DIGITAL MOCK-UP: A USEFUL TOOL IN AIRCRAFT DESIGN

D. Camatti, S. Corpino, M. Pasquino
Department of Aerospace Engineering (DIASP), Politecnico di Torino

ABSTRACT

This paper shows the activity we are now involved in, focused on the improvement of conceptual design methodologies by the integration with modern parametric 3D CAD software tools. This is implemented both at system level and at subsystem level and the integration between them is optimised. The result is a Digital Mock-Up at Conceptual Level, whose usefulness will be shown.

1 INTRODUCTION

Our research activity at the Department of Aeronautic and Space Engineering at the Politecnico di Torino is focused on aircraft conceptual design. We are currently working at it as Aerospace Engineering PhD students though two of us had already gotten involved into it as undergraduate students carrying out their graduation theses. Our activity fits into the broader research which has been carried out throughout [1] [2] [3] [4] by the Systems Engineering Research Group at DIASP whose professor co-ordinator is Prof. S. Chiesa. The research group draws inspiration from the fundamental studies of Prof. G. Gabrielli [5] [6].

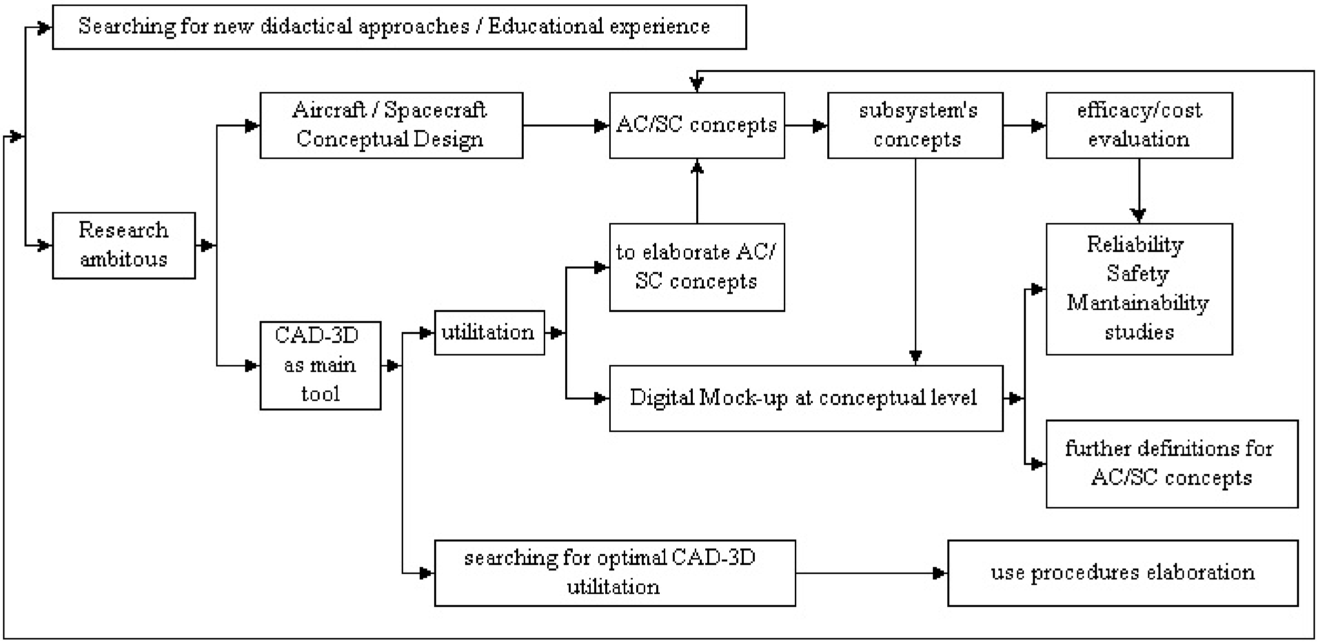


Fig.1: Topics involved in group activity

Figure 1 is an attempt to explain and underline how all different aspects of our research are connected with each other, as a typical feature of Systems Engineering.

On one hand figure 1 shows the educational purpose of our activity which is widely discussed in [1] (paper presented at this very congress), on the other it underlines how our research fits into the broader aircraft conceptual design research. Figure 1 also illustrates that the main feature of our work has been the introduction of the new parametric 3D CAD techniques which have gained importance and have become essential if not pre-eminent. The main role of new parametric 3D CAD techniques, how these techniques have been used within the aircraft conceptual design activity and the study turned towards the optimisation of 3D CAD tool utilisation have already been discussed in [7] and will be talked over in the next paragraph.

Figure 1 also reminds the use of 3D CAD software tool within the Digital Mock-Up analysis, that is the study of the subsystems installation inside the airframe. We have already applied this technique in a previous work [8] which shows the usefulness of the Digital Mock-Up at Conceptual Level (DMUCL). Paragraph 3 will deal with the effective carrying out of the DMUCL. Eventually paragraph 4 will consider the advantages that a DMUCL analysis can bring. These advantages partly have been already discussed in [7], partly stem from the possibility of the DMUCL integration in a methodology now elaborated [9].

