AN ACADEMIC EXPERIENCE ABOUT AIRCRAFT DESIGN: AFFORDABLE ADVANCED JET TRAINER

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Abstract

Aim of the paper is to show how conceptual design may be considered both as research activity and educational tool. In particular a conceptual design of a light supersonic trainer with an extensive utilisation of 3D CAD is shown. The educational aspect as well as the future development are discussed.

1 Introduction

Within the traditional research activity started by Prof. Giuseppe Gabrielli [1] [2], who had been one of the most famous Italian aeronautical designer since 1930s up to 1970s as well as the manager of the historic Institute of Aircraft Design, forerunner of the present DIASP, the Aeronautical Systems Engineering team working at DIASP has carried on the research activity focusing on Conceptual Design. At the beginning the activity was mainly thought of as a research activity dealing with carrying out more efficient Conceptual Design computing methodologies [3], [4], [5].

Later on, the research activity has been also thought of and developed as a tool enabling to verify the feasibility of alternative solutions, which stem from the project technical data, and/or to compare them with each other. The research activity has also revealed itself as an important educational tool since it provides the students with a complete and integrated outlook on an aerospace system. Chances are also that a few students might get involved into the carrying out of the project design. In this case the importance of our research activity as an educational tool gets even bigger.

The educational relevance of the activity gained importance in the first half of 1990s and turned towards the conceptual carrying out of a very big-sized cargo air-vehicle fits into the major research activity at the DIASP. The conceptual and preliminary design of the above mentioned air-vehicle, called C 1350 “Gulliver” (figure 1), was carried out through the development and accomplishment of about 20 graduation thesis (one in Electronic Engineering and all the others in Aerospace Engineering).

The technical result was outstanding because the concept of such an unconventional aircraft was carefully studied [6], various aspects were probed [7] and about 20 students got involved into a real design activity. The main problem encountered throughout the project was a high difficulty in information exchanges between students; such a difficulty was mainly due to the lack of scheduling and planning out the time the students should get started and involved into their graduation thesis. Actually Italian Universities do not establish when students are required to start working at their final year project leaving the choice to the free planning of students themselves on the basis of their personal evaluation. As a result, in comparison with what expected as figure 1 shows, the research project took much longer to be completed. Moreover a more intense effort was demanded from the teaching co-ordinators in order to cope with the lack of available results expected from students whose work was behind schedule or not yet completed thus making it hard for other students to get started and proceed with their own work.

The problems encountered led to the adoption of a different approach for the next conceptual design research activity from the System Engineering Team at DIASP.

TOGW = 1350 t
Payload = 530 t
OEW = 428 t
Range = 4700 NM
Engines = 6 GE90 turbofan   Thrust = 420 kN each
Tot. thrust = 2520 kN
Take-off run = 3500 m
Cruising mach = 0.77

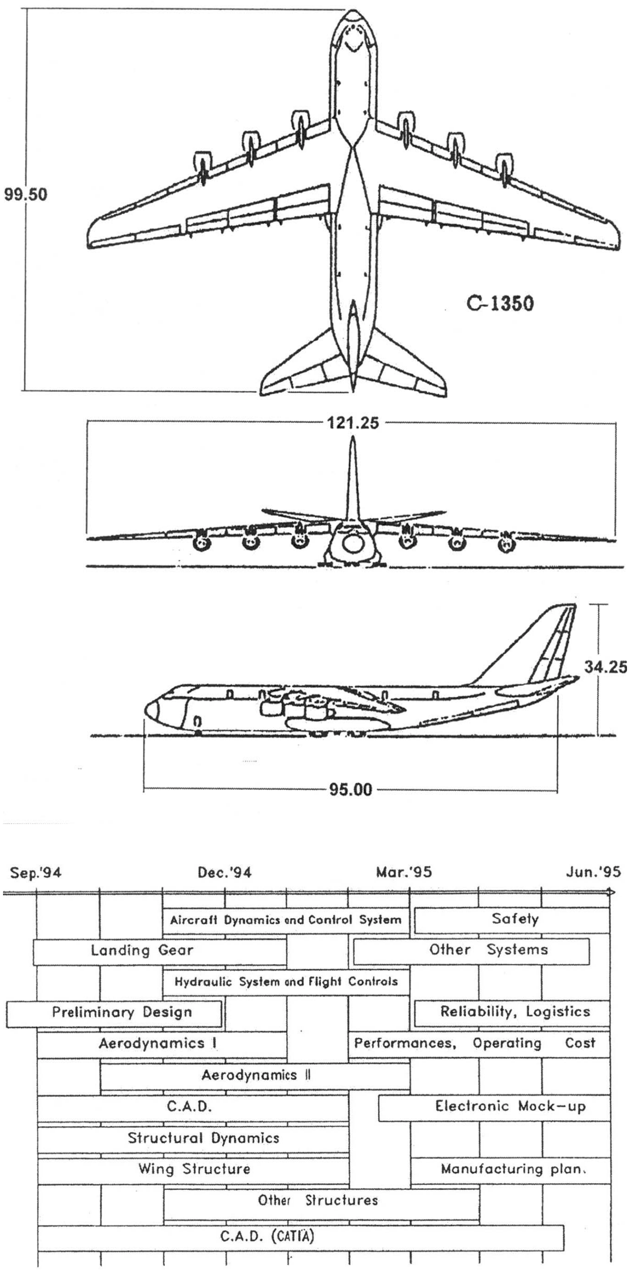

Fig1: C1350 "Gulliver" project

The new research activity focused on a supersonic trainer aircraft, characterised by high safety levels, formative efficiency and cost-effectiveness. These requirements stem from the reasons which led to the development and carrying out of the project itself. They are:

a) Willing to contribute to the flight safety within a wider research study financed by CNR (Italian National Research Council) in two different ways:
   1) Providing with ideas for a didactically efficient trainer aircraft enabling to improve pilots skill levels;
   2) Hypothesising an aircraft characterised by such a high safety level that it can be considered a convincing "test-case" for a developing methodology started within the above mentioned CNR founding and aiming at dealing with and improving safety, reliability and maintainability characteristics since the very beginning of a project [8].
b) The consideration that nowadays supersonic trainer aircraft lack (after the by now overcome experiences of the Northrop T38 TALON and the SEPECAT JAGUAR), notwithstanding the growing interest in "LEAD-IN FIGHTER TRAINER" [9] as the proposed projects DASA MAKO and SAMSUNG KMX-II show, even though they can be considered more as "light fighters" rather than "trainers" because of their size and weight.
c) Willing to develop new methodologies, within a research activity focused on the carrying out of new Conceptual Design methodologies, which can be adopted for aircraft characterised by a more complex configuration than that of a cargo aircraft.

