Advisory Report For CIRA USV Project

Peer Review Committee

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I. Foreword

The main concerns of the PRWG refer to the objectives of the entire USV program and to the vehicle shape proposed by CIRA for the next USV-X. This is the reason why most of the Report is devoted to these points; suggestions are given for possible alternatives that appear feasible from a strictly technical/scientific view point. A number of specific comments are also made on single paragraphs of the USV-X phase A Activity Report; PRWG believes that these comments will help improving the quality of the Report and avoiding contradictions between requirements and specifications.

II. Overall objectives of the USV program

PRWG believes that more realistic objectives should be set for the short/medium term time scale. Due to the many uncertainties of the long glide flight at hypersonic conditions it would be suitable that experiments on the aerodynamic shape (that dictates the aerothermodynamic reentry conditions) be the first objectives of the USV-X program. To clarify this point it is appropriate to address the two most similar programs dealing with hypersonic vehicles: the Expert by ESA and the OTV 37X-B by Air Force. Both these vehicles have well defined architectures (the Expert capsule and a scaled down version of the Space Shuttle) and their reentry trajectories can be considered as being fixed so that experimenters can design their P/Ls accordingly.
This is not the case for USV-X where it is just its shape the subject of the experiment aimed at a safe reentry of a winged body. A large number of aerodynamic features must be identified that would require many flights (to optimize the shape, the control surfaces, the GNC etc). It is the vehicle itself the subject of the experimentation. The aerothermodynamic conditions will change with the choices made on the vehicle shape.
Only in a long term, whenever an “optimum” architecture has been found for a “low risk” reentry, the USV-X program could reach the maturity of the Expert and OTV programs and add-on P/L can be offered to the scientific community.

III. FTB-1 - Objectives

PRWG expresses some concerns on the motivations of FTB1 flights. It might be reasonable to include, at the end of the mission, a simulated landing, before opening the parachute, to check the aerodynamic performances at landing conditions.

IV. USV-X Vehicle choice

Drop tests, suborbital and orbital reentry tests should aim at the same goal: check the flight behaviour of the very same vehicle at all flight conditions encountered during reentry.
If these are the logical objectives then a first prerequisite is to select and concentrate on a single typical vehicle architecture and to test that at the different flight conditions (hypersonic, supersonic, subsonic, landing).
It is clear that the main FTB-X design restrictions are those imposed by available features of VEGA launch vehicle regarding dimensions and masses of payloads being installed inside the LV head fairing. Those restrictions considerably reduce the capacities for flying demonstration of the new proposed concept of gliding atmospheric re-entry with high L/D ratio and low wing loading as opposed to the basic Shuttle Orbiter concept.
It is appropriate to recall the drastic C_L drop and the reduction of manoeuvring capabilities that occurs at subsonic conditions caused to the very low aspect ratio of the clipped wing (a C_L reduction of about 50% is expected with respect to the FTB-1 shape).
In conclusion PRWG stresses the contradiction between the FTB-1 and the USV-X objectives: a hypersonic shape is being tested at subsonic/supersonic conditions and a “wingless” winged body (closer to a lifting body) is being considered as vehicle for hypersonic flight. It is hard to understand what would be the benefit for a gliding vehicle to flight test the selected “clipped” wing geometry that is not able to cope with the assumed requirements of the USV program.

V. Specific comments on USV-X Phase A - Activity report

The comments and criticisms contained herein are presented solely to assist CIRA in improving the presentation of the FTB-X project and to eliminate contradictions between reqs and specs.
A number of comments and criticisms made on single paragraphs would be eliminated if the PRWG suggestions, as reported in the Conclusion, could be followed.