The entire research activity presented in this paper has been tailored on an advanced trainer vehicle (with also possible operational employments) named SCALT (Supersonic Combat Affordable Light Trainer or Safe Competitive Advanced Light Trainer) and elaborated at DIASP. The SCALT study and carrying out are widely debated in [10] and [11].

2 PARAMETRIC 3D CAD WITHIN THE CONCEPTUAL DESIGN ACTIVITY : ADVANTAGES AND PROBLEMS TO BE SOLVED

At the beginning of a new design different kinds of choices have to be made:

- qualitative choices, mainly architectural choices such as the shape of the bodies, and others like the kind of material to use, etc. ;
- quantitative choices, such as the sizes of different parts, the values of functional parameters (for example the engine rating required, rate of flow in onboard systems, forces acting on aerodynamic surfaces, etc.)
- The main activities to perform in order to make these choices are:
- conceiving and carrying out the drawing of the object you are studying. Notice that in some cases the 2D drawings are integrated by solid models (wooden-made or in polypro foam, for example);
- building up a mathematical or a physical model of the object, that leads you to fix numerical value for parameters.

The sequence of these two steps, often repeated several times, characterises the typical design activity (see fig.2).

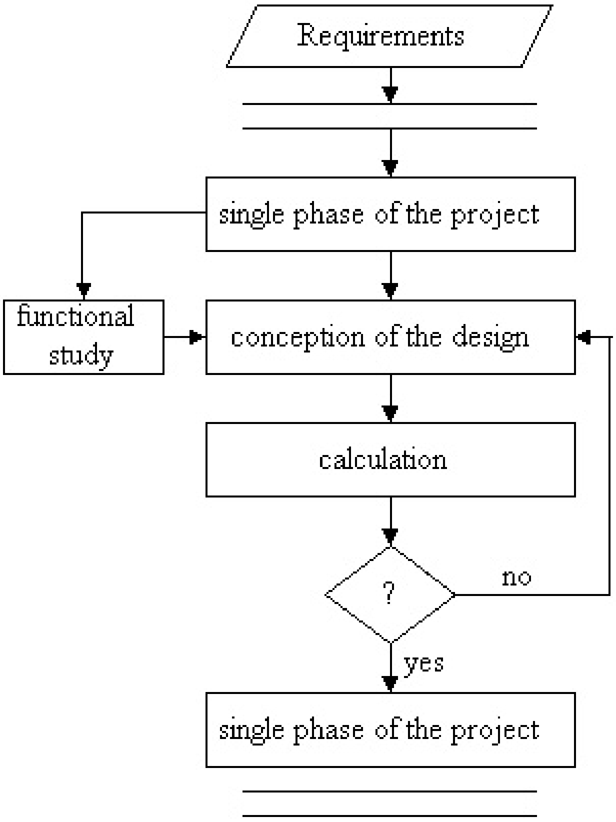


Fig.2: Design activity

When dealing with simple items, the conceiving activity may be fulfilling. Conversely when complexity increases a detailed and quantitative definition becomes necessary.

Conceiving and carrying out the drawing activity has been scarcely used until now in the development of aircraft conceptual design methodologies. The conceptual design was carried out only by the adoption of analytical or/and numerical algorithms. Notwithstanding the effort required, it did not lead to a satisfactory definition of the item. A typical example is the estimation of fuel tanks capacity by calculating the internal volume of the wing.

The introduction of parametric three-dimensional CAD software integrated into the conceptual design methodology represents, in our opinion, a great improvement.

The possibility to visualise the object in a very realistic way, and to observe it from different directions thanks to rotation tool, represents a substantial contribution to the designer.

Modern CAD software allow to obtain:

- a “solid model” of an object. The so called solid model is the geometric digital representation of the real object. It is the visual expression of the computer internal mathematical representation of the object.
- a parametric model of an object. This feature allows us to integrate CAD software in a computerised mathematical procedure. The parametric feature means that it is not necessary to specify the object’s size once and for all, but it is possible to define it everytime. Furthermore, there is the possibility to assign explicit relations between different dimensions so that changing one of them, every depending data changes as a consequence.

Figure 3 shows the new conceptual design methodology defined and set up with regard to the SCALT project, as discussed in [7] [8] [10] [11].

