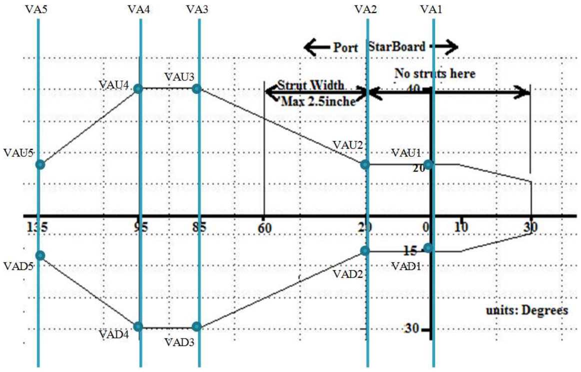

Fig. 1 : Ideal Visibility Pattern for transport airplanes [5, 7]

The requirements for windshield are the following [6](Fig. 1):

1. The pilot's view never obstructed from 30-degree starboard to 20-degree port.
2. The window frames are less-than 2.5 inches from 20-degree port side to 60-degree port side.

The intermediate output of automation process shown in Fig. 2 and the final outcome after completing the design presented in Fig. 3.

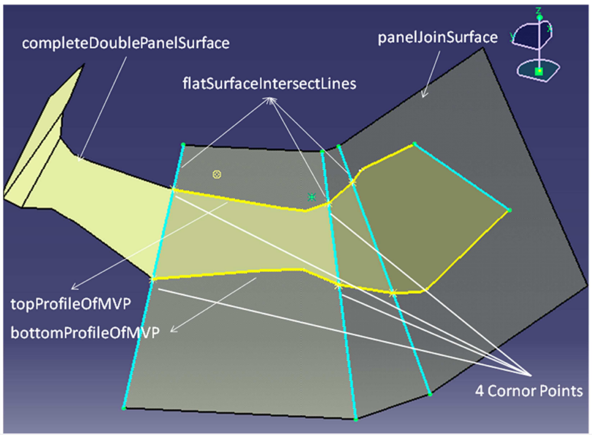

Fig. 2 : Hidden outputs from the visibility pattern [5]

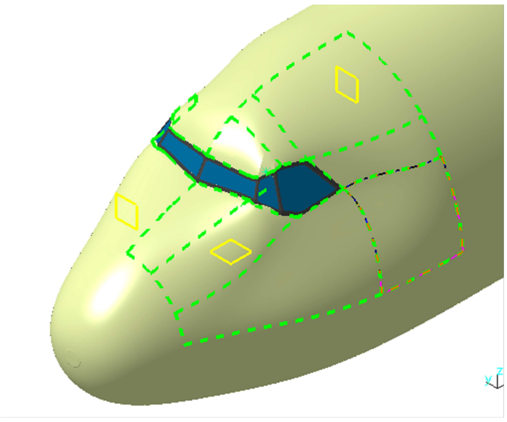

Fig. 3 : Final output of fuselage integration templates on cockpit [5]

3.2 Automated Meshing Methodology for a Design Automated Geometry

The automated meshing method for a parameterized geometry presented by Munjulury et. al. [10]. In a parametric geometry, the number of surfaces remains the same at all times, whereas in a design automation the number of surfaces either increase or decrease during the processes. The surfaces are named and remembered by the CADNexus [11] program for a parametric geometry but the same procedure does not work in design automated geometry as the surfaces get new names for every update. The following section presents the design methodology implemented for a design automated geometry.