1.1 Purpose

This section clearly states that the FTB-X is to be a "flying test bed" upon which atmospheric re-entry experiments will be conducted in the future. To be successful in that role, the FTB-X vehicle must be able to attract European customers (researchers). Hence, versatility of the design is essential. In future reports CIRA should adopt a "European perspective" and clearly state what types of experiments FTB-X is capable of performing, noting their value to the European aerospace community. For the external customers, more clear definition of testing capabilities & conditions of FTB-X shall be required for participation and also clear identification of costs and time associated with R&D needed as well.
Depending on the versatile requests for design or technology aspects by the external customers, it may sometimes be required to conduct the joint-development of FTB-X vehicle with the external customer. If this is the case, the project will be more complex and divergent and become uncertain. Potential customers are like to pose questions similar to those developed by the PRWG.

4.1.1 Phase-A Mission Objectives

The statement of "An improved gliding re-entry and a high manoeuvering capability as compared to Space Shuttle" shall be misleading. "A longer flight duration" surely allows "for more extended in-flight testing capabilities in high energy hypersonic flight conditions" as FTB flying laboratories, but this does not always mean a more operational capability of the re-entry vehicle.
The USV-X configured vehicle might be laterally and/or directionally unstable for low-speed flight regime (below supersonic/transonic), although there is no analysis found in the document. This should be conducted as Phase-A design studies.
Since FTB-1 configuration is not the representative of USV-X, for both design validation and risk mitigation purposes, this aspect should be envisaged in Sub-orbital Re-entry Test (SRT). Could a SRT mitigate this paradox?

4.1.1.1 Orbital Re-entry Test

This re-entry test from 200km LEO is stated to be the "reference mission" for the FTB-X vehicle. The US Space Shuttle is stated to be the "reference vehicle." FTB-X is to better the performance of the Shuttle by demonstrating "improved gliding re-entry and high manoeuvering capability." In future reports such statement must be backed up with figures which clearly show that FTB-X does indeed exceed Shuttle's aerodynamic efficiency and cross-range capabilities. The PRWG expresses some doubts as to CIRA's ability to meet such goals with the current FTB-X vehicle since it wings have been "clipped" to accommodate the VEGA Booster. Unsubstantiated statements will hurt CIRA credibility in the eyes of potential customers.
CIRA further states that the FTB-X shall demonstrate angles-of-attack equal to or less than 20-degrees, plus longer duration re-entry profiles. It should state why these are better for re-entry missions. Advantages should be clearly spelled out.

4.1.3 System Design Requirements

Aerodynamic Shape: Stating "improved L / D ratio" compared to the Shuttle requires that we compare apples-to-apples. The relatively poor L / D of the Shuttle (~ 1.1) occurs at an angle of attack of 40—44 degrees. The vehicle itself is capable of higher L / D at lower angle of attacks.

Does the FTB-X vehicle clearly show an advantage when compared to Shuttle at the same angles-of-attack?

The goal of improving W / Sr again must be compared numerically to the Shuttle. Furthermore, CIRA must acknowledge that the FTB-X should show substantial improvement since it is not required to either carry humans or land in a conventional manner as does the Shuttle.

These system design requirements are too general for a contractor to develop a design. They need to be "fleshed out" (more detail).

Under "Launch System," the VEGA is spelled out as the only launcher. It might be more "saleable" to the European customers if follow-on variations of FTB-X would be compatible with other launchers. This might allow a full wingspan on the "FTB-X2" and improved aerodynamic efficiency.

Notably missing from this section is any mention of payload accommodation. Potential European customers would be displeased with the current FTB-X since it will not support their missions. Only the CIRA-defined-mission is now supported. Some volume must be defined as a "payload section."

Section 4.2 Conceptual Configuration Trade-off and Selection

Almost every aerospace system ever developed considered "payload" as a fundamental parameter. Yet there have apparently been no trade-off studies on this subject. This must be addressed if FTB-X is to attract paying customers in the future.

Section 4.2.1 VEGA Usable Volume

While a new, "increased" volume is described in this section, the new volume does not represent a significant improvement. The "new volume" does not relieve CIRA from producing a "clipped-wing" vehicle. This non-ideal vehicle will suffer a loss of L / D as a result of accommodating the VEGA launcher.