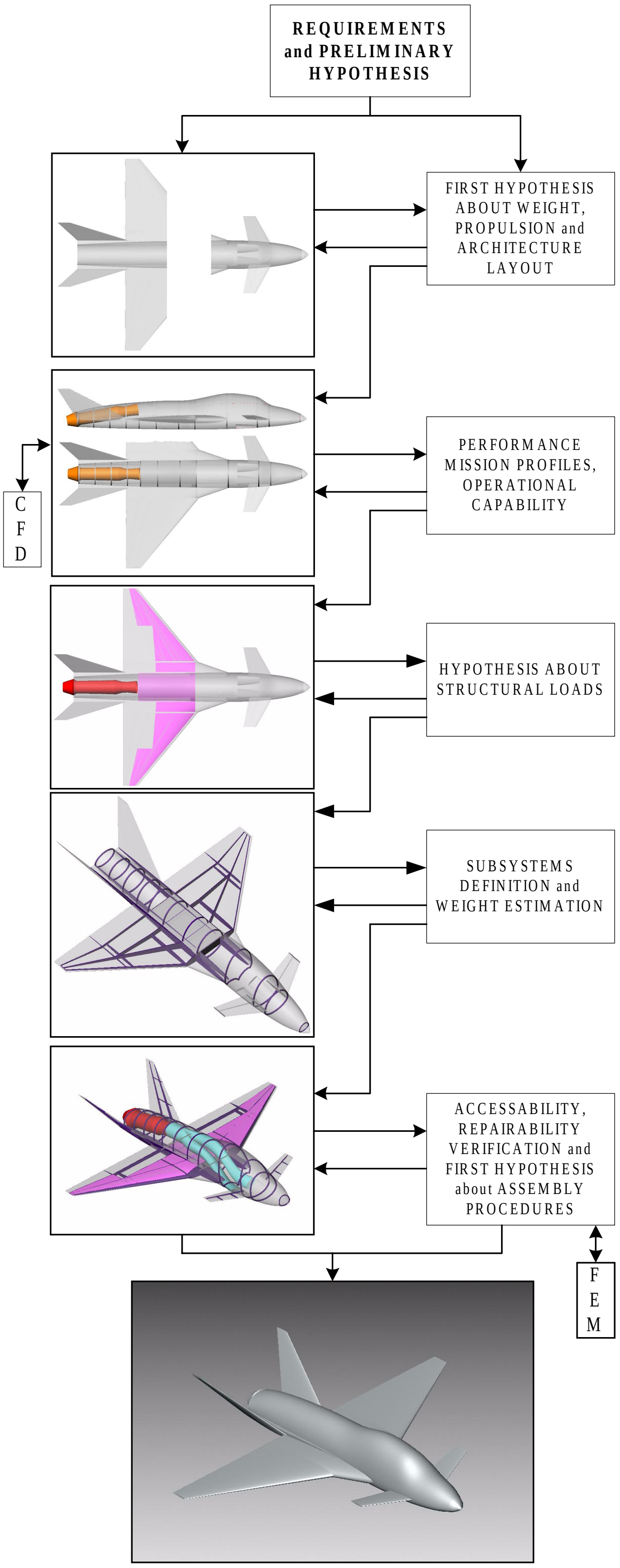


Fig.3: new conceptual design methodology

Unfortunately there are also some problems related with the utilisation of CAD software. They are shown in figure 4, which compares advantages and disadvantages of this tool. In particular, the generality of CAD represents a problem in some way. In fact, this means that the same object can be obtained in different ways (one of which is probably better than the others) and that there are not standard sequences to follow. This suggested us to begin a research activity which aims at defining standard optimised procedures. This target has been

pursued during the development of the SCALT,

which gave us the possibility to conceive, develop and test the new methodology integrated with the drawing procedure. SCALT project represents the first case study; the research turned forward the optimisation of drawing procedures is carried on through other case studies [7] [8].

PARAMETRIC CAD-3D	
ADVANTAGES	PROBLEMS
• Realistic visualisation. • Parametric design. • Characteristics calculation during the phase of design.	• General characteristics of the software, not directly addressed to aeronautical applications. • Several different ways to obtain the same item.

Fig.4: CAD characteristics

3 DIGITAL MOCK UP AT CONCEPTUAL LEVEL

The 3D parametric CAD tool reveals its power and its problems also in the subsystem definition phase. On one hand it is possible to obtain a complete and precise concept of the aircraft, making the results of the design much more reliable than those with the classic methodologies. On the other hand the problems related to the procedures still remain. All layout subsystems, included the structural scheme, have been foreseen. Each one, excluding the structural scheme, has been defined on the basis of a block scheme layout. Later on they have been sized by mathematical algorithms or by simulation models. The study of the installation of sized systems on the airframe has been carried on by the definition of the Digital Mock-up at Conceptual Level (D.M.U.C.L.). Figure 5 sums up the procedure used to build the DMUCL of the SCALT aircraft.

The usefulness of the DMUCL consists in the possibility of:

- obtaining a detailed definition of the item you are studying (for example an aircraft);
- verifying the actual possibility of the airframe to contain all systems foreseen and check the right positioning of each equipment;
- allowing a very accurate and easy estimation of the centre of gravity and geometrical quantities;
- allowing preliminary studies of maintenance characteristics.
- studying the interface between equipments and structural elements.

Figures from 6 to 11 show the results of the DMUCL study applied to the SCALT subsystems.

