

AN MBSE-ORIENTED FRAMEWORK FOR AEROSPACE SYSTEMS EDUCATION: THE CEA-UFMG LIGHT-AIRCRAFT DESIGN-BUILD-TEST TRADITION

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Abstract

Aerospace engineering education increasingly requires learning environments capable of connecting disciplinary knowledge to systems thinking, model-based reasoning, physical implementation and evidence-based review. This paper presents an MBSE-oriented educational framework for aerospace systems education grounded in the light-aircraft design-build-test tradition of the Center for Aeronautical Studies at the Federal University of Minas Gerais (CEA-UFMG).

The proposed framework does not treat Model-Based Systems Engineering (MBSE) as a software-dependent subject. Instead, MBSE is used as an organizing logic to connect mission definition, requirements awareness, aircraft configuration, simplified analytical models, fabrication constraints, experimental culture, technical documentation and review evidence. The framework builds on a distinctive academic environment in which complete aircraft projects, historical design reports, workshop practice, composite manufacturing, wind-tunnel activities, hangar-based aircraft work and flight-test culture can be interpreted as educational artifacts for aerospace systems formation.

The study is structured as an educational framework contribution supported by a descriptive case implementation. The introductory implementation involved a mission-based aircraft-design activity in which first-year aerospace engineering students proposed controlled conceptual variants of a complete reference aircraft. Five groups addressed different missions: trainer, short takeoff and landing operation, cross-country flight, efficient operation and monitoring/observation. The activity was structured around simplified calculations, spreadsheet-based models, benchmark comparison, three-view drawings, technical reporting and oral presentation over approximately sixty days.

Aggregated post-activity student responses are used as preliminary implementation evidence, not as causal proof of learning gains. The aggregated responses suggest that the activity created opportunities for students to mobilize systems thinking, multidisciplinary communication, requirements awareness, model-based reasoning, physical-implementation awareness, trade-off reasoning and technical communication. The contribution of the paper is the translation of a classical aircraft design-build-test educational tradition into an MBSE-oriented framework compatible with broader aerospace systems formation and industry-informed discussions on the competencies expected from future engineers.

Keywords: engineering education, aerospace systems, model-based systems engineering, aircraft design education, design-build-test, systems thinking, project-based learning

1. Introduction

A distinctive opportunity in aerospace engineering education emerges when students are exposed not only to disciplinary content, but also to an institutional environment in which aircraft have historically been conceived, documented, fabricated, tested and used as learning artifacts. The Center for Aeronautical Studies at the Federal University of Minas Gerais (CEA-UFMG) represents such a

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context. Its light-aircraft tradition, associated with the work of Prof. Claudio Pinto de Barros and subsequent academic projects, has provided students with access to complete aircraft design reports, conceptual and preliminary design practices, fabrication resources, experimental infrastructure and flight-test culture [1, 2].

This design-build-test environment is a central element of the educational model discussed in this paper. Previous descriptions of the UFMG Aerospace Engineering program identify CEA-UFMG resources that include an aerospace manufacturing laboratory, aircraft in flying condition, a flight-test laboratory with a hangar at the Conselheiro Lafaiete airfield and wind-tunnel facilities for teaching and research [3]. Flight-test instrumentation work developed within the CEA-UFMG context also highlights the role of the Conselheiro Lafaiete hangar in expanding applied aeronautics research and in allowing students to connect theory and practice through operational aircraft [4]. Together, these elements create an early immersion in aeronautical engineering culture: students learn that models, drawings and spreadsheets are connected to materials, manufacturing processes, tests, operational constraints and real aircraft.

This institutional background is particularly relevant because aerospace engineering education is being challenged to move beyond discipline-isolated instruction. Contemporary aerospace development requires engineers who can reason across requirements, interfaces, models, assumptions, verification evidence, manufacturing constraints and lifecycle decisions. Therefore, the educational question is not only how to teach aerodynamics, structures, propulsion, flight mechanics or control, but how to help students understand how these domains interact within a complete aerospace system.

Engineering education literature reinforces the value of design-centered and project-based experiences for developing problem formulation, trade-off reasoning, technical communication and lifecycle awareness [5, 6, 7]. In aerospace education, design-build-fly activities, wind-tunnel-supported learning and flight-test education further demonstrate the importance of connecting theoretical instruction to physical aerospace practice [8, 9, 10].

Model-Based Systems Engineering (MBSE) provides a useful organizing logic for connecting these educational dimensions. In an academic context, however, MBSE should not be reduced to software training, formal notation or the use of a specific modelling environment. Its educational value lies in making explicit the relationships among mission objectives, requirements, functions, architectures, assumptions, analytical models, physical implementation, evidence, decisions and review actions. This interpretation is consistent with recent efforts to introduce MBSE and systems-thinking competencies into engineering curricula without making tool proficiency the central educational goal [11, 12, 13].

