APPLICATION OF THE INTEGRATED PRODUCT TEAM (IPT) CONCEPT TO THE RE-ENGINE OF A VERY LIGHT JET (VLJ)

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Keywords: *Re-Engine, VLJ, Integrated Product Team, Lean Engineering*

Abstract

The Lean enterprise is one who consistently and continually identifies and eliminates waste in its products and processes for the purpose of adding value. While concepts such as Lean Manufacturing and Lean Supply Chain Management are becoming widely known and adopted, Lean Engineering and Lean Product Development remain markedly under-utilized in many industries. Lean Product Development emphasizes two distinct approaches: the first is "doing the right thing" and the second is "doing things right".

The Gas turbine Lab at Embry-Riddle University recently embarked on a very ambitious project to re-engine a very light jet (VLJ) that had twin, fuselage-embedded, turbojet engines. After several unsuccessful attempts to fit new Turbofan engines inside the fuselage the project was temporarily halted. To better explore alternatives, a simulated Integrated Product Team (IPT) was formed. The stakeholders were identified and each stakeholder then outlined his requirements and risks for the team. The engineers were tasked with finding alternate solutions to be judged.

Five different configurations were outlined as possible solutions. The IPT then agreed on a set of criteria to judge all of the configurations. A grading scale was implemented with the stipulation that the grade be agreed upon unanimously by the IPT members. Whenever disagreement was difficult to resolve, a mock A3 report was created to better understand and converge on a grade. A configuration that was substantially different from the starting point emerged as a clear winner. The winning configuration was presented and scrutinized by all involved including the customer, FAA Designated Engineering representatives (DER), FAA Designated Airworthiness Representatives (DAR), and the engine manufacturer, and was adopted as the best possible solution.

1 Introduction

Industry, as a whole, seems to have been slow to motivate members of their product development (PD) organization, mainly engineers, to become fully engaged in the enterprise's Lean journey. While the manufacturing and supply chain segments, for instance, have readily adopted such initiatives as "6-sigma" or lean manufacturing, the engineering community has found only frustration. For example, 6-sigma is a powerful tool of statistical process control, but demands a mass-production-type environment to show its true potential. Design engineers, for instance, rarely tackle the same specific task twice.

However, it is imperative that the engineering community become fully engaged. As Fabrycky and Blanchard [1] point out, the design organization will have a significant impact on the product's Life Cycle Cost (LCC), Figure 1. Typically, 80% of the LCC are permanently embedded in the product's "DNA" prior to the start of the production phase. This observation becomes more critical when one considers that during the conceptual and detail design phases, product costs incurred are still considerably smaller. This fact is likely to exacerbate the problem since organizations tend to focus more of their executive attention on costly items and projects.

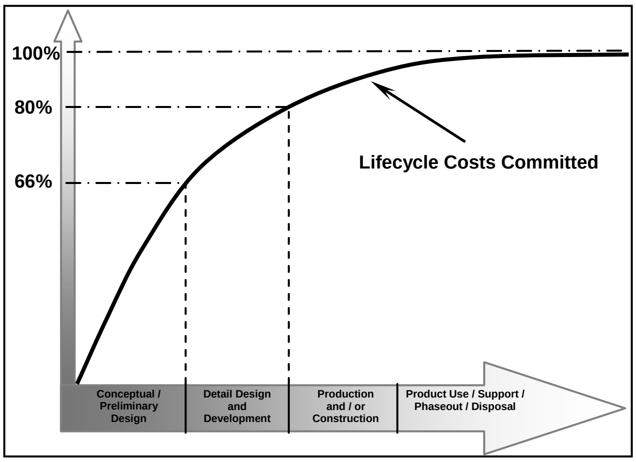

Fig. 1. Lifecycle Costs (LCC) Committed per Product Phase (adapted from [1]).

Much work has been done in the field of Lean Product Development, such as identifying the "how-to" of properly mapping value in the PD organization, McManus [2], as well as its many benefits. One of the most potent chapters in the book of Lean PD is the employment of the Integrated Product Team (IPT).

The successful IPT is formed of representatives of all the enterprise stakeholders. Murman et. al [3] identify three distinct levels of enterprises: *program* enterprises, *multi-program* enterprises, and *national and international* enterprises. As to the definition of a stakeholder, scholars offer varying opinions. However, Kochan and Rubinstein [4] list three criteria to further identify tiers of stakeholders: (a) by the extent of their contribution, (b) by the extent of their control and influence over resources, and (c) by the power they have over the enterprise.