Two automatic meshing methodologies are presented, the first case uses Fine^{TM}/Open with OpenLabs to create the mesh automatically by the use of Python script (Fig. 4). The imported geometry is a STL file format, both mesh and solver settings are

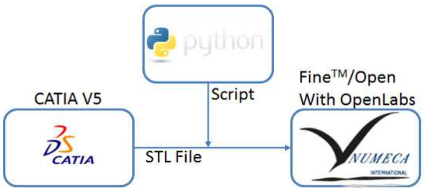

Fig. 4 : Methodology for Design Automated Geometry with Fine^{TM}/Open with OpenLabs [12]

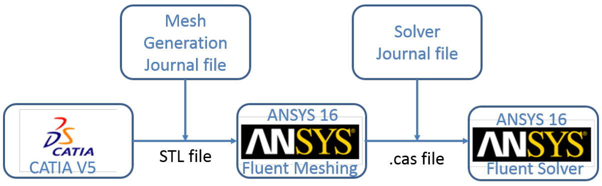

Fig. 5 : Methodology for Design Automated Geometry with Ansys® [13]

saved in the script. The outputs namely lift and drag are saved in an ASCII file (with .mf extension), these values are later used by modeFRONTIER [14] in the optimization process. In the second case, Ansys® creates the automated meshing by using two Journal files (Fig. 5), the imported geometry is a STEP file format. The first file includes mesh settings and it creates a case file (.cas file extension) to be run for simulation, the second file has the solve settings and takes the case file for simulation. The ASCII file stores the results, these results are examined in modeFRONTIER during the optimization process.

4 Integrated Design and Optimization

Multidisciplinary aircraft conceptual design is an appropriate framework (Fig. 6) to establish the stated complexity, as numerous engineering domains must interact to give a clear idea of the whole system. Robust interfaces provide an automatic interaction between these disciplines.

A multidisciplinary optimization framework connecting Geometric model, Aerodynamic model, and Structural model is proposed. The performed optimization on the windshield flat panels and the shape of the fuselage shown in Fig. 3. Fuselage weight estimation [15, 16, 17] obtained by combining the weight penalty method with the complex geometry. The optimization of a 2D model provided the angle of the middle strut. Further 3D geometry Shape and structure optimization [18, 19, 20, 21, 22, 23] of the fuselage is performed.

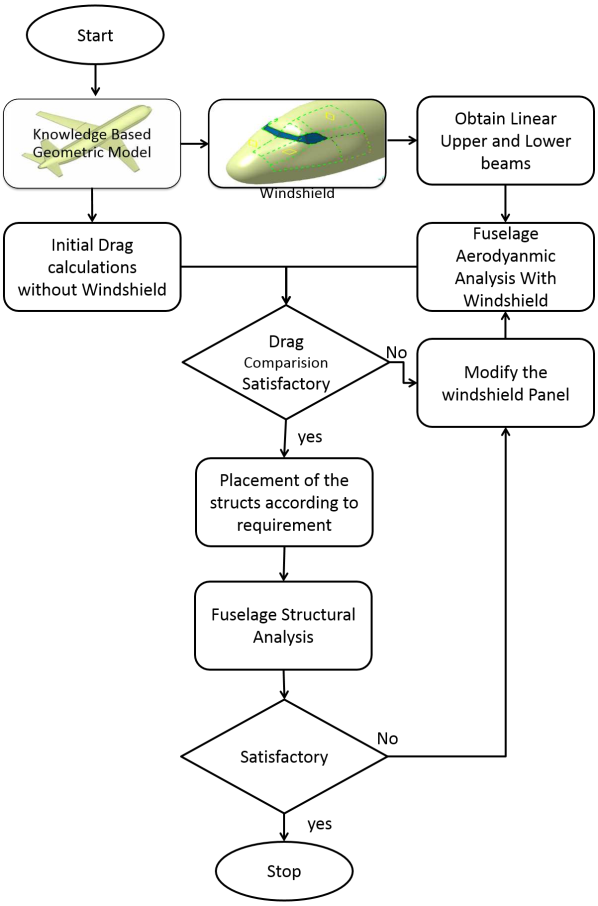

Fig. 6 : Integrated Multidisciplinary Optimization Framework for Design Automated Geometry

$$Min : W(x); C_D(x) \tag{1}$$

Subjected to:

$g_1(x) : V_f(Required) \leq V_f$
$h_1(x) : \sigma \leq \sigma_{Critical}$
$k_1(x) : S_{ref} * C_{L(Critical)} \leq S_{ref} * C_L$
$x_{low} \leq x_i \leq x_{up}$
W = *Weight of the Wing*
V_f = *Fuel Volume*
S_{ref} = *Reference Area*
σ = *Bending stress*
C_L, C_D = *Coefficient of Lift and Drag*

4.1 Aerodynamic Analysis

The mesh created in Fluent meshing based on the STEP-model and in HEXPRESS™ Using the STL-model. Both the models are exported directly from CATIA. The computational domain consisted in this case of a rectangular block. Fluent meshed with tetrahedral elements Fig. 7 with refinements in the region around the fuselage and in the wake, while HEXPRESS^{TM} meshes with hexahedral unstructured elements Fig. 8. To ensure adequate boundary layer resolution along the fuselage, inserted 30 layers of prism elements at surface and thickness of the first layer adjusted so that non-dimensional wall distance y+ stays below unity.

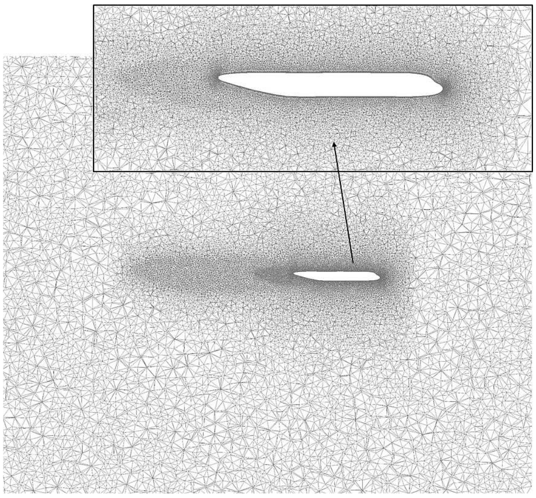

Fig. 7 : 3D Ansys model mesh

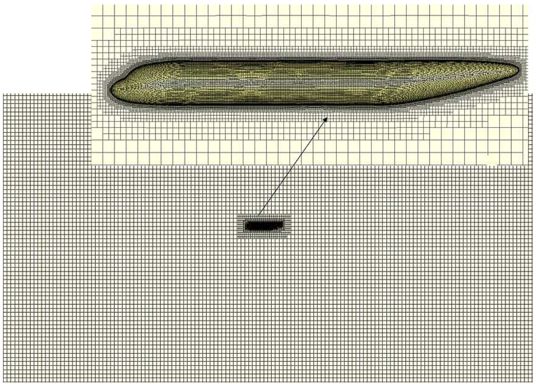

Fig. 8 : 3D Fine/Open model mesh

A far-field boundary condition prescribed on all sides of the domain, except on outlet behind fuselage, where pressure set to its far-field value and other properties extrapolated from the interior (Pressure Outlet in Fluent). The freestream Mach number was 0.78, and the freestream static pressure 26500 Pa, corresponding to 10 km altitude in the standard atmosphere. Simulation performed with the segregated solver in Fluent and convective fluxes are discretized with a second order upwind scheme, and the coupled algorithm used for pressure-velocity coupling. Similar solver conditions are applied in Fine^{TM}/Open with OpenLabs.

4.2 Structural Weight Estimation

BeX program assigns the values of each station for the fuselage geometry and determines the required dimensions need for initial estimation. In this manner, the weights are closely correlated with the generated fuselage geometry in RAPID.