Section 4.2.2 Vehicle External Shapes Classification

Adoption of the V-tail as on the baseline FTB-1 is a good decision. First, it explores a control arrangement different than the Shuttle, and secondly, it may afford some limited controllability, even during the initial phases of re-entry, thus minimizing the size and weight of the reaction control system.

Section 4.2.3 FTB-X CAD Model

Use of CATIA as a CAD program is commendable. CATIA has become an industry standard.

4.3 Aerodynamic and Aero-thermodynamic Analysis

The document shows the aerodynamic analysis in the range between Mach 2-25, however it should be analyzed in the low-speed flight regime below Mach 2. For reusable FTB-X with several missions, the recovery requirement may affect the total vehicle design.

Regarding the sharp TPS & Hot Structure required for key USV-X components, it should not be the in-flight technology verification, but it should be the prerequisite qualification for multi-purpose FTB. High thermal loads for long re-entry duration (hour-long) demands very advanced TPS capability. Although extensive R&D's for developing UHTC are underway today, no practical UHTC/UHTM is currently available beyond 2000C without ablation. Under the present UHTC/M status, CIRA's requirement is too much demanding and depending on too risky technology, which will result in program uncertainty as a result. CIRA should take into account of these aspects. (*If such UHTC is to be flight-tested as payload, it should be an attractive experiment).*

In the document, CIRA mentioned the possibility of employing the active cooling design as an alternate option of UHTC. As technology challenge, it is attractive, but as mission success criteria it is not recommended.

Section 4.3.1.1 Project Requirements Influence
Requirement 1: High Manoeuverability: The clipped wing design will limit the usefulness of manoeuvers since such manoeuvers will not be demonstrated on a "practical design."

Requirement 2: Capability to Manage Long Missions: These one-to-three hour re-entry profiles will impact both TPS and heat load to the structure. A clearly defined methodology to manage thermal input is essential.

Requirement 3: Moderate Angle-of-Attack With Respect to Shuttle: It is stated that the FTB-X will re-enter at an angle-of-attack of 20-deg or less, compared to the Shuttle which re-enters at 40-deg. It is correct that this will impose higher heat loads on the lee side of the vehicle due to the lower degree of expansion. It should be noted that the Shuttle operates at high angles-of-attack (40—44-deg) only during the period of maximum heating.

Requirement 4: A Winged Vehicle Similar to FTB-1: This is impossible to do considering the constraints of the VEGA launcher.

Requirement 5: Nothing listed in Report

Requirement 6: Higher Efficiency With Respect of Shuttle: It should be demonstrated via wind tunnel tests that this requirement can be achieved with the current clipped-wing vehicle. Compare FTB-X with the Shuttle at the same angles-of-attack. The addition of vertical winglets (as on configuration FTB-X-2.2.2) would enhance L / D.

Requirement 7: Low Wing-Loading (W/S): Even considering the total plan form (including fuselage), the clipped wing vehicle will be challenged to meet this requirement.

Requirement 8: Use of the VEGA Launcher: Again we come to the single requirement that negatively impacts all the preceding requirements.

Section 4.3.1.2 Description of Used Approach
Presently only the continuum flow regime has been analyzed. With the proposed extended re-entry profile, the vehicle will spend a significant amount of time in rarefied flow. Analysis of the rarefied regime and real-gas effects should be coupled with wind tunnel measurements. This is essential before flight can be considered.

Section 4.3.1.4 Aerodynamic Analysis
It is commendable that a wide range of Reynolds number has been selected. CIRA should continue to analyze and conduct ground testing over as large a Reynolds number range as possible. Particular attention should be paid to the methodology used to adjust ground test results to flight conditions.