The CEA-UFMG tradition offers a concrete foundation for this type of MBSE-oriented education. Classical light-aircraft development activities already require students to connect mission definition, aircraft configuration, weight estimation, aerodynamic modelling, performance assessment, stability considerations, structural loads, manufacturing constraints, experimental verification and technical documentation. In this sense, the proposed framework does not replace the historical CEA-UFMG approach. Instead, it reinterprets that approach through a contemporary systems-engineering lens, making its implicit systems logic explicit and scalable across different stages of aerospace engineering formation.

This paper proposes an MBSE-oriented educational framework for aerospace systems formation grounded in the CEA-UFMG light-aircraft design-build-test tradition. The framework connects classical aircraft-design pedagogy with modern competencies expected from aerospace engineers, including systems thinking, requirements awareness, model-based reasoning, multidisciplinary communication, traceability, trade-off analysis and evidence-based technical review. The approach is intentionally based on non-proprietary educational artifacts and academic infrastructure, allowing industry-relevant competencies to be discussed without relying on sensitive industrial data or high-fidelity commercial tools.

The framework is also motivated by an academic-industrial perspective on aerospace engineering formation. Its purpose is not to define a proprietary training program, but to identify systems-thinking, model-based reasoning, traceability and evidence-review competencies that can be cultivated within an academic environment using non-proprietary educational artefacts.

An introductory implementation of the framework is discussed through a mission-based aircraft-design activity carried out in the aeronautics component of an introductory Aerospace Engineering course at UFMG. In this activity, first-year students worked with controlled conceptual variants of a complete reference aircraft. Five groups addressed different mission profiles: trainer, short takeoff and landing operation, cross-country flight, efficient operation and monitoring/observation. The activity lasted approximately sixty days and included mission definition, benchmark comparison, spreadsheet-based calculations, three-view drawings, technical reporting and oral presentation.

This implementation was not intended to produce complete aircraft designs or validated technical solutions. Rather, it was designed as an early systems-thinking exercise in which students could experience how a change in mission affects configuration, geometry, performance, operation, cost, complexity and technical communication. A complete reference aircraft was used as a stable educational artifact, enabling controlled modifications while preserving a link to an existing design logic. In this way, introductory students could engage with authentic aerospace reasoning without being required to master advanced mathematical models at the beginning of the program.

The research question addressed in this paper is: how can a historical light-aircraft design-build-test tradition be translated into an MBSE-oriented educational framework for broader aerospace systems formation?

The main contribution of this paper is the definition of a scalable educational framework that connects the CEA-UFMG design-build-test tradition to contemporary MBSE-oriented aerospace education. This contribution is developed through four elements: (i) characterization of the CEA-UFMG aerospace learning ecosystem as a source of educational artifacts; (ii) mapping between classical aircraft-design pedagogy and MBSE-oriented educational elements; (iii) description of an introductory mission-based implementation using controlled variants of a reference aircraft; and (iv) discussion of aggregated student-response evidence as an initial indication of competency development and framework limitations.

The paper is organized as follows. Section 2 presents the institutional and educational background of the CEA-UFMG light-aircraft design-build-test tradition. Section 3 defines the MBSE-oriented educational framework. Section 4 presents the study design and evidence strategy. Section 5 describes the introductory mission-based implementation. Section 6 discusses implementation evidence and perceived competency mobilization. Section 7 discusses implications for industry-informed aerospace systems education. Section 8 presents limitations and future work, followed by the conclusion in Section 9.

2. Institutional and Educational Background

2.1 Educational foundations for aerospace design-build-test learning

The introductory section positioned the central educational problem: aerospace students must learn not only disciplinary content, but also how disciplinary decisions interact within complete systems. This section expands that argument by situating the proposed framework within engineering education literature and aerospace-specific learning experiences.

Engineering design education has long emphasized that graduating engineers should be capable of formulating problems, developing alternatives, evaluating trade-offs and communicating decisions, rather than only solving well-defined analytical exercises [5, 14]. Project-based and problem-based learning approaches respond to this challenge by exposing students to open-ended situations in which they must produce artifacts, justify assumptions and negotiate constraints [6, 15, 16]. In the CDIO perspective, engineering education should also expose students to the broader lifecycle of conceiving, designing, implementing and operating engineering systems [7].

Aerospace education provides a particularly suitable context for this type of learning because aircraft-design problems naturally integrate mission, configuration, aerodynamics, structures, propulsion, stability, control, performance, manufacturing, operation and safety. Previous aerospace education experiences have used aircraft-design projects, design-build-fly activities, wind-tunnel-supported learning, rapid-prototyped models and flight-test education to connect theoretical learning to physical aerospace practice [8, 17, 9, 18, 10]. The educational value of these experiences is not limited to the final technical result. It lies in helping students develop systems thinking, requirements awareness,

model-based reasoning, multidisciplinary communication and evidence-oriented review habits.