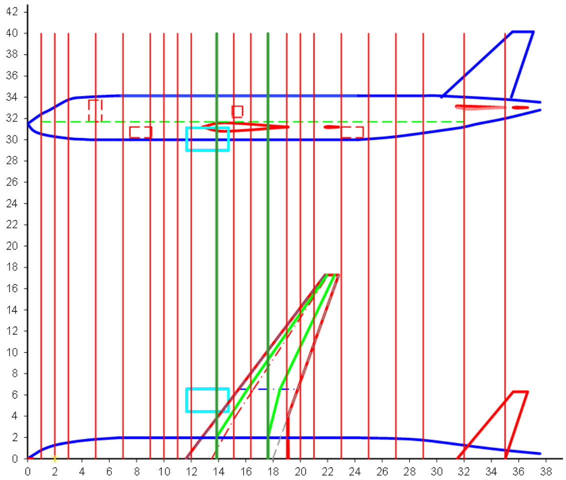

Fig. 9 : Example a/c with lengthwise divisions into stations and zones [17]

The primary structural analysis uses the fuselage weight penalty method [16] and the complicated fuselage geometry to obtain an estimated weight of the fuselage weight from BeX [17] program. Weight penalty method is quite old and still valid to a great extent. It can only deal with one load case, i.e., the pull-up case, however, gives considerably a good weight estimation. The cutouts or penalties can be precisely placed and defined in detail to the extent needed to describe the fuselage design in full. The penalty locations are shown in Fig. 9 describe fuselage length divided into different zones starting from the nose. The cost of making a cutout increases from the nose of aircraft towards the green lines (indicating the forward and rear wing attachments) and vice versa if starting from the tail. The designer has to indicate a placement of zone or zones of the cutouts or penalties and the weight penalties are computed.

5 Results and Discussion

Initial shape optimization performed on 2D geometry of the aircraft found that the angle of the middle strut at 42.5 degrees for minimum drag. Initial 2D geometry pressure distribution is shown in Fig. 10 and drag with respect to the angle of the middle strut shown in Fig. 11 and the color red indicates high pressure and the blue is low pressure.

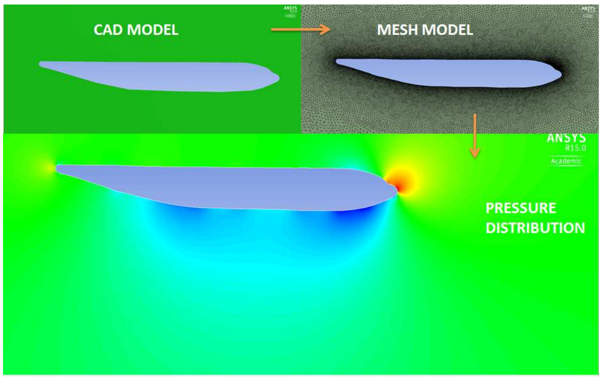

Fig. 10 : CAD model (upper left), Mesh model (upper right) and Pressure distribution for initial 2D Analysis

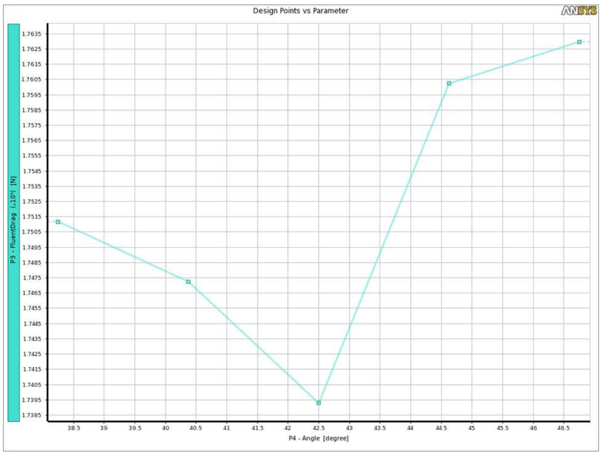

Fig. 11 : Shape optimization results for 2D Ansys model

After 2D optimization, the fuselage is modified for reducing pressure drag of the body and it is also be observed from velocity (Fig. 12) and pressure (Fig. 13) plots for the 3D case. The results obtained are reasonable, the geometry of the fuselage with windshield needs cleaning/simplified during the optimization process, it requires more investigation.

Velocity and pressure contours for the 3D model for Ansys® (Fig. 13, Fig. 12) and for Fine^{TM}/Open with OpenLabs (Fig. 15, Fig. 14) are as shown. The optimized inclinations for the 3-flat panels (considering symmetric), starting from the center towards the port side are 42.5 deg, 48.6 deg and 55.8 deg.