The successful IPT will also include a moderator or facilitator. The role of the member is to clearly express his organization's value to the other stakeholders, its capabilities, and share lessons learned. But a key success factor is to maintain a spirit of openness and collaboration, in other words uphold the principle that "*the product is the boss*". The objective here is not to solicit a compromise but to make others aware of the many pitfalls of designing in a vacuum. Another significant key success factor is upper management's buy-in and support. The major role of the facilitator is mainly to educate the others on various Lean tools with which the IPT can accomplish its mission and ensure forward progress at all time. It is important that the facilitator be well equipped and empowered for such a task. In such an environment, the IPT will consistently produce a product that adds value to all stakeholders.

2 Problem Statement

The Gas Turbine Laboratory at Embry-Riddle University was tasked to conduct a feasibility study to re-engine a very light jet (VLJ), originally equipped with twin fuselage-embedded turbojets. These old turbojets delivered very poor performance that restricted the range, and thus competitiveness of the aircraft. Modern turbofans were identified to meet the customer's range needs as well as increase the cruise speed of the aircraft. Upon selection of the appropriate engine, detailed engine geometries were obtained from the OEM's and, based on the customer's instructions; the process to try and fit the new engines in the fuselage started.

It was quickly discovered that the fit wasn't automatic and much modification was needed. Fig. 2, for instance, shows the difference in size between the engine inlet diameter and the old orifice in the existing frame (2 inches smaller diameter) where the previous inlet ducting passed through, and the apparent misalignment. In this case, this frame is a major structural frame and carries the secondary wing spar.

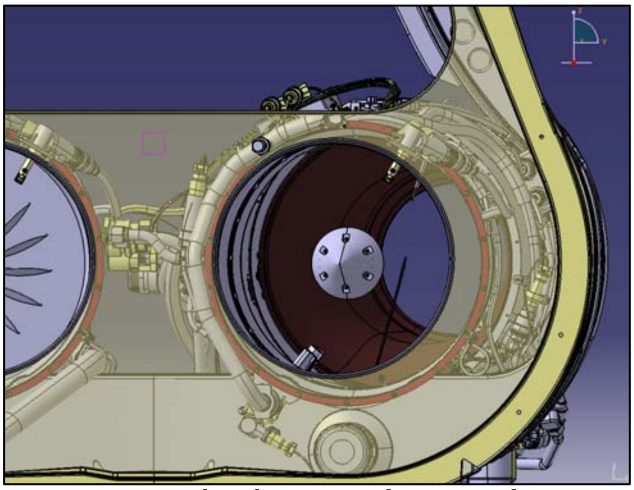

Fig. 2. Engine Inlet Shown in Relation to Inlet Ducting Orifice Located within a Major Frame, which is made semitransparent for ease of visualization. (Image is not to scale)