2.2 The CEA-UFMG light-aircraft design-build-test tradition

The Center for Aeronautical Studies at the Federal University of Minas Gerais (CEA-UFMG) provides a distinctive institutional context for aerospace systems formation. Historically, the CEA-UFMG has been associated with the design, construction and testing of light aircraft, creating an educational culture in which students could interact with complete aircraft projects rather than only with isolated theoretical topics. This tradition is strongly associated with Prof. Claudio Pinto de Barros and with subsequent academic developments involving light aircraft, high-performance aircraft and experimental activities [1].

Within this tradition, aircraft projects served not only as technical deliverables, but also as educational artifacts. Complete design reports, configuration studies, drawings, weight estimates, aerodynamic calculations, performance analyses, stability considerations, loads, manufacturing discussions and test-related documentation provided students with an organized view of the aircraft as an integrated engineering system. Such artifacts allowed students to understand how design decisions propagate across several domains and how assumptions must be documented for later review.

The methodology for the development of light subsonic aircraft proposed in the CEA-UFMG context organizes aircraft development through stages such as specifications and requirements, preliminary studies, conceptual and preliminary design, detailed design, manufacturing, ground testing and flight testing [2]. Although a full aircraft-development cycle cannot be reproduced within an introductory course, its logic can be adapted pedagogically. Mission definition, configuration reasoning, simplified calculations, comparison with reference aircraft and critical discussion of limitations can be introduced early, while more advanced modelling, manufacturing and validation activities are gradually developed in later stages of the curriculum.

The FCA-1 Guara project is treated in this paper as a representative educational artifact of this tradition, not as the central object of the proposed framework. Its importance lies in the fact that a complete, organized and historically situated aircraft project can be used as a stable reference for controlled educational modifications [19]. Similar reference artifacts allow students to study an existing design logic before proposing changes, reducing the risk of unconstrained speculation and making trade-offs more visible.

2.3 Physical and experimental infrastructure as educational infrastructure

A central characteristic of the CEA-UFMG context is that aerospace education is not limited to classroom exposition or paper-based design exercises. Previous descriptions of the UFMG Aerospace Engineering program identify CEA-UFMG resources that include an aerospace manufacturing laboratory, aircraft in flying condition, a flight-test laboratory with a hangar at the Conselheiro Lafaiete airfield and wind-tunnel facilities for teaching and research [3]. Flight-test instrumentation work developed within the CEA-UFMG context also highlights the role of the Conselheiro Lafaiete hangar in expanding applied aeronautics research and in allowing students to connect theory and practice through operational aircraft [4].

This physical and experimental infrastructure is pedagogically significant. Workshops, machining and CNC resources, fiberglass and carbon-fiber composite manufacturing, wind-tunnel activities, hangar-based aircraft work and flight-test culture expose students to the fact that an aircraft is not only a mathematical object. It is a physical system whose design assumptions must eventually interact with materials, manufacturing processes, experimental evidence and operational constraints. This type of exposure is consistent with aerospace education experiences in which wind-tunnel testing, rapid-prototyped models, aircraft models, flight experience and academic flight testing were used to connect theoretical learning to physical aerospace practice [9, 18, 10, 20].

At an introductory level, this ecosystem allows simplified calculations and spreadsheet-based models to be interpreted as first approximations of a larger engineering process. Students may begin by comparing wing area, power, weight, payload, range or operational mission. Later in the curriculum, the same reasoning can be revisited through aerodynamics, structures, flight mechanics, manufacturing, wind-tunnel testing, instrumentation and flight-test evidence. The educational value therefore

emerges from continuity: early simplified models are not isolated exercises, but entry points into a broader aircraft-development culture.

The use of real or historically documented aircraft projects also supports authenticity. Students are not asked to solve a disconnected textbook problem. Instead, they work with aircraft that have mission, geometry, configuration choices, assumptions, documentation and a connection to a broader institutional history. This allows the instructor to introduce the idea that engineering design is not a linear sequence of formulas, but a structured process of making assumptions, evaluating consequences, documenting decisions, manufacturing physical artifacts, testing hypotheses and revising models as new evidence becomes available.

2.4 From design-build-test culture to MBSE-oriented education

Model-Based Systems Engineering (MBSE) provides a contemporary language for organizing this educational ecosystem. According to the INCOSE perspective, MBSE supports requirements, design, analysis, verification and validation activities through model-based representations across the system lifecycle [21]. In this paper, however, MBSE is not introduced as a tool-centric or notation-centric subject. The objective is to use MBSE-oriented reasoning to make explicit relationships that were already implicit in classical aircraft-design and design-build-test education.