Figure 2 briefly illustrates the process through which the guiding lines for the new research project development have been defined starting from the above mentioned basic requirements. This research project was initially implemented and led by a small group of teachers supported by the helpful contribute of one single student within his graduation thesis [10] in order to avoid the problems previously arisen within the C 1350 "Gulliver" research activity where many students had been actively involved. The activity output [11] is now

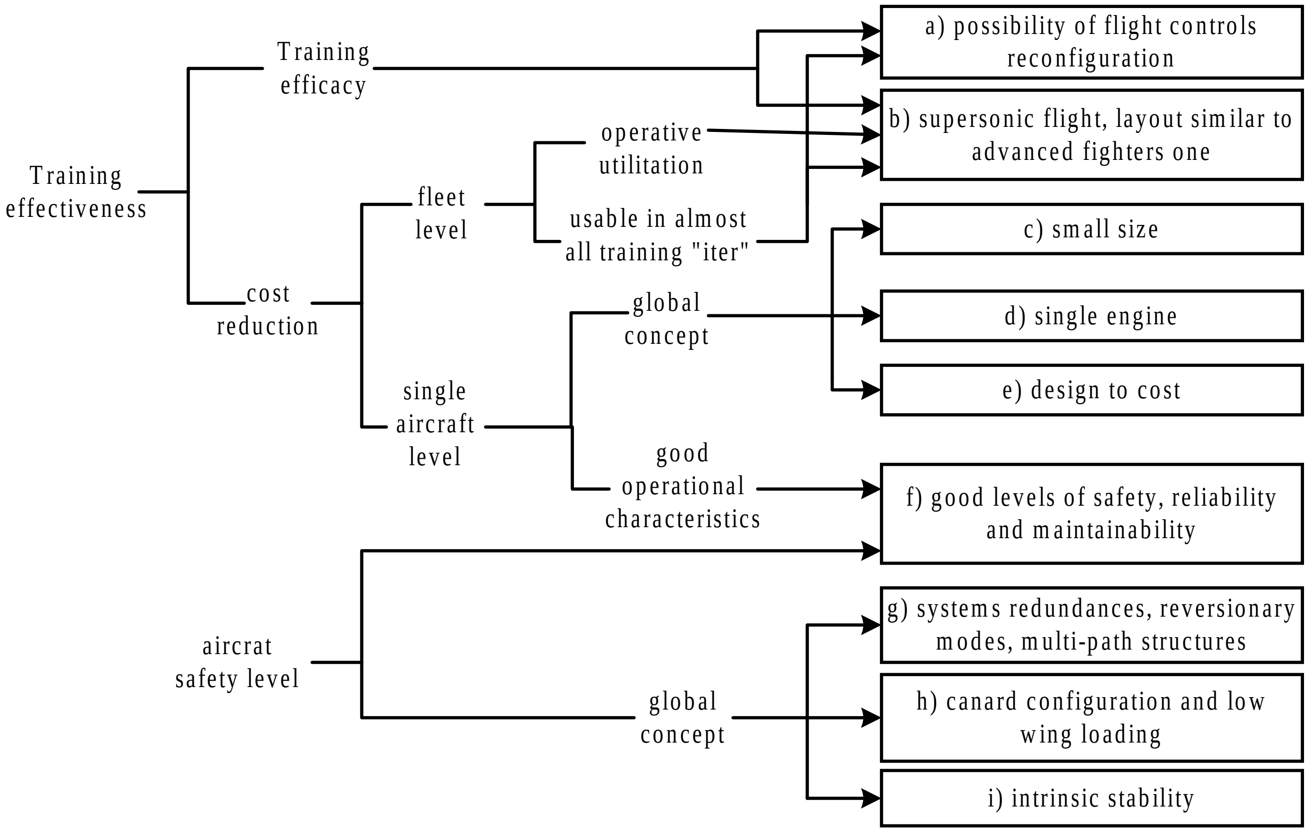

Fig2: Advanced trainer requirements

considered the “first definition level” of the “SCALT” aircraft (Safe Competitive Advanced Light Trainer/Supersonic Combat Affordable Light Trainer) (fig3).

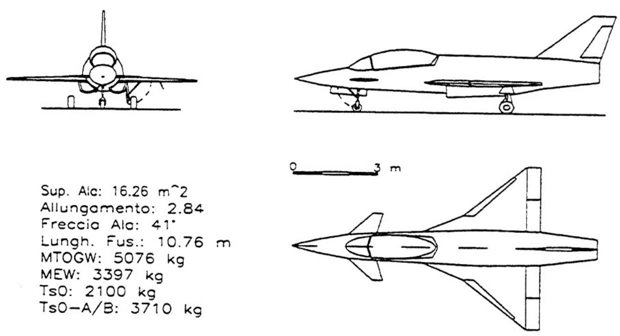

Fig3: SCALT first definition level

The acronym SCALT was adopted only at the beginning of the next stage of the research activity whose result was the “further definition level” of the SCALT aircraft. The “further definition level” of the SCALT aircraft is the present paper’s main target as the next paragraphs show.

2 THE SCALT FURTHER DEFINITION LEVEL

The decision of undertaking this new research activity was made at the beginning of 1999 on the basis of three guiding reasons:

a) Willing to propose again a design research activity which some students could actively take part at. Moreover that design research activity and the conceptual design activity carried out within an industrial environment should be as much as possible alike;
b) Improving the “first definition level” of the SCALT which could be regarded as an adequate trainer aircraft though its operational employment did seem yet far to come. As figure 2 shows, its deficiency was not acceptable from a cost-effectiveness point of view taking into account the trend towards a high reduction of the military fleets;
c) Willing to check out the helpful contribute of the highly modern parametric solid modelling CAD 3D

software tool within a conceptual design research activity.