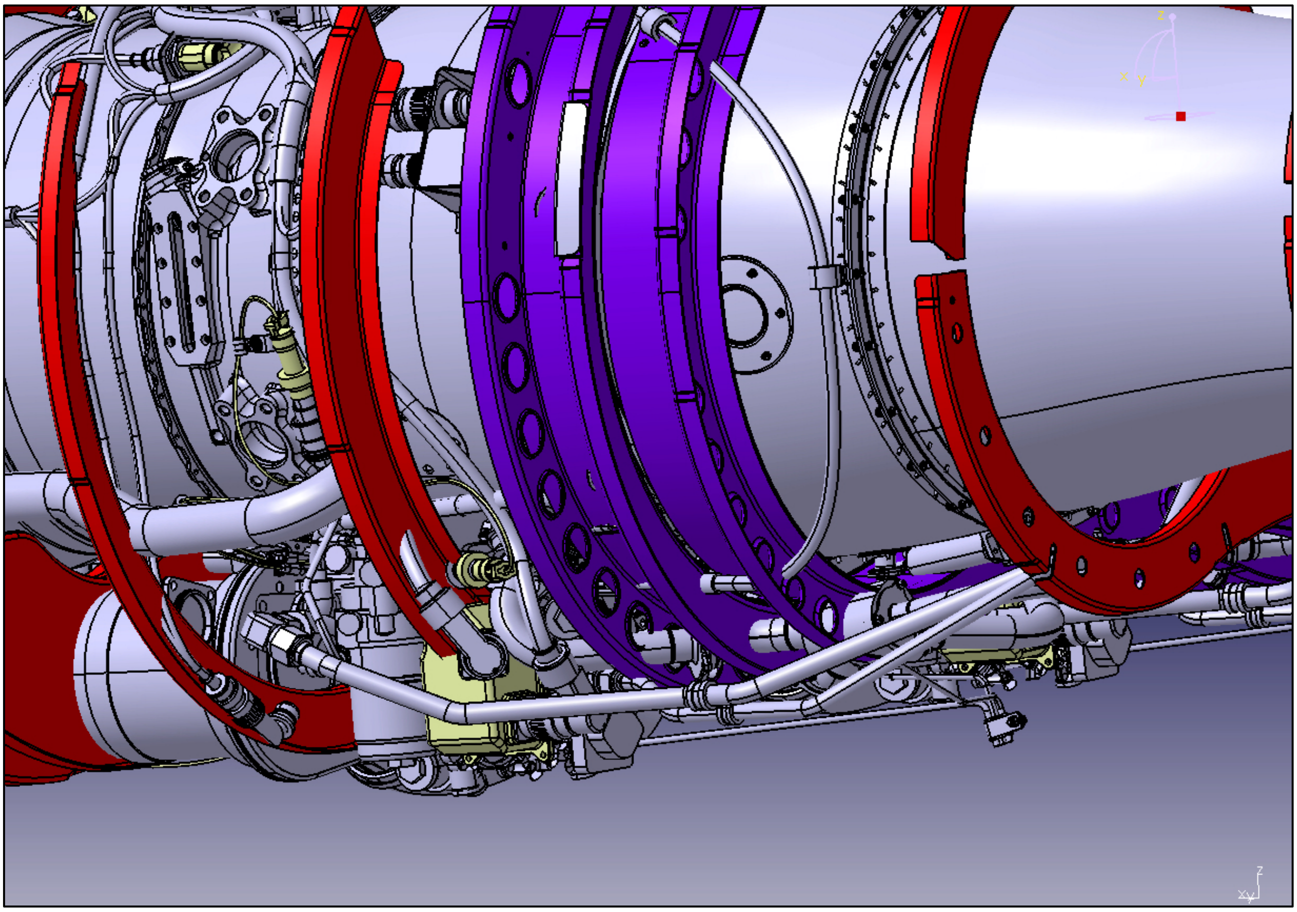

Fig. 3. Isometric View of Turbofan Auxiliary Systems, Pipes, and Tubes Interfering with Major Aircraft Frames and Protruding Outside the Aircraft Skin (front of aircraft is to the left, image is not to scale).

The team then embarked on a tedious process to visit every frame, stringer, and component impacted by the proposed change. The list of items to be modified grew to include inlets, inlet ducting, frames, stringers, mounting points, access hatches, and exhaust ducts and nozzles, to name a few. The list of affected systems also grew to include almost all the systems of the aircraft. Figs. 3 and 4 show the interference of the engine auxiliary systems with the aircraft frames. The large purple frames in the middle of the figures are where the main fuselage (front two thirds segment) mates with the rear third segment of the fuselage, and are considered a major structural component.

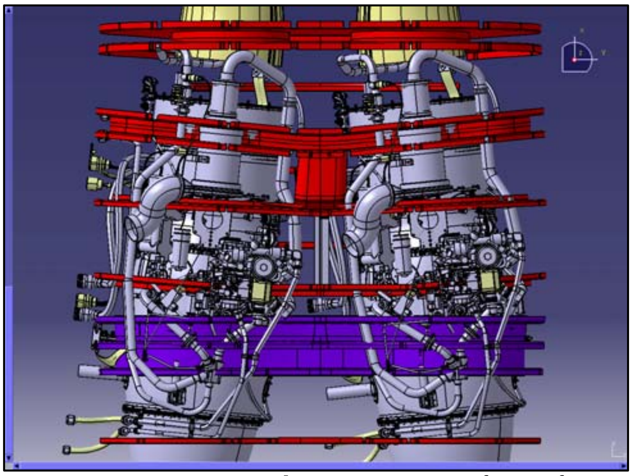

Fig. 4 Bottom View Showing Extent of Interference Between Engine Auxiliary Systems and Aircraft Frames (front of aircraft is up, image is not to scale).

One of the customer's primary business objectives was to avoid a rejection by the Federal Aviation Administration (FAA) of the Supplemental Type Certificate application in favor of an entire aircraft recertification program, which would be an order of magnitude more costly and time consuming. Frustration mounted as the team realized that this objective was becoming less achievable as time passed by.