Section 4.3.1.5 Aerothermal Analysis
CIRA states: "…the risk of a premature laminar-to-turbulent transition, causing strong local overheating, must be taken into account using proper design margins." In the design process, such design margins are realized by assuming the worst case: "turbulent flow." Weight saving can be best realized by careful analysis of the lee-side heating. With the stated objective to better the design of the Space Shuttle, the FTB-X design will be challenged to substantially reduce the TPS weight percentage. The Shuttle TPS weighs 18,000 pounds, which is 12.5% of the Shuttle's dry weight. Shuttle TPS varies in weight from 9.15 pounds per square foot on the leading edges to

only .33 pounds per square foot on low heating areas of the lee side. For highly efficient re-entry vehicles, TPS surface roughness, cross-flow, and instability of the laminar boundary layer are the most important considerations.

It is correct that shock impingement on the wing will generate high heat loads due to shock-shock interaction. This high heating rate, using the proposed extended re-entry profile, will result in a high heat input to the vehicle structure in that area. This must be carefully analyzed in order to properly design the structure in that area. In addition, extensive ground tests would be advisable.

4.3.2 Flight Mechanics

4.3.2.1 Re-entry Mission Analysis

If the FTB-X is to be a true "technology demonstrator," it must be capable of meeting the needs of various customers. This translates into the ability to fly various re-entry profiles, thus demonstrating the advantages and disadvantages of these profiles. This of course would dictate that the TPS be robust enough to handle the most severe conditions. Obviously this would add weight to the vehicle, but the versatility would be worth the extra weight. Designing the vehicle for a narrow range of re-entry conditions will not attract customers.

4.3.2.2 Trim Maps and Stability Properties

CIRA should revisit papers written about the first Shuttle flight during which NASA did not properly account for Mach number, real-gas, and viscous effects when they adjusted perfect-gas wind tunnel data to flight conditions. This resulted in the trim point being close to the limit of the elevon deflection. Wind tunnel results can give erroneous trim points if not properly adjusted. CFD results should be at the correct Mach and Reynolds numbers and take real-gas effects into account.

4.4 System Architecture

4.4.1 Thermo-mechanical Configuration and Structural Layout

CIRA states that the wing leading edge will be constructed of UTHC, but would be capable of handling actively-cooled leading edge designs. Even if the active cooling in not required for the baseline design, having the ability to host such systems is attractive for future customers. CIRA must design as much versatility into the vehicle as possible within the constraints of weight and cost. The internal layout does not indicate any volume for experimental payloads. This will make this project "hard to sell" to other European customers.

4.4.2.1 Internal Thermal Protection System

Again concerning the need for versatility in order to attract European customers, the ability to actively cool potential payloads would be advisable.

4.4.3 Avionics Architecture

CIRA states that the avionics architecture can support payloads. This section should clearly state quantitatively the amount of excess bandwidth and data-rates the system can support.

4.4.4 Reaction Control System

Reaction control propellants should be "operationally friendly" as well as "environmentally friendly." This should be the case even at the expense of added weight and volume. Toxic and corrosive propellants will result in substantially higher operational costs due to the strict safety procedures required. Every attempt must be made to keep operational costs low in order to attract customers.

4.5.2 Mission Analysis

Again it should be emphasized that mission flexibility is essential for a true "research vehicle." CIRA should avoid restricting their future options. Potential customers may desire considerably different missions.

4.6 Safety Considerations

CIRA should consider in the design process how to best accommodate safety requirements. CSG may have requirements which would substantially impact FTB-X design.

VI. Conclusions

It seems appropriate a review of the USV short/medium term objectives; it is suggested that the objectives be restricted to the aerothermal experimentation of different shapes of winged reentry vehicles. Providing P/L opportunities on board of the vehicle to different experiments proposed by external customers should be a long term objective.
From a technical/scientific point of view the solution indicated for the USV-X shape appears unable to meet the main requirements of a "low risk" reentry vehicle. Since this choice seems to be motivated by the compatibility with the existing VEGA fairings it seems advisable to seek other possible alternatives of different launch vehicles capable to accommodate a demonstrator with the similar hypersonic shape of FTB-1