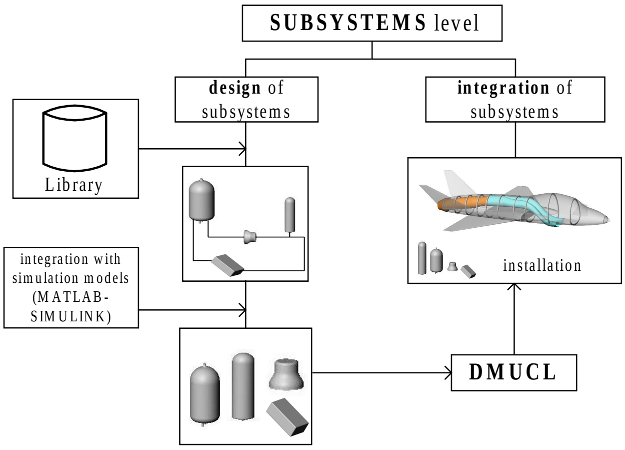


Fig.5: DMUCL procedure

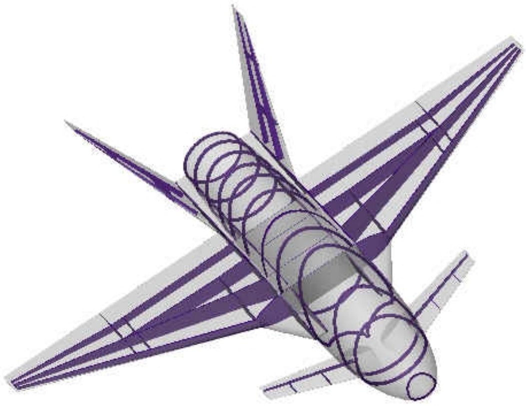


Fig.6: Structural layout

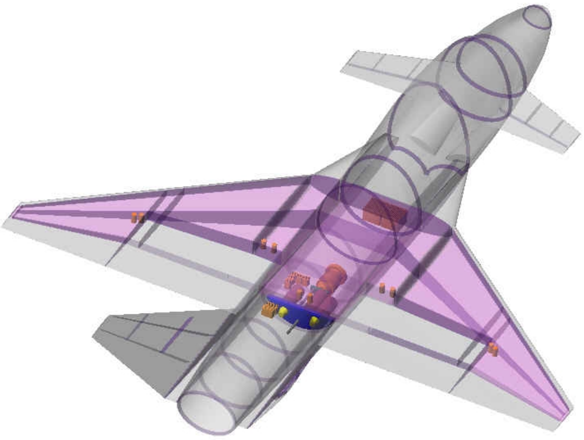


Fig.9: Fuel system and secondary power

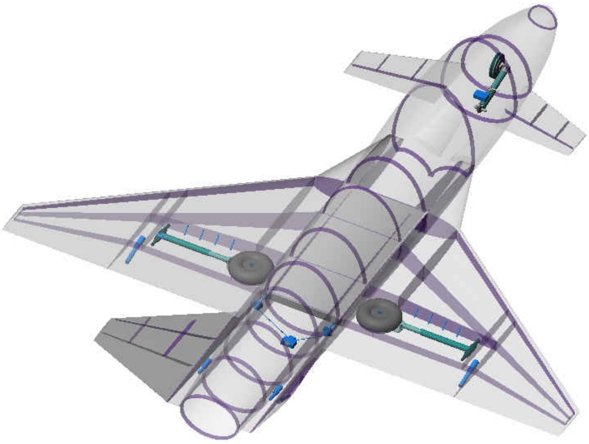


Fig.7: Flight controls and landing-gears

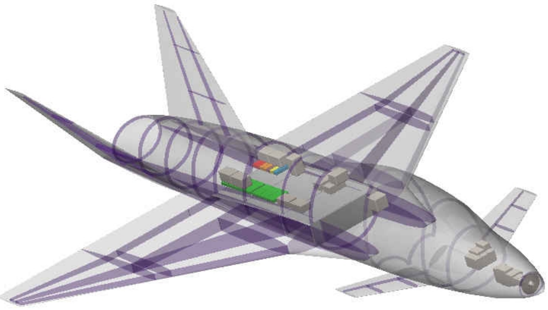


Fig.10: Avionic system and computing

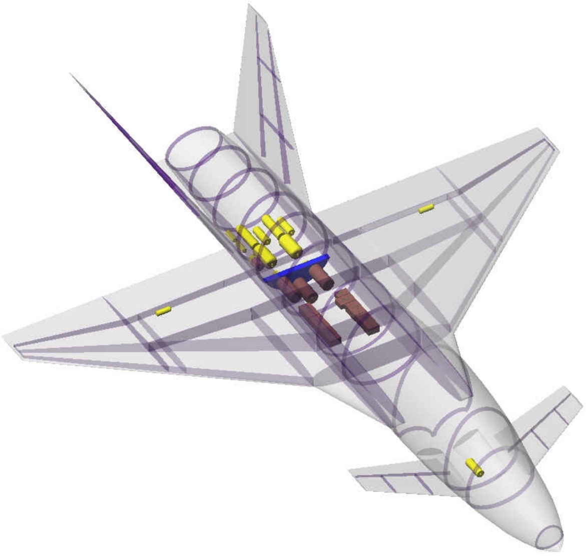


Fig.8: Hydraulic and electrical systems

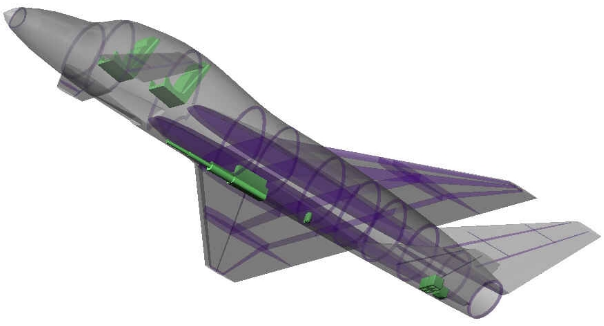


Fig.11: Armament and furnishing

The study of Digital Mock-Up lead us to the following observations:

- it is possible to note the solution chosen for the secondary power system: it is fully integrated with ECS and APU, based on AMAG (Aircraft Mounted Accessory Gear Box) and discussed in [9] and [11];
- most equipments of the hydraulic system are located in the rear part of the fuselage beneath the engine. As a result the maintainability improves because of two reasons: first because of the high concentration of elements within the same area and second because of the reduced number of pipes and connections which may be disconnected in case the rear part of the fuselage has to be removed. It is clear that this area has to be protected by fire-extinguishing devices;
- the fuel system is fully contained in the wing (external, internal and central sections fuel tanks) with two motor-driven booster pumps for each tank;
- the air and oil coolers, using fuel as refrigerant, are grouped in three areas only. Two of them are located near AMAG and thus have to be protected by fire hazards;
- the 27mm Mauser Gun is located at the bottom of the fuselage and thus making the reloading easier;
- avionics equipments and subsystems control computers are easily accessible. Most of them are located on the upper wing centre section sides avoiding the interference between Maintenance technicians;
- flight control systems consist of: linear actuators for ailerons, rudders and spoilers placed near the respective aerodynamic surfaces and thus easily accessible; three drive units for foreplane, leading edge flaps and flap-elevons placed in accessible areas of the fuselage. Each drive unit, constituted by two hydraulic motors, is connected by shafting to the actuators. In particular there are four linear jackscrews for foreplane and flap-elevons. These last ones will be more widely discussed in the next paragraph.

Figure 12 shows the complete DMUCL. The present figure is a very important result as it demonstrates the physical feasibility for all subsystems foreseen to be installed on the airframe. It has to be remembered that the traditional preliminary design methods allowed the installation test to be accomplished only successively. Figure 13 and 14 then show how simple CAD controls make it very easy to evaluate quantities. In particular, figure 13 verifies the fuel capacity of the wing structure, centre section included, by calculating the volume of the integrated tanks.

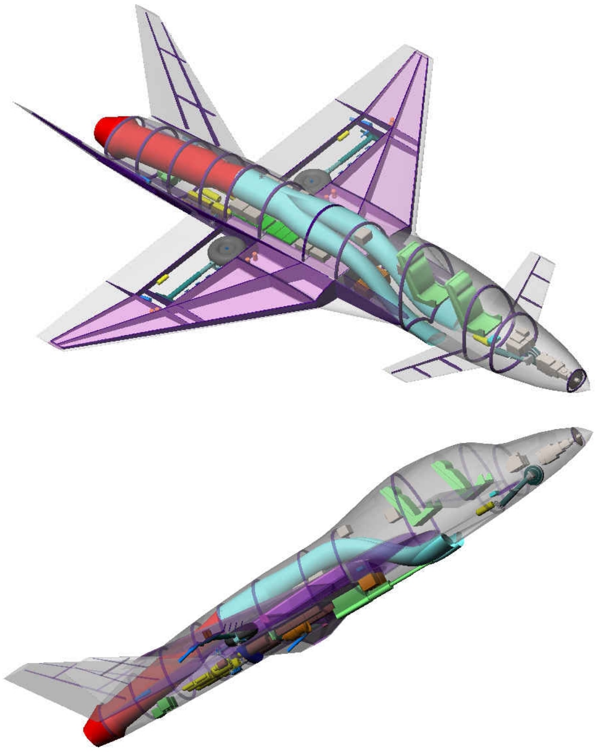
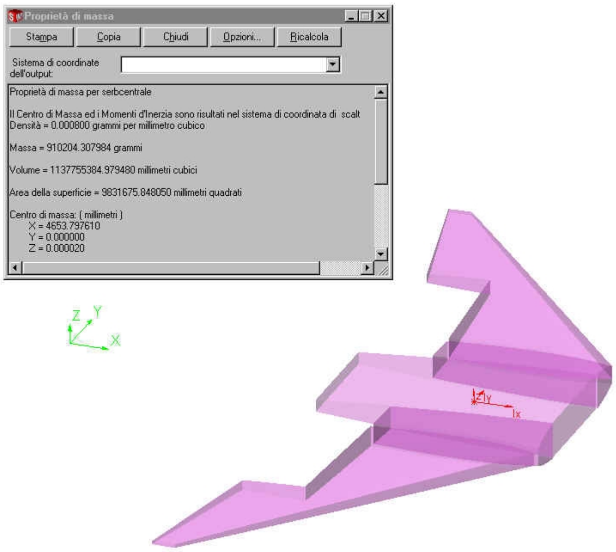
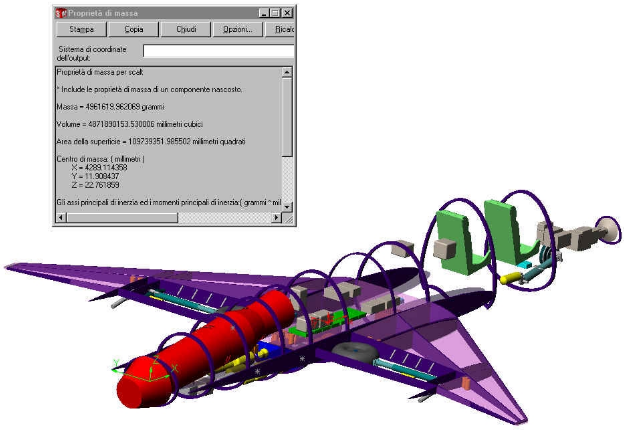