Murman et al [3] assert that the Lean Enterprise not only "*does things right*" but that it also "*does the right thing*". While the team was convinced that it was "*doing things right*", it questioned whether it was "*doing the right thing*". The team then decided to halt and take a more critical look at the project as a whole.

3 The Lean Approach

3.1 Isolating the Problem

Too often, a manager, a team lead, or any internal or external customer walks over to the engineer, briefly presents a problem along with how it should be solved. This approach is harmful on many fronts: first, it forbids the engineer from actually thinking about the problem and simply turns him or her into a technician. Secondly, accountability and ownership then migrate away from the engineer, and thirdly, and more importantly, with time it promotes an environment of apathy and indifference. So the first step was to isolate the problem and remove all else to the category of suggested possible solutions.

The problem was simply that of an aircraft that is underpowered and suffers from exceedingly poor fuel efficiency. Replacing the fuselage-embedded powerplant with a more modern version, but also fuselage-embedded, is simply one possible solution. Another solution is to make the aircraft lighter, and another is to select a different installation configuration. This thought process also helped lay the foundation for building a value proposition for this project. Clearly, the design domain needed more in-depth exploration. But more importantly, the question was who should make the decision. The answer was to form an IPT comprised of all the stakeholders to carefully weigh all options and ultimately unite on a going-forward solution.

3.2 IPT Formation and Procedure

- The stakeholders consisted of the following organizations or entities: the customer, the customer's customer (or end user), the engineers, the manufacturing as represented by the mechanics who would carry out the alteration, the maintenance and service organization, and the regulatory authority, which in this case is the FAA.
- Each representative then began to list the desires of his organization on one hand, and the limitation and risks on the other. This took the tone of an educational session where information was freely shared without reservation. This information exchange proved to be most valuable. While issues such as maintenance costs and marketability were somewhat obvious, others such as insurability were not.
- Prior to identifying some possible solutions, the team decided to first identify a set of criteria that would act as the basis for judging the solutions against each other and determining a winner. The criteria were:
    - difficulty,
    - risk,
    - time,
    - cost, and
    - reward
- Difficulty mainly pertained to resources including human, such as engineering expertise, software, and hardware, such as what would be required by an extensive flight test program, for instance. Time and Cost are self explanatory. Risk aimed to identify the likelihood of failure. For instance, having the FAA disallow an STC due to an overly complex modification, even if such a modification was the product of a sound engineering design, constituted a failure. Reward defined the degree by which the design achieved all or most of the requirements set by the customer. The scale was from 1 to 10, with a low score constituting goodness.

It was important to identify the criteria prior to identifying possible solutions. This limited the discussion and efficiently eliminated ideas that were unsuitable. Another important condition was imposed; that the IPT members would agree unanimously on the rating they would assign each solution for each category. This was a difficult condition to enforce, as will be discussed later.

3.3 Early Exploration of the Design Domain

A key success factor of the IPT's work is devising a solution that has acceptance and support from all stakeholders. This necessitates that all stakeholders participate in making that decision. This then requires that the solution is tailored, as much as possible, to everyone's needs and capabilities. Critics of Lean surmise that such an approach leads to unacceptable compromises that sacrifice quality, among other features.

Taking the needs and capabilities of other stakeholders into consideration ensures a better design in the end. An example of such consideration is, for instance, early investigations of TIG welding instead of overly expensive LASER welding and tailoring the design to it, or assessing the likelihood of timely procurement of complex parts and opting for a less complex part to meet the time-to-market targets. Such initiatives can only be made possible with early input from the manufacture and procurement sides of the house – during an IPT setting.

The IPT then began to write down all possible ideas to address the problem statement that was discussed earlier. The ideas were many and ranged from the overly simple to the excessively complex. The IPT quickly realized that sorting out all these ideas can be a time consuming, and potentially charged, exercise. It was then decided to institute a tiered evaluation system. This meant that, in addition to the previously mentioned criteria for evaluation, a first tier elimination round was necessary.

Each [solution] contributor was then allotted a few minutes to describe the key features of the solution. The criterion for quick elimination was a score of 10 (worst possible score) in two or more of the aforementioned criteria. Two examples are outlined for illustration:

3.3.1 Substantial Redesign of the Wings and Canopy

This solution focused on attacking the two major sources of aerodynamic drag. However, both the customer and the FAA stakeholder representatives gave this solution a 10. One of the customer's yet-to-be-revealed goals was to replace the existing turbojets since they are extremely loud and violate recent FAA [Noise] regulations [5]. The FAA stakeholder representative's logic was that a structural alteration of the wing will require a fairly substantial recertification of the wing, as well as the control surfaces. The substantiation and flight test program would consume most of the budget. Therefore, this solution was eliminated during the first round.