In order to prevent the new research activity from getting into the previously encountered troubles due to a lack of co-ordination and communication among the students involved, this time only two students got involved into the research activity also considering that the CAD 3D software tool could cope with the reduced number of helpful people working at the project.

Main driver of the new SCALT concept definition was, as already mentioned (b), the necessity of providing an acceptable operational employment without giving up the small size and weight aircraft requirements within a cost-effective perspective.

As the first step of the activity, the two tendentiously antithetic requirements of adequate operational level and small size (and weight) were both met foreseeing a limited armament quantity, constituted only of “smart weapons” though, and thus highly effective. Although a reduced war loads mean a decrease in aircraft weight, the use of “smart weapons” does imply a more sophisticated avionics system on-board and thus a consistently increase in size, which, however, was limited thanks to the adoption of external pods housing the avionics needed only for a few operational activities. Figures 4, 5 and table 1 respectively show the armament configurations foreseen, the avionics system layout and the process leading to the separation between avionics equipments housed into the external pods and on-board aircraft.

What elaborated so far brought to the adoption of new values in comparison with those of the SCALT “first definition level”:

a) An increased aircraft maximum take-off gross weight (MTOGW) up to a value of about 7500 kg chosen on the basis of resemblance with other similar aircrafts;
b) A new air intakes design to allow the external pods or two AIM120 AMRAAM missiles, for an air-to-air mission, to be jointed to the fuselage bottom sides. This is the only feasible configuration since the small aircraft size, the will of a good track and the size of weapons like the HARM missile let one single pylon per wing to be foreseen and adopted.

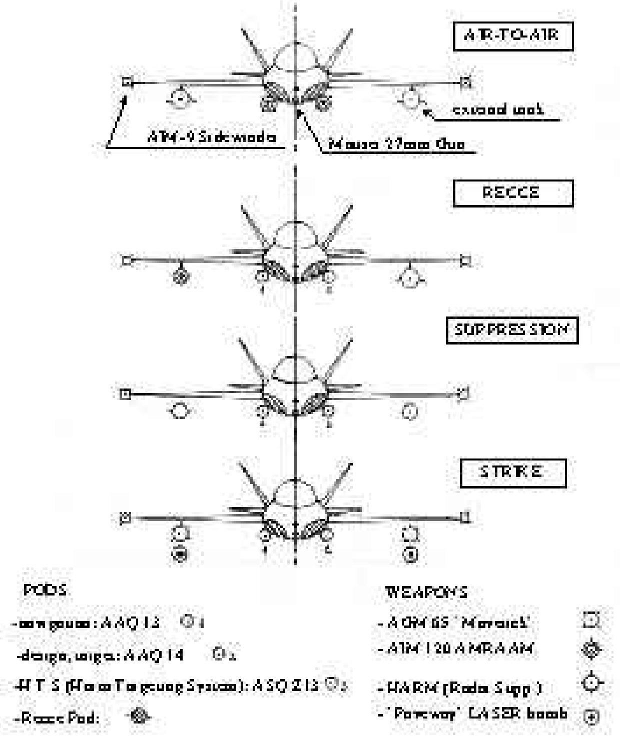

Fig4: SCALT armament

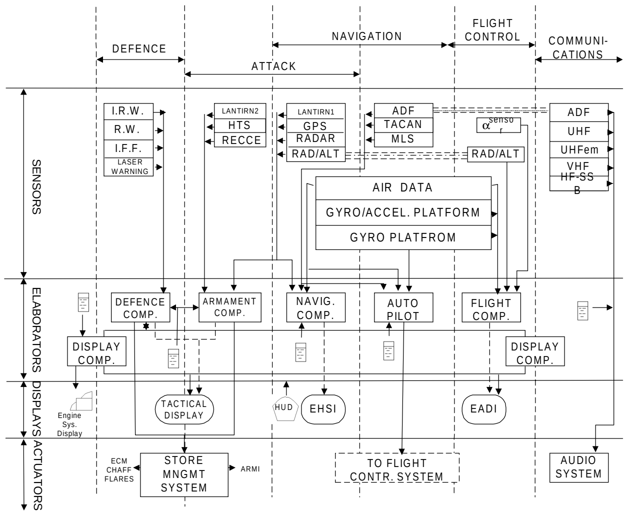

Fig5: SCALT avionic system

A preliminary study about the SCALT landing gear stemmed from the considerations cited above. That was carried out by a foreign student who completed a research project [12] during the year 1999 attending one academic year at the Polytechnic of Turin.

FUNCTIONES	MISSIONS	APPARATUS	INSTALLATION
Radar detection	B-C-D-E	RW	On-board
Radar identification	A-B-C-D-E	IFF	On-board
Infra-red detection	B-C-D-E	IRW	On-board
Electronic computer measures	B-C-D-E	ECM-generator	On-board
CHAFF&FLARES	B-C-D-E	chaff&flares dispensers	On-board
Target designation	B	LANTIRN2	Ext-pod
Radar tracking	C	HTS	Ext-pod
Recce	D	RECCE-POD	Ext-pod
Visual intensification to navigate	B-C-D	LANTIRN1	Ext-pod
Position determination 1	A-B-C-D-E	GPS	On-board
Radar observation	A-B-C-D-E	RADAR	On-board
Ground proximity observation	A-B-C-D-E	RAD/ALT	On-board
Position determination 2	A-(B-C-D-E)	ADF	On-board
Position determination 3	A-(B-C-D-E)	TACAN	On-board
Instrumental landing	A-B-C-D-E	MLS	On-board
Air data acquisition and elaborat.	A-B-C-D-E	ADC	On-board
Inertial navigation reference	A-B-C-D-E	IN	On-board
Attitude pitch, roll angle	A-B-C-D-E	SAHR	On-board
Communication	A-B-C-D-E	VHF,UHF,UHF(em), HHF/SSB	On-board
Elaboration	A-B-C-D-E	Seven computers	On-board
Displays	A-B-C-D-E	Five displays and five keyboards	On-board
PEACE MISSIONS			
A=ferry			
WAR MISSIONS			
B=Interdiction/Strike	C=S.E.A.D.	D=recce	E=air-to-air

Tab1: Shearing between onboard or pod avionics equipments installation

A new methodology, contextually elaborated and, as already mentioned, widely based on the modern parametric CAD 3D software tool was the driver of the development of the SCALT further definition concept level. Next paragraph sums it up [13] [14] [15].