Fig.12: Complete digital mock-up



```
Sistema di coordinate
dell'output:

Proprietà di massa per serbcentrale

Il Centro di Massa ed i Momenti d'Inerzia sono risultati nel sistema di coordinata di  scalt
Densità = 0.000800 grammi per millimetro cubico

Massa = 910204.307984 grammi

Volume = 1137755384.979480 millimetri cubici

Area della superficie = 9831675.848050 millimetri quadrati

Centro di massa: ( millimetri )
        X = 4653.797610
        Y = 0.000000
        Z = 0.000020
```

Fig.13: Fuel capacity evaluation



```
Sistema di coordinate
dell'output:

Proprietà di massa per scalt

* Include le proprietà di massa di un componente nascosto.

Massa = 4961619.962069 grammi

Volume = 4871890153.530006 millimetri cubici

Area della superficie = 109739351.985502 millimetri quadrati

Centro di massa: ( millimetri )
        X = 4289.114358
        Y = 11.908437
        Z = 22.761859

Gli assi principali di inerzia ed i momenti principali di inerzia:( grammi * mil
```

Fig.14: Subsystems centre of gravity evaluation

Figure 14 illustrates the definition of the centre of gravity co-ordinates for the subsystems, since the weights estimation has been previously accomplished within the subsystems design analysis phase (at subsystems level and, in many cases, at components level).

4 DMUCL AND INTEGRATION WITH RAMS METHODOLOGY

As already been stated, DMUCL represents a very good means to integrate the Conceptual Design with a methodology [9] turned towards dealing with Reliability, Availability, Maintainability and Safety characteristics from which the acronym RAMS derives. Figure 15 schematically shows the RAMS methodology underlining how technical and logistical activities follow one another. The technical activities are mainly the conceptual design and the development and the definition of the support. Logistical tools used are partly traditional, partly originally made up within the methodology development itself. They are:

- PFMEA (Preliminary Failure Modes and Effects Analysis), useful for performing the Safety and Reliability project design;
- FMECA (Failure Modes and Effects and Criticality Analysis);
- RCM (Reliability Centred Maintenance), useful for optimising the Maintenance program;
- MPFMEA (Maintenance Process Failure Modes and Effects Analysis): i.e. FMEA performed on the succession of operations of a maintenance process in order to prevent critical situations or probable mistake sources.

Figure 15 illustrates how RAMS methodology might be integrated with DMUCL.

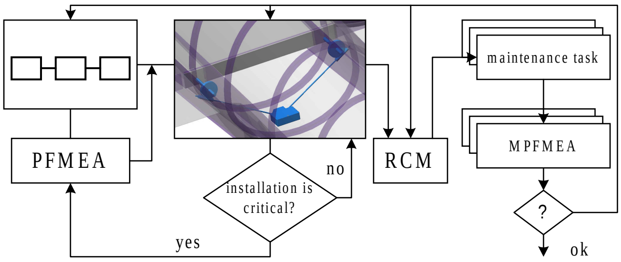


Fig. 15: RAMS methodology

SCALT flap-elevon actuation (fig.16) has been considered as subsystem example.

As it can be noted the system (at “black boxes” level) is constituted by:

a) one drive unit encompassing two hydraulic motors (fed by two different hydraulic circuits) which may add up their own torque when both two clutches are engaged to give one torque value as drive unit output. The clutches make also one single hydraulic motor to be disengaged possible when that motor happens to brake down;

b) two shafts to transfer torque at high angular speed towards both the right and left flap-elevon jackscrew linear actuators;

c) these actuators get mechanic power (low torque value and high angular speed) from the shafting coming from the Drive Unit and transfer high force at low linear speed to the flaps-elevator themselves.