From this perspective, a mission statement can be interpreted as the initial expression of stakeholder intent. Aircraft configuration becomes a system architecture. Simplified performance, stability and weight calculations become analytical model elements. Workshop practice and composite manufacturing introduce physical implementation constraints. Wind-tunnel activities, hangar work and flight-test culture introduce verification awareness. Design reports and presentations become evidence artifacts. Discussions of limitations, assumptions and future verification become part of an evidence-based review process.

Table 1 summarizes how the CEA-UFMG educational ecosystem can be interpreted through an MBSE-oriented educational lens. The table is not intended to claim that historical CEA-UFMG projects were formally developed using MBSE tools. Rather, it identifies how the underlying systems logic of the tradition can be made explicit for contemporary aerospace education.

This interpretation supports the central argument of the paper: the CEA-UFMG tradition is not only a historical asset, but also a foundation for a scalable MBSE-oriented framework for aerospace systems formation. The framework proposed in the next section builds on this foundation by organizing educational activities according to competencies, artifacts, model elements and evidence generated throughout the learning process.

3. MBSE-Oriented Educational Framework

3.1 Framework rationale

Building on the institutional and educational background discussed in Section 2, the proposed framework translates the CEA-UFMG light-aircraft design-build-test tradition into an explicit MBSE-oriented educational structure. The purpose of this translation is not to claim that historical CEA-UFMG projects were developed using formal MBSE tools. Rather, it is to identify and organize the systems logic already present in aircraft development: mission definition, requirements awareness, configuration choices, analytical models, assumptions, materials, manufacturing constraints, experimental evidence, trade-offs and technical decisions.

The framework is therefore positioned as an educational bridge between classical aircraft-design pedagogy and contemporary systems-engineering competencies. At one end, it preserves the practical and historical strength of the CEA-UFMG context: complete aircraft projects, reference design reports, fabrication culture, experimental infrastructure and flight-test awareness. At the other end, it provides a vocabulary for making relationships among objectives, architectures, models, implementation constraints, evidence and review actions visible to students.

This approach deliberately avoids treating MBSE as a tool-training subject in the introductory context. The emphasis is placed on MBSE-oriented reasoning: students progressively learn to ask what the aircraft is expected to do, how it is configured, which assumptions support the analysis, which models are being used, what physical constraints affect implementation, what evidence is generated and

Table 1 – CEA-UFMG design-build-test ecosystem interpreted through an MBSE-oriented educational lens.

Educational element	CEA-UFMG learning artifact or practice	MBSE-oriented interpretation
Mission definition	Light-aircraft mission statements, operational intent and aircraft-role discussions	Stakeholder intent, mission needs and initial requirements awareness
Reference aircraft projects	Complete aircraft reports, drawings, configuration data and historical project documentation	Baseline system representation and reusable educational architecture
Simplified calculations	Weight estimates, wing loading, power loading, performance, stability and loads spreadsheets	Analytical model elements with explicit assumptions and limited validity range
Design comparison	Benchmark aircraft, historical examples and comparison between variants	Trade-off analysis, alternative evaluation and decision rationale
Fabrication resources	Workshop practice, machining, CNC resources, fiberglass and carbon-fiber composite manufacturing and hangar-based aircraft work	Link between model assumptions, materials, manufacturability and physical implementation constraints
Experimental and flight-test culture	Wind-tunnel activities, ground-test logic, hangar operations and flight-test awareness supported by regional airport infrastructure	Verification awareness, evidence generation and model-review logic
Technical reports and presentations	Written reports, three-view drawings, tables, plots and oral defense	Communication artifacts, traceability records and review evidence
Curricular progression	Introductory activities followed by advanced aerodynamics, structures, flight mechanics, manufacturing, testing and design	Scalable formation pathway from low-fidelity models to higher-fidelity engineering reasoning

how decisions should be documented and reviewed. This interpretation is consistent with MBSE education efforts that emphasize systems thinking, traceability and model-based reasoning rather than tool proficiency alone [11, 12, 13].

3.2 Framework structure

The proposed framework is organized into six educational layers: mission and requirements, system architecture, analytical models, physical implementation, evidence and review, and technical communication. These layers are not intended to reproduce a complete industrial MBSE process. Rather, they provide a scalable educational structure that can be applied from introductory activities to more advanced aerospace projects.

At the introductory level, each layer is represented by low-fidelity artifacts such as mission statements, comparison tables, simplified spreadsheets, conceptual drawings, qualitative trade-off discussions and oral presentations. At later stages of the curriculum, the same layers can be revisited through higher-fidelity models, fabrication activities, wind-tunnel tests, instrumentation, flight-test data and more formal systems-engineering representations. This progression allows the framework to connect early systems thinking with advanced disciplinary learning and physical aerospace practice.

The relationship among the institutional context, the educational layers and the targeted competencies is summarized in Figure 1. The figure should be read as a conceptual synthesis of the framework: the CEA-UFMG design-build-test context provides educational artifacts, the MBSE-oriented layers organize these artifacts into a structured learning sequence, and the targeted competencies indicate the intended educational direction.