3 NEW CONCEPTUAL DESIGN METHODOLOGY

Figure 6 sums up the new methodology developed and applied to the SCALT "further definition level". As it can be noted, the conceptual design is now conceived as a series of phases following one another, characterised by the use of calculation algorithms, and of CAD design phases.

It has to be observed that the CAD design phases lighten up all work, especially the calculation phases. Figure 6 illustrates the advantages:

- Establishing the size of the rear and the front part of the aircraft respectively on the basis of the chosen engine and cockpit;
- Making it easier to define the size of the central part of the aircraft and the wing size on the basis of the Mach cone (in the case of a supersonic aircraft) and/or of the fuel quantity to be housed inside the aircraft;
- The possibility of hypothesizing the structural layout (that is to say wing spars, ribs and spar frames) once the external shape has been defined (considering also the possibility of a further improvement thanks to the adoption of CFD modules). The definition of the structural layout is a preliminary condition for the systems and sub-systems installation;

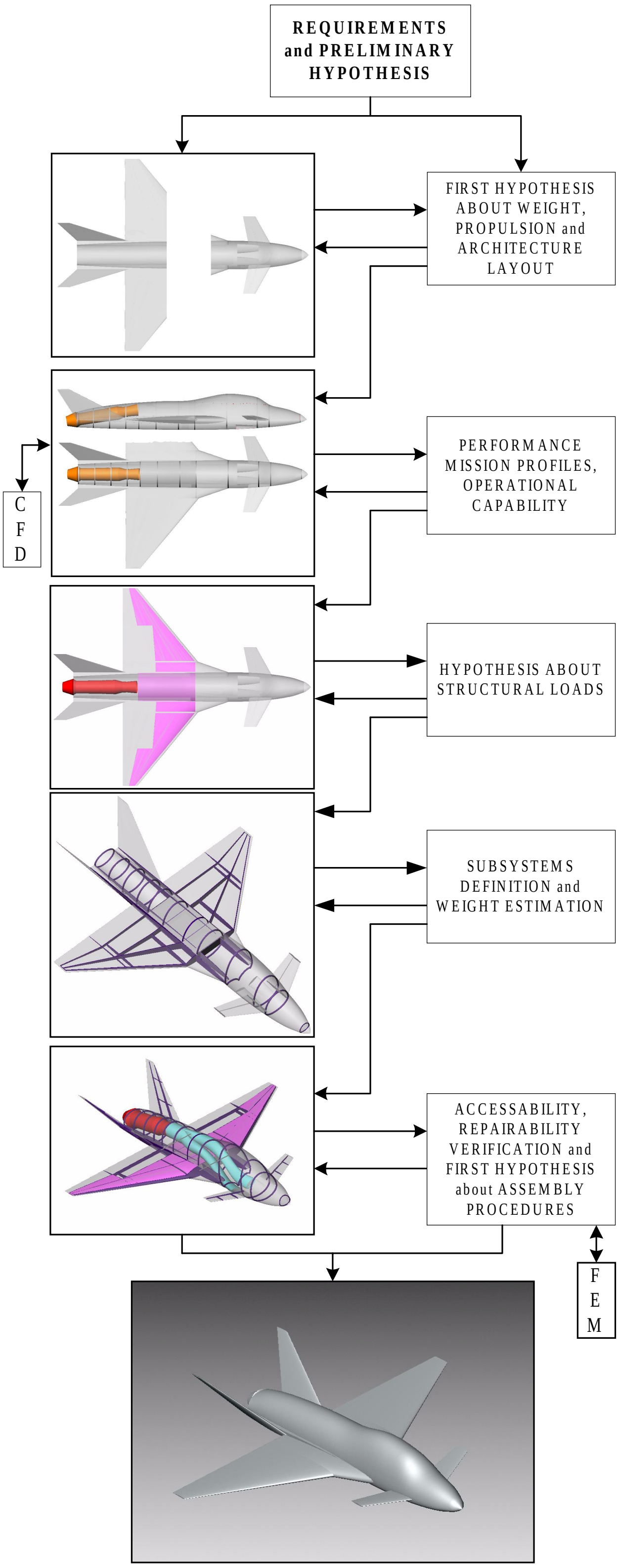

Fig6: Conceptual design new methodology

- Proceeding to the systems and sub-systems installation after the subsystems themselves have been defined. Systems and sub-systems installation aim at carrying out the Digital Mock-Up Conceptual Level (DMUCL). Figure 7 schematically shows how the DMUCL is carried out and figure 8 shows what has been achieved in the case of the SCALT aircraft.

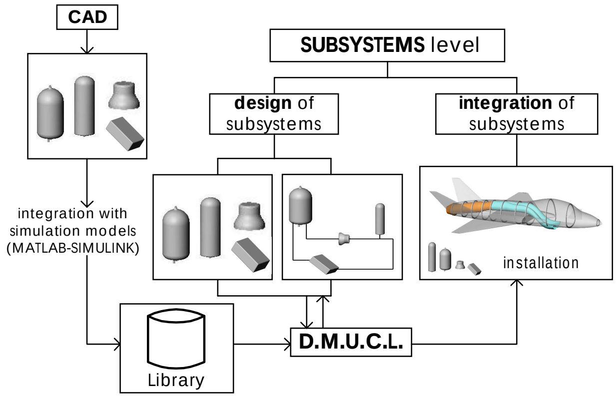

Fig7: Construction procedure of DMUCL

Works [16] and [17] more widely deal with DMUCL. It has to be observed that the DMUCL carrying out activity, apart from providing the possibility of the maintenance accessibility and the first steps of the assembling procedures study, succeeds in attaining extremely important goals as far as the accuracy level of the elaborated concept is concerned. They are:

- The possibility of considering and estimating different aircraft centre of gravity positions (depending on the fuel volume on-board and the weight of the weapons carried) that have to match with the aerodynamic centre longitudinal location, subsonic and, if feasible, supersonic;
- The possibility of verifying the feasibility of all required systems installation as the aircraft external configuration has been conceived.