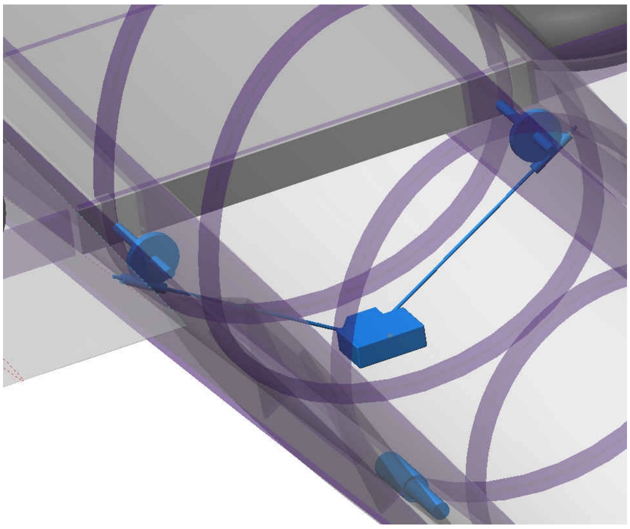


Fig.16: Flap-elevon actuation system

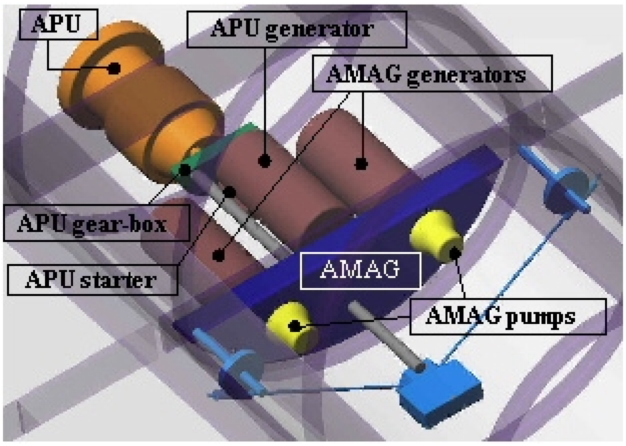


Fig.17: Flap-elevon actuation system installation choice

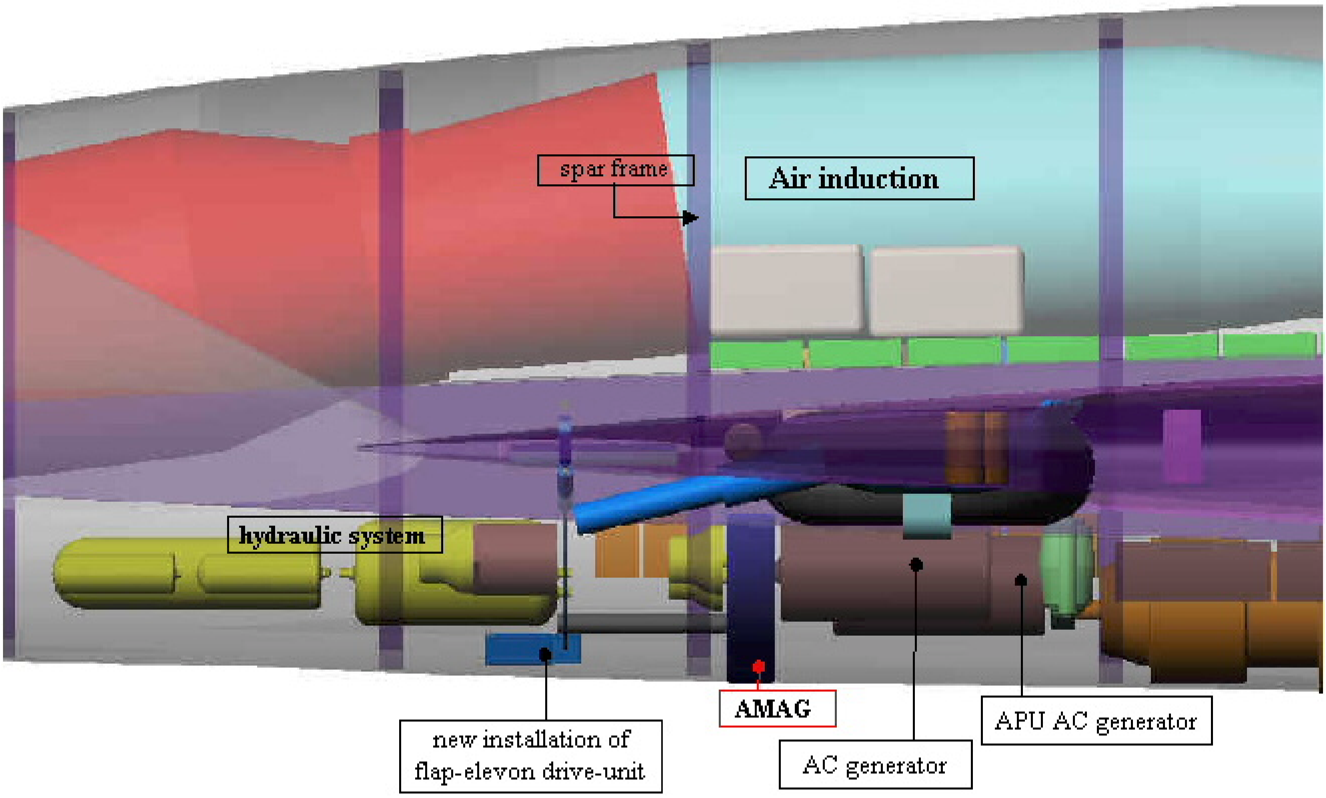


Fig.18: Flap-elevon actuation system installation choice – lateral view

ITEM	Q.TY	FAILURE MODE	EFFECT	PROBABILITY	CRITICALITY
jack-screw	2	broken	system blocked (by computer control to avoid asymmetry)	low	high
shafting	2	broken	system blocked (by computer control to avoid asymmetry)	very low	high
drive unit	1	one motor not running	marginal less of performances	high	low
		total inefficiency	System blocked	very low	high