Table 2 then details the six educational layers of the framework and their interpretation.

The same framework can operate at different levels of fidelity. In an introductory course, the model may be a spreadsheet, physical implementation may appear as a qualitative discussion of manufacturing or maintenance constraints, and evidence may be a comparison table or a normalized plot. In

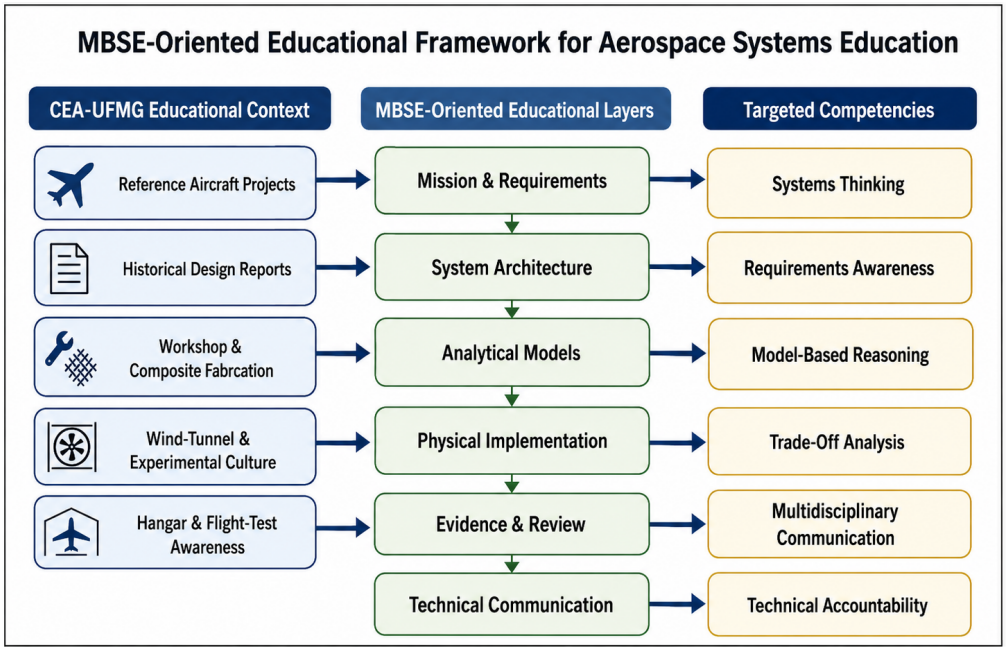


Figure 1 – Conceptual representation of the MBSE-oriented educational framework linking the CEA-UFMG design-build-test context, educational layers and targeted competencies.

an advanced design course, the model may include aerodynamic, structural or flight-dynamics simulations, while physical implementation may involve workshop practice, composite fabrication or prototype construction. In a research or pre-industrial environment, the evidence may include wind-tunnel measurements, manufacturing data, ground-test results or flight-test evidence. The educational principle remains the same: students should understand how mission, architecture, models, materials, evidence and decisions are connected.

3.3 Competency mapping

The framework was designed to support competencies that are relevant both to academic formation and to contemporary aerospace practice. These competencies include systems thinking, requirements awareness, model-based reasoning, multidisciplinary integration, manufacturability awareness, trade-off analysis, evidence-based review and technical communication. They are not treated as abstract learning outcomes disconnected from the activity. Instead, each competency is linked to a concrete educational artifact generated by students.

Table 3 summarizes this relationship. The table also clarifies that the framework does not depend on proprietary industrial data. Its educational value comes from the structured use of non-proprietary aircraft-design artifacts, simplified models, academic infrastructure and progressively more mature physical or experimental evidence.

3.4 Design-build-test progression

A key feature of the framework is the explicit progression from conceptual reasoning to physical and experimental awareness. This progression is essential in aerospace education because aircraft are not only analytical systems; they are engineered products whose behaviour depends on configuration, materials, fabrication, testing, operation and maintenance. For this reason, design-build-test culture is treated as part of the educational framework, rather than as a separate extracurricular dimension.

The progression can be understood in four levels. First, students encounter the aircraft as a system concept, through mission definition, reference aircraft analysis and configuration reasoning. Second, they represent the aircraft through simplified models, drawings, tables and spreadsheet-based calculations. Third, they relate these models to physical implementation constraints, including materials, manufacturing processes, workshop practice, composite structures, maintenance and opera-

Table 2 – Structure of the MBSE-oriented educational framework.