3.3.2 Smaller Turbofan Fuselage-Embedded Engines

This solution suggested installing smaller Turbofan engines, with lower thrust. In this configuration, it might be possible to revert to the initial fuselage-embedded installation if the volumetric footprint of the smaller engines allows it. This suggestion received favorable marks from the Engineering stakeholder representative, but it received unfavorable marks from the customer. The customer again was looking forward to the increased thrust since the aircraft seemed to be underpowered. However, the other objectives would be met. Thus, no stakeholder was able to justify two scores of 10 so this solution passed to the second round of eliminations.

3.4 Selecting a Solution

After the first round of eliminations was concluded, five potentially acceptable solutions remained. These are:

- To continue with twin embedded Turbofans,
- Smaller Twin embedded Turbofans
- Single embedded larger Turbofan
- Twin pylon-mounted Turbofans over the wing, and
- Twin pylon-mounted Turbofans near the tail

The IPT was then tasked with thoroughly evaluating each solution and assigning it a

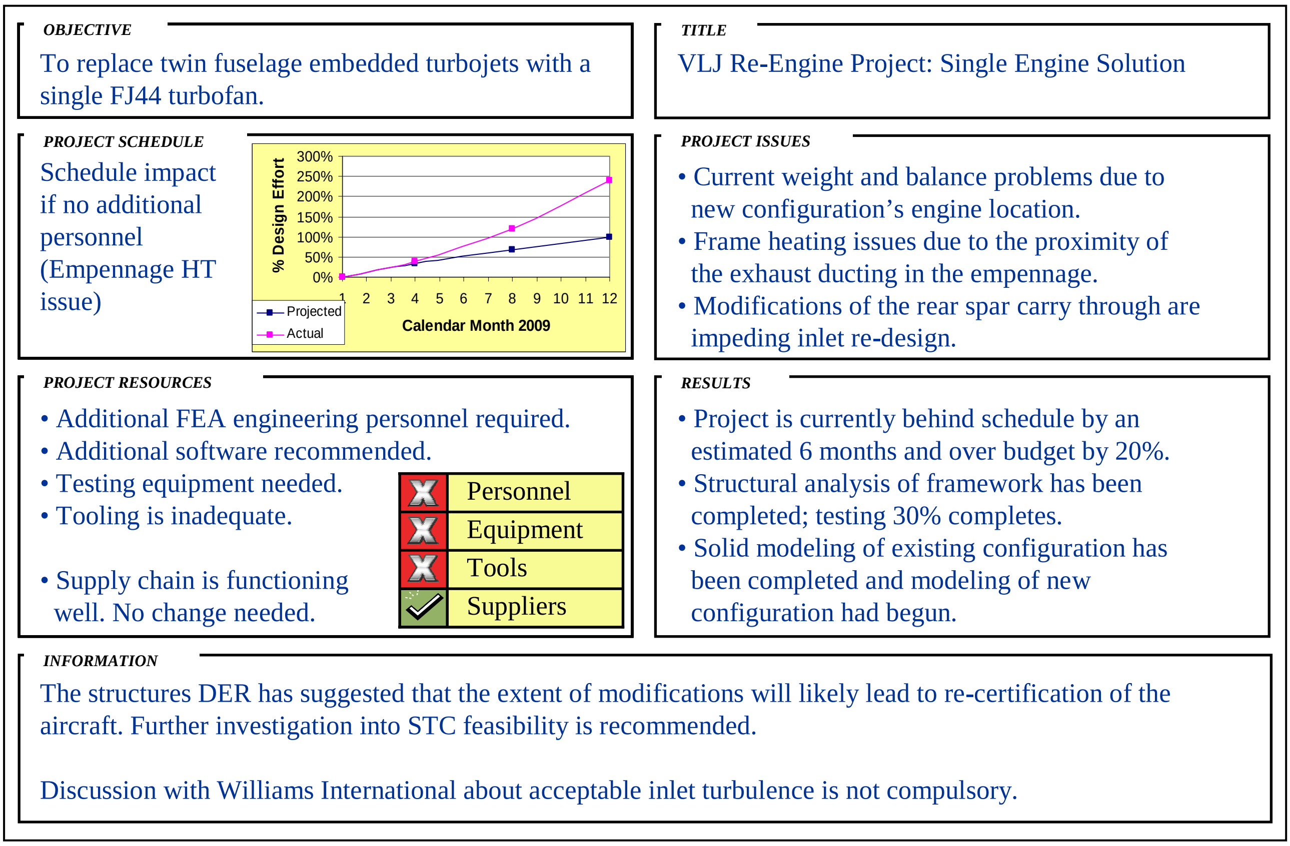

Fig. 5. Simplified "Mock" A3 Report of the Single Engine Solution with a Focus on Potential Engineering Design Issues.