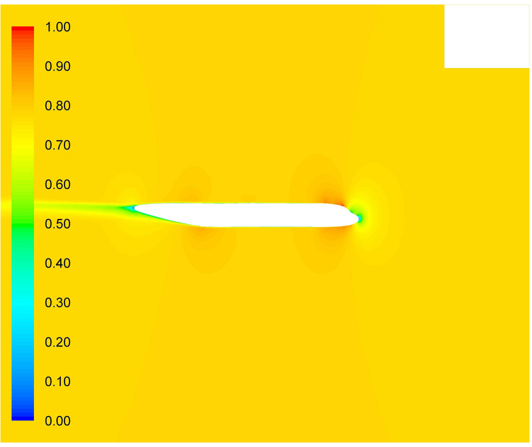

Fig. 12 : Velocity plot of 3D Ansys model

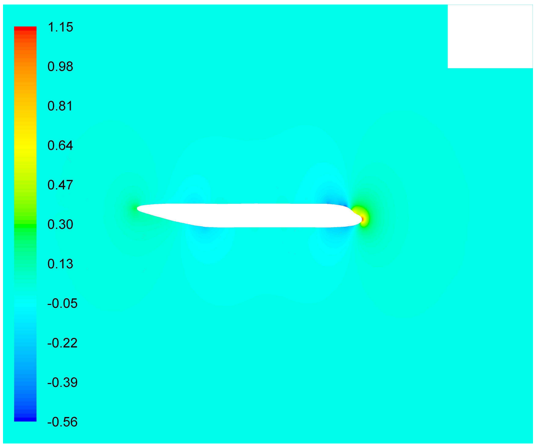

Fig. 13 : Pressure plot of 3D Ansys model

The methodologies presented for both Fine^{TM}/Open with OpenLabs and Ansys® worked well for the geometry without a windshield even as the number of surfaces/partitions varied significantly. As the windshield is applied, the geometry first needs adjustment such that it can be used in the optimization. The windshield is sensitive to variation in angles, therefore, the design space for the optimization is small. The programming for Fine^{TM}/Open

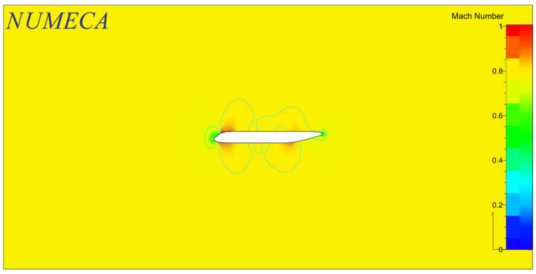

Fig. 14 : Velocity plot of 3D Fine/Open with OpenLabs model

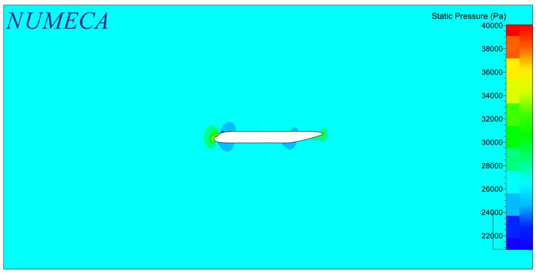

Fig. 15 : Pressure plot of 3D Fine/Open with OpenLabs model

with OpenLabs is relatively simple compared to Ansys® journal. All the python script is written in a single file in Fine^{TM}/Open with OpenLabs whereas meshing and solver settings are written in separate files in Ansys®.

6 Conclusion

The optimization framework shown in this paper implemented in the early design phase of the windshield. As the geometry is automated, the user can visualize the result instantly. The existing design is modified or the design from scratch depending on the necessity. The proposed optimization framework will enhance the conceptual designing process. Future work includes benchmarking of both the mentioned tools for an effective automatic meshing and demonstration of the methodology for various applications.

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