The final result of the conceptual design is given by fig.9 (system level), fig.10 (subsystem level) -and obviously by the aforementioned figg.5,8- and by tab.2 (performances estimation), tab.3. The last one summarizes the second level weight estimation, that became possible after subsystems definition and was implemented by utilising a detailed set of Weight Estimation Relationships (W.E.R.S.).

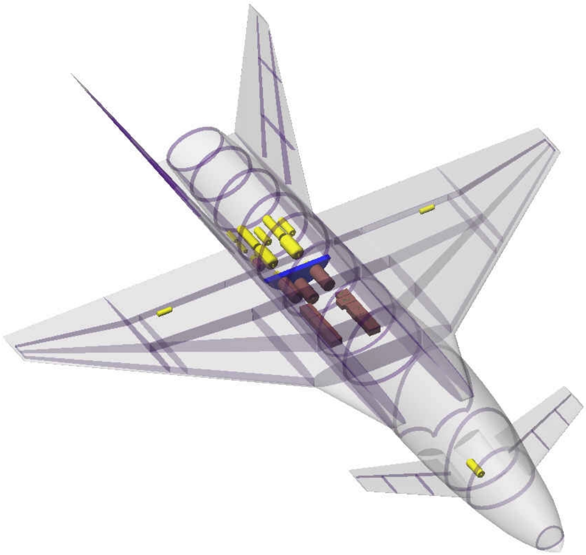

Fig.8a: DMUCL (example of a system)

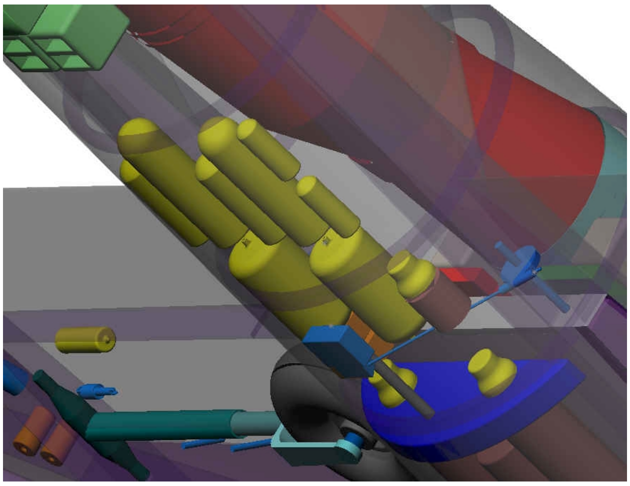

Fig.8b: DMUCL (view of a particular airplane zone)

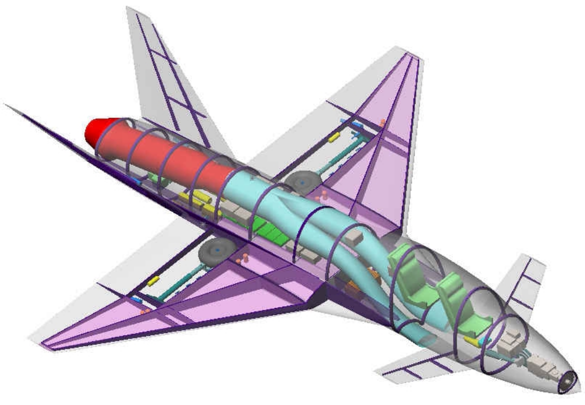

Fig.8c: DMUCL (complete)

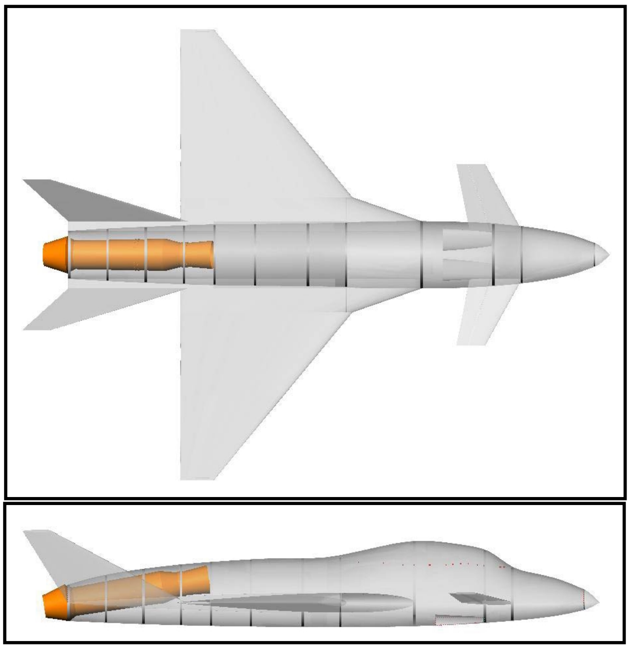

Fig9: SCALT view drawing

Characteristics and Performances	
W/S<350 kg/m^2 AR=3.75 b=9.1 m, S=21.6 m^2 $L_{fuselage}$=11.34 m	MTOGW=7500 kg T=7500 kg ITEC TFE 1042-70 "improved" with AB
$L_{TO} = L_{land} < 720$ m	
Mach max = 1.55	
LO-LO-LO "radar suppression" mission (fuel = 1800 kg, V = 250 m/s): mission range= 350 km	
Max vertical speed = 64 m/s	
Instantaneous turn (V = 180 m/s, sea level): radius = 416 m	
sustained turn rate (z = 15000 ft (ISA), with AB): angular speed = 19°/s	

Tab2: SCALT characteristics and performances

The initially hypothesized weights –at system level- (MTOGW, MEW, etc) are confirmed by the new obtained results.