rating. As previously discussed, and to ensure buy-in from all stakeholders, the condition of unanimity was imposed. However, disagreements soon arose and unanimity was more difficult to achieve than had been anticipated. To alleviate this situation, the concept of the A3 report was introduced. The A3 report was conceived by the Toyota Motor Company, and serves as a tool for describing the status of a project in a single snapshot. The term A3 comes from the convention for paper sizes. It refers to paper that is 11x17 inches. In this context, an IPT member created a mock A3 report to simulate what would be a project status after some time had passed.

Figure 5 shows a simplified A3 report of a single engine configuration. In this case, the member representing Engineering wanted to clearly express the difficulties of accommodating the jet exhaust nozzle deep inside the fuselage. The engineering stakeholder envisioned major issues with Weight and Balance, Heat Transfer, and inlet distortion. Eventually, the other members were convinced of the difficulties and risks of this solution and assigned it a high (unfavorable) rating.

The rating of the individual solutions continued until a winner emerged; the pylon-mounted, over the wing solution received the smallest total, table 1.

	Solution	Difficulty	Risk	Time	Cost	Reward	Total
1	Twin Embedded	9	8	9	8	3	37
2	Twin Embedded small	4	3.5	4	3	6	20.5
3	Single Embedded large	7.5	4.5	7	2	4.5	25.5
4	Twin Over Wing	5	2.5	3	4.5	3.5	18.5
5	Twin Tail	6	5.5	5	6	5	27.5

Table 1 IPT Solution Ratings

4 Summary and Discussion

Solution 4 envisioned twin Turbofan engines mounted on pylons over the fuselage. This configuration allowed for the engines to be at the same axial location as their predecessors, thus minimizing any adverse impact on the CG location. It received extremely high marks from the mechanics stakeholder organization as it greatly simplified maintenance and overhaul. It also received very favorable ratings in the risk category since the FAA is more accustomed to this configuration and is less likely to impose special requirements. This was a concern [of all the fuselage embedded solutions] given the engines proximity with respect to engine fire suppression and rotor burst issues. The customer saw the opportunity to add a substantial luggage compartment where the engines used to be and markedly enhance the marketability of the aircraft. Lastly, the aerodynamicists commented on the potential for enhancing the low-speed lift characteristics of the aircraft. Given that the engines are outside the fuselage, the wing root can now be redesigned with an aerodynamic section (instead of an opening for the inlet), and the engine inlet can and will act as a boundary layer re-energizer device.

Solution 4 satisfies all the stakeholders' needs by taking them into consideration upfront. While not a compromise, this solution is designed collaboratively by all the members. It can also be clearly seen that risk has been minimized and the likelihood of success is significantly greater. Lastly, since all stakeholders participate, it is highly likely that they will all support the project during unforeseen events. Figure 6 shows a conceptual design of the aircraft.

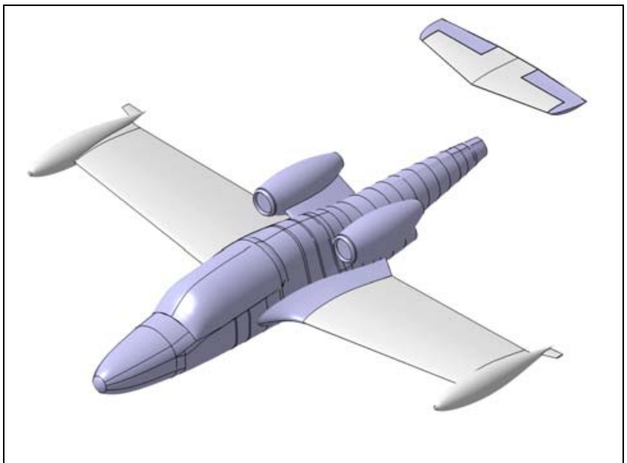

Fig. 6. Preliminary Concept of the Pylon-Mounted Configuration.

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