Framework layer	Educational question	Typical student artifact	MBSE-oriented role
Mission and requirements	What is the aircraft expected to accomplish?	Mission statement, operational scenario, benchmark comparison	Stakeholder intent, mission needs and requirements awareness
System architecture	How is the aircraft configured to satisfy the mission?	Configuration choices, three-view drawings, subsystem descriptions	System architecture, interfaces and configuration reasoning
Analytical models	Which simplified models support the design decisions?	Spreadsheet calculations, weight estimates, performance estimates, stability indicators	Model-based reasoning with explicit assumptions and validity limits
Physical implementation	What material, manufacturing and operational constraints affect the design?	Manufacturing discussion, material choices, fabrication constraints, maintainability considerations	Link between models, physical artifacts, manufacturability and operation
Evidence and review	What evidence supports or challenges the design choices?	Tables, plots, benchmark comparison, wind-tunnel or test awareness, limitation analysis	Traceability, evidence quality, verification awareness and review logic
Technical communication	How are assumptions, decisions and results communicated?	Technical report, drawings, calculation records and oral presentation	Communication artifact and design-rationale record

tional feasibility. Fourth, they are introduced to evidence-generation logic through wind-tunnel culture, ground-test awareness, hangar-based work and flight-test reasoning.
Table 4 summarizes this progression.
This progression is especially important for early formation. Introductory students may not yet be able to perform advanced aerodynamic analysis, structural sizing or flight-test data reduction. Nevertheless, they can understand that an aircraft-design decision is never purely numerical. A wing-area change, a landing-gear choice, a payload addition or a propulsion modification affects not only performance estimates, but also structure, manufacturing, operation, testing and safety. This is the type of systems reasoning that the framework aims to cultivate from the beginning of the program.

3.5 Relationship with the CEA-UFMG educational ecosystem

The CEA-UFMG context provides the framework with a concrete foundation. Its light-aircraft design-build-test tradition offers complete reference projects, historical aircraft documentation, fabrication resources, experimental culture and flight-test awareness. These elements allow students to engage with authentic engineering artifacts while remaining within an academic and non-proprietary environment.
In this sense, the framework is not an external methodology imposed on the CEA-UFMG tradition. It is a way of making explicit the systems logic already present in that tradition. Mission definition, configuration selection, weight estimation, aerodynamic modelling, performance evaluation, stability analysis, structural considerations, manufacturing, ground testing and flight testing are all connected in classical aircraft development. The MBSE-oriented framework organizes these connections so that they can be intentionally used for education.
The framework also supports curricular scalability. In the first year, students can work with controlled modifications of a reference aircraft, simplified calculations and qualitative trade-off reasoning. In later courses, the same aircraft-system logic can be revisited through aerodynamics, structures, flight mechanics, systems engineering, manufacturing, wind-tunnel testing and design projects. At the final stages of formation, students can connect academic models to experimental evidence, prototype development, hangar-based activities and more mature design reviews.

Table 3 – Competency mapping in the MBSE-oriented educational framework.

Competency	Educational activity	Evidence generated	Expected progression
Systems thinking	Relating mission, configuration, performance and operation	System-level description and design rationale	From isolated variables to aircraft-level reasoning
Requirements awareness	Translating mission intent into design priorities	Mission table, benchmark comparison and design constraints	From informal objectives to explicit requirements logic
Model-based reasoning	Using simplified analytical calculations to support decisions	Spreadsheet models, assumptions and plots	From numerical substitution to assumption-based modelling
Multidisciplinary integration	Connecting geometry, weight, propulsion, performance, stability, fabrication and operation	Integrated report and cross-domain discussion	From discipline fragments to integrated design consequences
Manufacturability awareness	Discussing materials, fabrication, maintenance and operational constraints	Material choices, manufacturing comments and implementation limitations	From conceptual geometry to physical aircraft constraints
Trade-off analysis	Comparing benefits and penalties of design changes	Variant comparison, normalized indicators and limitation analysis	From single-objective improvement to balanced decision-making
Evidence-based review	Identifying what supports the design and what remains uncertain	Tables, figures, critical comments and future-work statements	From final answers to reviewable engineering evidence
Technical communication	Presenting assumptions, methods, results and limitations	Written report, drawings and oral presentation	From informal explanation to structured engineering communication

3.6 Academic-industrial perspective

The framework is also informed by an academic-industrial perspective on aerospace engineering formation. The involvement of industry-facing authors in the present work reflects the relevance of the competencies addressed by the framework, especially systems thinking, model-based reasoning, traceability, multidisciplinary communication and evidence-based review. However, the framework is not presented as a proprietary industrial training program. It is an academic model designed to prepare students for the type of reasoning increasingly required in complex aerospace environments. This distinction is important. The proposed framework does not require sensitive industrial data, company-specific processes or specialized commercial software. Its purpose is to create an educational bridge between academic aircraft design-build-test traditions and the competencies expected in contemporary aerospace practice. By doing so, it allows universities with strong project-based and experimental traditions to organize their educational assets in a language that is compatible with modern systems engineering while preserving academic autonomy.