The described aircraft configuration (as the figures mentioned above show) gives the chance to observe various characteristics, elaborated by the Research Team. These characteristics stem from the search for innovative solutions and they have been adopted after a careful comparison with more traditional configurations has been considered.

The following choices have to be observed:

a) In order to have an aerodynamic clean fuselage shape, considering also the necessary internal volume and the frontal area constraint because of the pilots presence, the fuselage medium height is conspicuous; subsequently, a huge internal volume is guaranteed. In this way, as it can be noted from DMUCL, all aircraft systems have been quite easily contained and positioned on board.

RESULTS	[KG]
wing weight	404.74
horizontal tail weight	72.99
vertical tail weight	108.97
body weight	759.16
main landing gear weight	438.67
nose landing gear weight	74.29
flight controls weight	220.79
propulsion installation weight	102.84
propulsion controls weight	9.25
air induction weight	178.33
fuel system weight	48.34
secondary power/ECS weight	93.99
avionics weight	386.1
instruments weight	80.98
hydraulic system weight	86.48
electric system weight	265.7
Furnishing & armament weight	197.58
MEW	4255.12
OEW	4475.12
MTOGW	7505.37
fuel (internal) weight	1806.25
weapons weight (with pods/SEAD mission)	1120

Tab3: Weight estimation results

b) The delta-foreplane configuration with wing trailing edge extensions that reach the jet outlet sides, that we can call “back-strakes”. These last ones carry two “butterfly” surfaces characterized by good stealth characteristics. Small flaps are placed in the rear part of the back-strakes; they are very effective for low speed pitch control thanks to the shield effect due to the “butterfly” surfaces.
The shield effect is also useful to reduce engine outlet I.R. signature.

c) The adoption of an “almost-mid” wing and the idea of placing the engine (the engine front diameter is smaller than the fuselage height) with a certain inclination angle in order to allow the air ducts coming from the air-intakes (on the bottom of the fuselage to have high and effective performances at high angle of attack) to pass over the centre wing section. These choices have been made in order to obtain low aerodynamic drag and favourable stealth characteristics.
A further contribution to the low detectability is given by the bending air ducts path, so the compressor blades are hidden away from the enemy radars.

d) In a detailed analysis of the internal configuration the above mentioned architecture will turn out to be very functional regarding the following aspects:
   - AMAG (Aircraft Mounted Accessories Gear-box) easy installation and configuration design.
   - The possibility of removing the engine out of the fuselage without breaking the structural continuity.
   - Most parts of the hydraulic system are placed in a limited area so that the necessity of pipes connections/disconnections is minimized when the rear part of the fuselage has to be removed. This last operation is not frequent, because it is necessary only when the whole AMAG removal/substitution is required. The AMAG “plug-in” configuration let the single rotor assembly to be removed.

e) The retraction of the main landing gear only in the wings implying rotation towards the inside (thus reducing the rolling inertial moment). The landing gear high let external weapons like HARM missiles to be carried. The wide