Tab.1: preliminary FMEA of flaps-elevons actuation system

PFMEA, as tab. 1 shows, may point out, even though on the basis of a preliminary definition, the need for very basic configuration choices to be made like the idea of adopting a Drive Unit with two motors fed by different circuits. In this way if one engine breaks down (and that is likely to happen taking into account the complexity of a motor itself and even more its servo valve, as well as the possibility of a failure in the feeding circuit) that event may still be considered as a low criticality effect event. The high criticality effect event will just occur in case of total inefficiency due to the breaking down of both motors during the same flight. It is clear that is a very low probable event.

Considering now the subsystem installation on-board aircraft, the RCM application has revealed the necessity of undertaking scheduled inspections of the Drive Unit. In fact, as already well known, the advantages of redundancy are almost inessential if at the beginning of each single flight both parallel branches of the respective Reliability Black Diagram are guaranteed to be working when set in action. The first installation study aimed at lining up the power shafting coming from the Drive Unit and the jackscrews installed into the wing rear “back strakes”. Thanks to the installation of the Drive Unit beneath the wing centre section, immediately before the AMAG, the shafting run parallel to the y axis. The MPFMEA revealed that the Drive Unit disassembly would be critical since the Drive Unit was almost completely enclosed between AMAG, wing centre section and A.C. generators (fig.17). The problems encountered led to the choice of the installation of the Drive Unit abaft the engine spar frame. The Drive Unit is now located beneath the actuators as figure 17 and 18 show. The shafts are now inclined and thus a wee bit longer than it was before. The accessibility has been enhanced allowing the accessibility operations within an area where most of the hydraulic apparatus are gathered to be uniformed. Moreover this solution avoids the necessity of disconnecting hydraulic systems in case the rear part of the fuselage downstream the engine spar frame has to be removed.

5 CONCLUSIONS

Taking into account the enhanced definition and precision level attained for the Conceptual Design activity as well as the possibility of narrowing the study down to fundamental detailed choices (remembering in particular the example illustrated in the previous paragraph) we do believe in the usefulness of DMUCL.

ACKNOWLEGEMENTS:

The authors are very grateful to Ing. N. Viola for her precious contribution.

REFERENCES

[1] S. Chiesa, L. Borello, P. Maggiore, *An academical experience on aircraft design: affordable advanced*

jet trainer", 22nd ICAS Congress, Harrogate, UK, August 2000.

[2] S. Chiesa, *Un metodo di progetto preliminare per velivoli da trasporto*, 4th AIDAA National Congress, Milan, Italy, September 1977.

[3] L. Borello, S. Chiesa, P. Maggiore, *Avamprogetto mirato all'efficienza di sistema*, 11th AIDAA National Congress, Forlì, Italy, October 1991.

[4] S. Chiesa, P. Maggiore, *Hypersonic aircraft design methodology* proceedings, 19th ICAS Congress, Anahaim, CA, USA, September 1994.

[5] G. Gabrielli, *Un metodo per la determinazione della superficie alare e del suo allungamento nel progetto dei velivoli*, Vol. 86, Accademia della Scienze, Turin, Italy, 1951/52.

[6] G. Gabrielli, *Lezioni sulla scienza del progetto di aeromobili*, Ed. Levrotto e Bella, Turin, Italy, 1975.

[7] S. Corpino *Utilizzo del CAD 3D parametrico per studi di configurazione in avamprogetto: applicazione ad un velivolo da addestramento avanzato*, Graduation Thesis in Aerospace Engineering, Polytechnic of Turin, October 1999.

[8] S. Chiesa, M. Di Sciuva, D. Camatti, S. Corpino, M. Pasquino, *Utilizzo del CAD 3D parametrico per studi di configurazione e Digital Mock-Up nel progetto concettuale*, 15th AIDAA Congress, Turin, Italy, Novembre 1999.

[9] S. Chiesa, D. Camatti, G. Luda di Cortemiglia, *Design to System Effectiveness Methodology*, SOLE '99 International Logistics Symposium, Las Vegas, NV, USA, Aug 30-Sep 3, 1999

[10] S. Chiesa, L. Borello, M. Di Sciuva, P. Maggiore, *Proposta di velivolo da addestramento avanzato mirato alla sicurezza: valutazione di efficacia e efficienza e analisi del rischio*, 15th AIDAA Congress, Turin, Italy, Novembre 1999.

[11] M. Pasquino, *Proposta di velivolo da addestramento avanzato mirato alla sicurezza: studio di configurazione e valutazione di efficacia ed efficienza*, Graduation Theses, Polytechnic of Turin, October 1999.