4. Study Design and Evidence Strategy

The work reported in this paper is structured as an educational framework study supported by a descriptive case implementation. The objective is not to test a controlled pedagogical intervention or to statistically compare learning outcomes between groups. Instead, the study aims to formalize an MBSE-oriented educational framework derived from the CEA-UFMG design-build-test tradition and to illustrate its introductory implementation in an Aerospace Engineering course.

The evidence strategy combines four sources. The first source is the institutional and methodological background of the CEA-UFMG light-aircraft tradition, including historical project documentation, aircraft-development methodology, program descriptions and flight-test-related publications. The second source is the framework mapping developed in this paper, which relates classical aircraft-design practices to MBSE-oriented educational layers and competencies. The third source is the documented implementation of the introductory mission-based activity, including its group structure, deliverables, schedule and pedagogical constraints. The fourth source is the aggregated student-

Table 4 – Progression from conceptual design to design-build-test awareness.

Level	Educational focus	Representative artifacts	Formation objective
Conceptual system	Mission, role, configuration and operational intent	Mission statement, benchmark comparison, reference-aircraft analysis	Understand the aircraft as a complete system
Analytical representation	Simplified models and parameter relationships	Spreadsheets, plots, normalized comparisons and assumptions	Relate models to design consequences
Physical implementation	Materials, fabrication, maintainability and operational feasibility	Manufacturing discussion, composite or workshop awareness, configuration limitations	Connect drawings and models to physical aircraft constraints
Experimental evidence	Ground-test, wind-tunnel, hangar and flight-test awareness	Test logic, evidence discussion, uncertainty and review comments	Understand verification, validation and evidence-based review

response form used as post-activity evidence of participation, group functioning and perceived competency mobilization.

Table 5 summarizes how each evidence source supports the claims made in the paper. The table is included to clarify the scope of the contribution and to avoid overstating the interpretation of the student-response data.

This design is appropriate for an exploratory educational contribution. It allows the paper to connect institutional practice, educational theory, MBSE-oriented reasoning and course-level implementation evidence without overstating causal claims. The student-response data are therefore interpreted as preliminary evidence of implementation quality and competency mobilization, not as definitive proof of learning gains. The limitations of this evidence strategy are discussed explicitly in Section 8.

5. Introductory Mission-Based Implementation

5.1 Activity context and pedagogical intent

The introductory implementation of the MBSE-oriented framework was carried out in the aeronautics component of an introductory Aerospace Engineering course at UFMG. The class included 35 students, organized into five mission-oriented groups. The activity lasted approximately sixty days and was designed as a first structured exposure to aeronautical systems reasoning, not as a complete aircraft design, fabrication or validation project.

The pedagogical intent was to expose students to the logic of aircraft development through controlled conceptual modifications of a complete reference aircraft. The FCA-1 Guara was used as the reference design artifact because it represents a complete and historically situated light-aircraft project from the CEA-UFMG tradition [19]. The purpose was not to redesign the aircraft in full, but to allow students to understand how mission changes propagate through configuration, geometry, propulsion, payload, operation, performance, physical implementation and technical communication.

This implementation followed the same principle described in the framework: students should not begin with isolated formulas, but with a mission-driven question. Each group received a different mission profile and was required to propose a conceptual variant of the reference aircraft. The modifications had to remain controlled, preserving the relationship with the original design and avoiding unrealistic redesigns disconnected from the reference configuration. In this way, the reference aircraft acted as an educational boundary condition: it provided a stable system architecture from which students could explore consequences, trade-offs and assumptions.

5.2 Mission-based group structure

The class was divided into five mission-oriented groups: Trainer, STOL Interior, Cross-Country, Eco/Efficient and ISR/Monitoring. Each mission was selected to expose students to a different set of design priorities and trade-offs. Table 6 summarizes the group structure, mission intent and central design conflict.

Table 5 – Evidence strategy and scope of claims in the study.

Evidence source	Role in the paper	Supported claim and limitation
CEA-UFMG institutional and methodological background	Establishes the existence of a historical design-build-test educational ecosystem involving aircraft projects, fabrication resources, experimental infrastructure and flight-test culture	Supports the claim that the framework is grounded in a real educational context; does not by itself demonstrate learning outcomes
Educational and MBSE literature	Provides theoretical support for project-based learning, design education, systems thinking, MBSE-oriented reasoning and aerospace design-build-test education	Supports the conceptual alignment of the framework with existing literature; does not validate the specific UFMG implementation
Framework mapping	Relates mission definition, architecture, models, physical implementation, evidence and communication to educational competencies	Supports the internal coherence of the proposed framework; remains a conceptual contribution requiring further application and assessment
Introductory course implementation	Describes the activity structure, missions, schedule, deliverables, reference aircraft and scope-control strategy	Supports feasibility of implementation in an introductory course; does not imply technical validation of the student aircraft variants
Aggregated student-response form	Provides post-activity evidence of participation, group functioning, activities performed and perceived competency mobilization	Supports preliminary interpretation of educational engagement and competency mobilization; does not constitute causal proof of learning gains

The mission distribution was intentionally broad. The Trainer group emphasized safety, simplicity and maintainability. The STOL Interior group emphasized operation in constrained runways and low-speed performance. The Cross-Country group emphasized speed, range and comfort. The Eco/Efficient group emphasized realistic efficiency improvements and sustainability discussions. The ISR/Monitoring group emphasized payload, sensors, visibility, endurance and operational usefulness. Together, these missions allowed the same reference aircraft to be interpreted through different systems priorities.