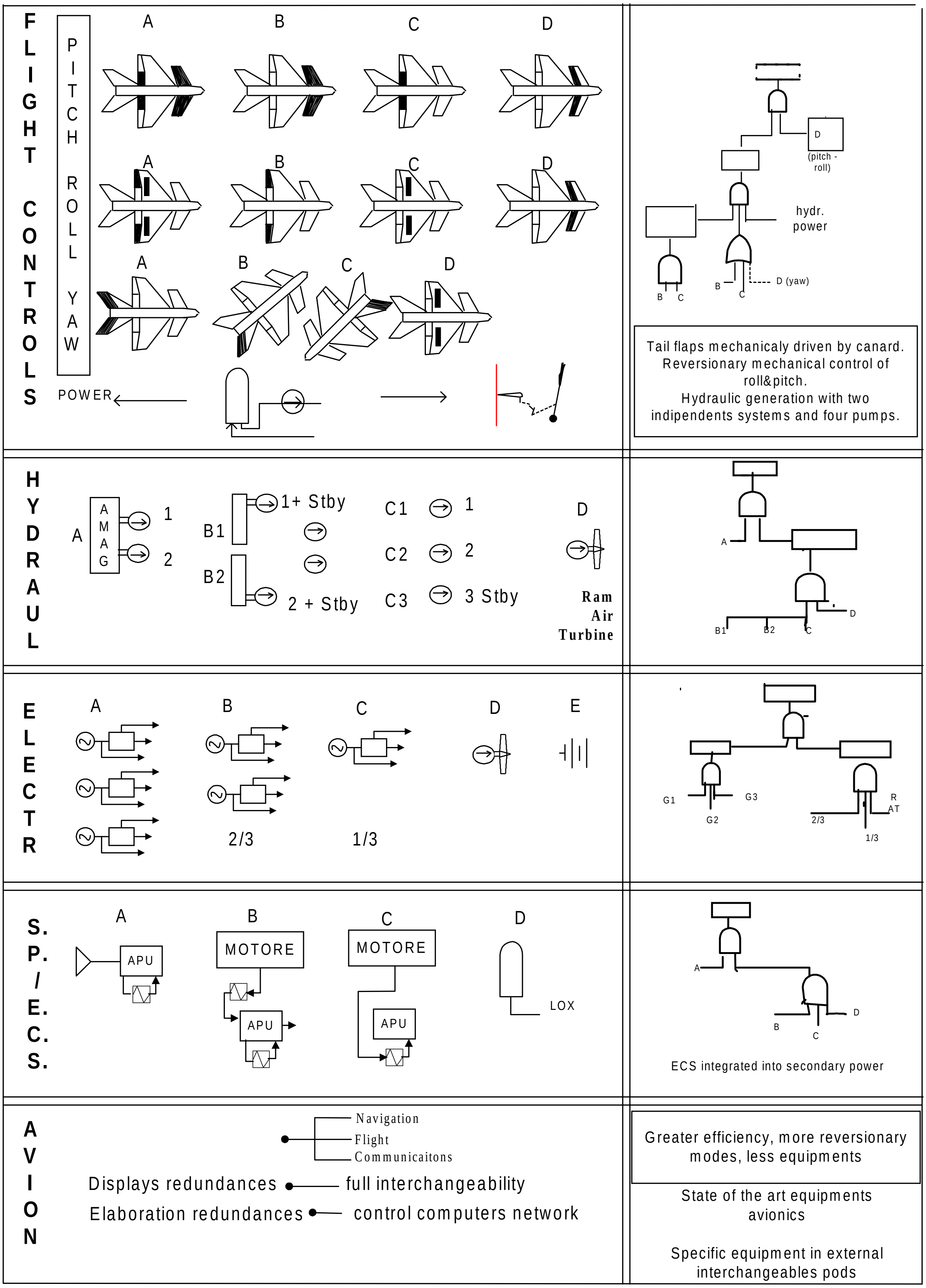

Fig10: SCALT subsystems redundancies

track and the low pressures tyres have also to be noticed.

f) Although the AMAG can be also set going by the engine, it is normally driven by APU, which works throughout the flight. The APU also integrates the air-conditioning system by a second turbine (for air expansion) which is engaged with APU itself, thus allowing to save energy, even though they are separated from the fluid-dynamic point of view.
   The heat exchangers of the air-conditioning system, as well as the coolers of all various machines that require it, exploit the fuel with refrigerating purpose. This enables to avoid the aerodynamic drag unlike all systems cooled down by external air where aerodynamic drag cannot be avoided.
g) Structural configuration integrated with systems and subsystems layout (bulkhead connected with engine mount and the main wing spar; the wing structural layout is optimised to support concentrated loads as landing gears, trailing edge surfaces and actuators).
h) In spite of the aircraft simple configuration, redundancies and on-board systems reversionary working modes are foreseen as shown in figure 10.

Further details can be found in works [13], [14] [15], [16] and [17].

The evaluation of subsystems costs, of the various phases of the programme and of the life cycle activities, are illustrated in tables 4 and 5. All SCALT values are quite good and positive, notwithstanding the scarcely optimistic hypothesis assumed (for instance the hypothesis of producing only 100 vehicles).

The SCALT caught up level of definition as over exposed renders interesting the application of the risks analysis even in an academic environment which is very realistic though. The risks analysis allows [18] the more critical aspects of the design to be evaluated for a successive development of the project, taking into account a mix of factors that can increase the risk for both subsystems and systems.

In particular, tracing what has already been conceived for another extremely innovative project carried out at DIASP (the above discussed C1350 Gulliver), a few elements have been priority considered in the application to the SCALT project, like the technological innovation level and the complexity level which together carry to an indicative score of the basic risk. Table 6 illustrates it.

4 BEYOND THE SCALT AND CONCLUSIONS

It is important to observe that the idea of starting a new research activity based on the previous acquired experience and turned towards the definition of a 3D CAD aircraft design procedure drew inspiration from the application of 3D CAD software tool to the SCALT aircraft research activity. Actually the modern 3D CAD software tool foresees different strategies to get one single result. These strategies may then be more or less effective depending on the present case studied.

The SCALT further definition level has pursued four results, as it should appear from what has been described above:

- Implementing an innovative and satisfactory aircraft concept;
- Defining a new conceptual design methodology widely based on 3D CAD software tool;
- Contributing to the didactic activity, both for the students directly involved in the research activity and for other students;
- Indicating a new research area turned towards the definition of optimised procedures for the 3D CAD utilisation.

The definition of optimised procedures for the 3D CAD utilisation and the implementation of a new conceptual design methodology have now become the main targets of the research activity leading to a PhD degree in Aerospace Engineering pursued by the same students that were previously involved into the research project within the completion of their

Hypotheses:
Prototypes number = 2; structural test frames number = 2; production of 100 aircrafts;
Aircraft life foreseen L = 10000 FH/ 20years; reference year for costs =2005;
Cost/engineering Hour =73 USD; Cost/labour H =55 USD; Cost/Maintenance Man Hour =66 USD;
C_f = fuel cost =0.33 USD/ l.;
Logistic support initial cost =1/3(aircraft cost); average mission time = 2.57 FH;
Maintenance levels = Organizational, Intermediate, Dépot ;
Maximum number of people working at maintenance at the same time = 4
Organizational and Intermediate Maintenance time percentage= 52%
[25% = Organizational maintenance; 45% = Scheduled maintenance; 30% = unscheduled maintenance]

Tab4: Hypotheses for costs estimation

COSTS: RAND / ROSKAM MODEL	***COSTS: BELTRAMO MODEL***
Man Hours for research and development = 4,5521,125	C_{b1} = 1,203,458 USD (wing)
C_1 = research and development costs = 586,200,463 USD	C_{b2} = 1,740,843 USD (fuselage)
MH test aircraft manufacturing= 3,223,450 hours	C_{b3} = 548,403 USD (tails)
test aircraft manufacturing cost= 189,114,854 USD	C_{b4} = 869,131 USD (propulsion)
C_2 = not recurrent production cost = 322,888,707 USD	C_{b5} = 301,021 USD (air induction)
$C_4 = \Sigma$ (not recurrent costs) = 909,089,170 USD	C_{b6} = 266,433 USD (landing gear)
C_3 = *single aircraft production cost*** = 10,146,536 USD	C_{b7} = 2,799,015 USD (avionics)
C_4 = single aircraft prize = 21,774,062 USD	C_{b8} = 144,912 USD (Second. Power / ECS)
C_5 = Prize + log. support initial cost = 29,032,000 USD	C_{b9} = 17,338 USD (fuel system)
	C_{b10} = 6,689 USD (electric system)
	C_{b11} = 27,273 USD (hydraulic system)
	C_{b12} = 286,470 USD (flight controls)
** PROFIT included	C_{b13} = 2,098,090 USD (assembly)
Financial interests not included	C_6 = *10,490,450 USD* (ΣC_{bi})

Tab5: Costs estimation

graduation thesis. In this way, as figure 11 shows, the design research activity has been stretched to postgraduate level (third level in Italian Universities). Figure 11 also shows how students of the first degree level (that is to say students attending the first three years courses) may benefit by the research activity undertaken

Students of the first level may in fact be required to design systems detailes which are part of the SCALT aircraft systems. The PhD students actively involved in the SCALT definition and implementation research project may now give the first level students tutorials concerning the above mentioned systems detailes design works, fully performed by using 3D CAD tools. In this way both a useful teaching experience and a further innovative research experience are attained.

As far as this last consideration is concerned, the research activity turned towards the optimisation of CAD 3D utilisation procedures is carried on with the intent of getting more students directly involved in the future. With regard to this future intent, in order to widen the research activity, new research areas are now being explored, like the Unmanned Combat Air Vehicle (UCAV) [18], “micro” UAV, experimenting and/or explorating vehicles used for space planet missions, innovative cargo aircrafts, transatmospheric aircrafts, technological demonstrators of transatmospheric vehicles, hypothesis of aircraft/car, etc.

Apart from improving the CAD 3D software tool utilisation, at least some of the above cited “preconceptual design” activities are expected to be further developed in order to carry on a highly interesting research activity.

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RISK ANALISYS: "SCORES" TABLE					
TECHNOLOGICAL LEVEL (1 = state of the art → 5 = advanced)					
5	6	7	8	9 avionics & flight controls	10
4	5	6	7 electric system hydraulic system fuel system	8 avionics configuration	9 secondary power / ECS
3	4	5	6 engine	7 flight controls	8
2	3	4	5 landing gear	6 structure	7
1	2	3	4	5	6
	1	**2**	**3**	**4**	**5**
COMPLEXITY	**1**= hydraulic system of an "executive" → **5**= hydraulic system of "F-22"				
SCORE = complexity + technological level					

Tab6: Risk analysis: technological levels and complexity

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AKNOWLEDGEMENTS:

The authors are very grateful to the other members of the "SCALT team" Ingg. D. Camatti, S. Corpino, M. Pasquino. A particular thank to the Ing. N. Viola for the precious cooperation given to this activity.

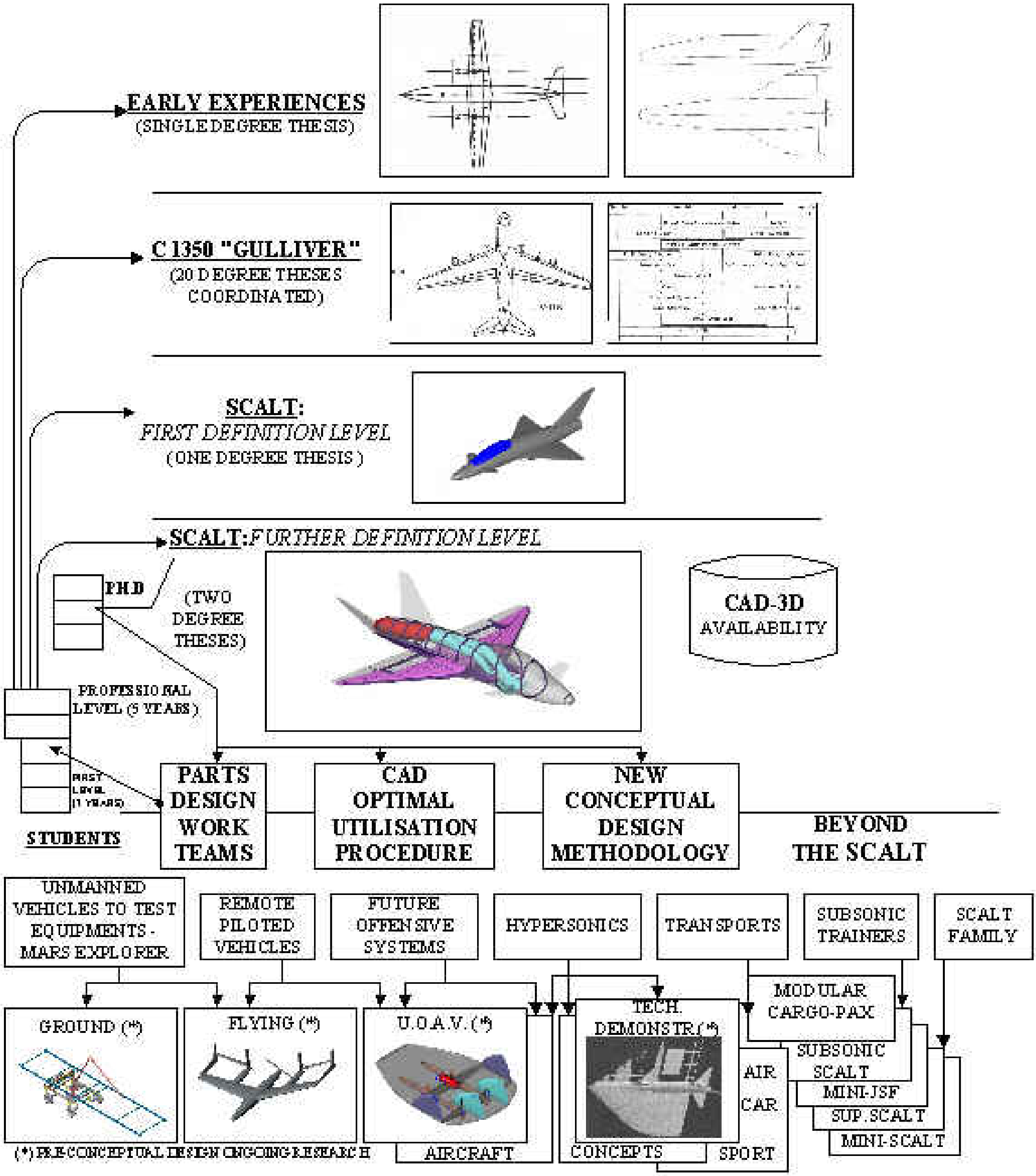

Fig11: Summary of design activities