5.3 Activity sequence and deliverables

The implementation was structured around progressive deliverables. The activity began with the presentation of the reference aircraft, group missions and expected outputs. Students then defined internal roles, compared the original aircraft with the proposed mission, benchmarked historical and modern aircraft, developed a first calculation spreadsheet, prepared three-view drawings, submitted preliminary report material, participated in a short pre-review with monitors and delivered the final report, spreadsheet and presentation.

The workflow of the introductory activity is summarized in Figure 2. The figure emphasizes that the activity was organized as a progressive sequence, beginning with mission briefing and role definition and moving toward reference comparison, simplified modelling, configuration representation, review, reporting and presentation. The callout elements in the figure should not be interpreted as additional deliverables, but as the main reasoning logics activated during the activity: mission-driven reasoning, model-based reasoning and evidence-oriented review.

Table 7 expands this workflow into the main deliverables and their educational purposes. Although the initial planning was organized as a 45-day schedule, the actual implementation lasted approximately sixty days, allowing additional time for spreadsheet development, report preparation, monitor feedback and final review.

The teaching monitors played an important role in the implementation. Their function was not to solve the design problem for the students, but to support intermediate reviews, identify inconsistencies,

Table 6 – Mission-based group structure used in the introductory implementation.

Group	Mission intent	Main design questions	Central trade-off
Trainer	Adapt the aircraft for initial pilot training	Landing gear simplicity, powerplant economy, low-speed handling, visibility, dual controls and maintenance	Simplicity and safety may reduce cruise performance and operational speed
STOL Interior	Adapt the aircraft for short and simple runways in interior regions	Wing area, high-lift devices, fixed and robust landing gear, stall speed and takeoff/landing distance	Improved field performance may increase drag and reduce cruise efficiency
Cross-Country	Adapt the aircraft for faster medium-distance travel	Drag reduction, retractable landing gear, power, fuel consumption, comfort, endurance and range	Higher speed may increase cost, power demand and operational complexity
Eco/Efficient	Reduce fuel consumption and environmental impact without requiring electric propulsion	Mass reduction, efficient engine, alternative materials, fuel consumption, SAF or future hybridization	Lower consumption may reduce performance, payload or increase acquisition cost
ISR/Monitoring	Adapt the aircraft for inspection, monitoring and observation missions	Sensor payload, electrical power, endurance, visibility, stability, low-speed operation and future sensor integration	Added payload and systems may affect weight, balance, energy demand and mission cost

encourage clearer assumptions and help students maintain the scope of the activity. This supervision structure was important because the students were mostly at the beginning of the program and had not yet completed advanced courses in aerodynamics, structures, performance or stability.

5.4 Use of simplified models and reference artifacts

The activity relied on simplified analytical models compatible with the students' mathematical background. Spreadsheet-based calculations were used to organize aircraft parameters, compare configurations, estimate the effects of design choices and support discussion of trade-offs. The emphasis was placed on the relationship between assumptions and consequences, rather than on high-fidelity numerical accuracy.

This decision was pedagogically important. First-year students cannot be expected to perform a complete aircraft design using advanced aerodynamic, structural or flight-mechanics models. However, they can understand that changing wing area affects wing loading and stall speed, that changing power affects performance and fuel consumption, that adding sensors affects payload and balance, and that landing-gear choices affect operation, drag, weight, maintenance and manufacturability. These relationships are sufficient to introduce systems thinking when they are organized within a clear mission-based structure.

The reference aircraft also served as a boundary condition. Instead of creating an aircraft from a blank page, students modified an existing configuration. This reduced the number of uncontrolled variables and made the activity more realistic. The reference design provided geometry, mission context, configuration logic and documented assumptions. The student variants therefore became controlled deviations from an existing aircraft concept, allowing comparisons between original and modified configurations.

5.5 Connection with design-build-test culture

Although the introductory activity did not include fabrication, wind-tunnel testing, hangar work or flight testing, it was deliberately positioned within the broader CEA-UFMG design-build-test culture. The connection with this culture should therefore be interpreted as contextual and formative, not as direct experimental evidence generated within the activity itself. Students were introduced to the idea

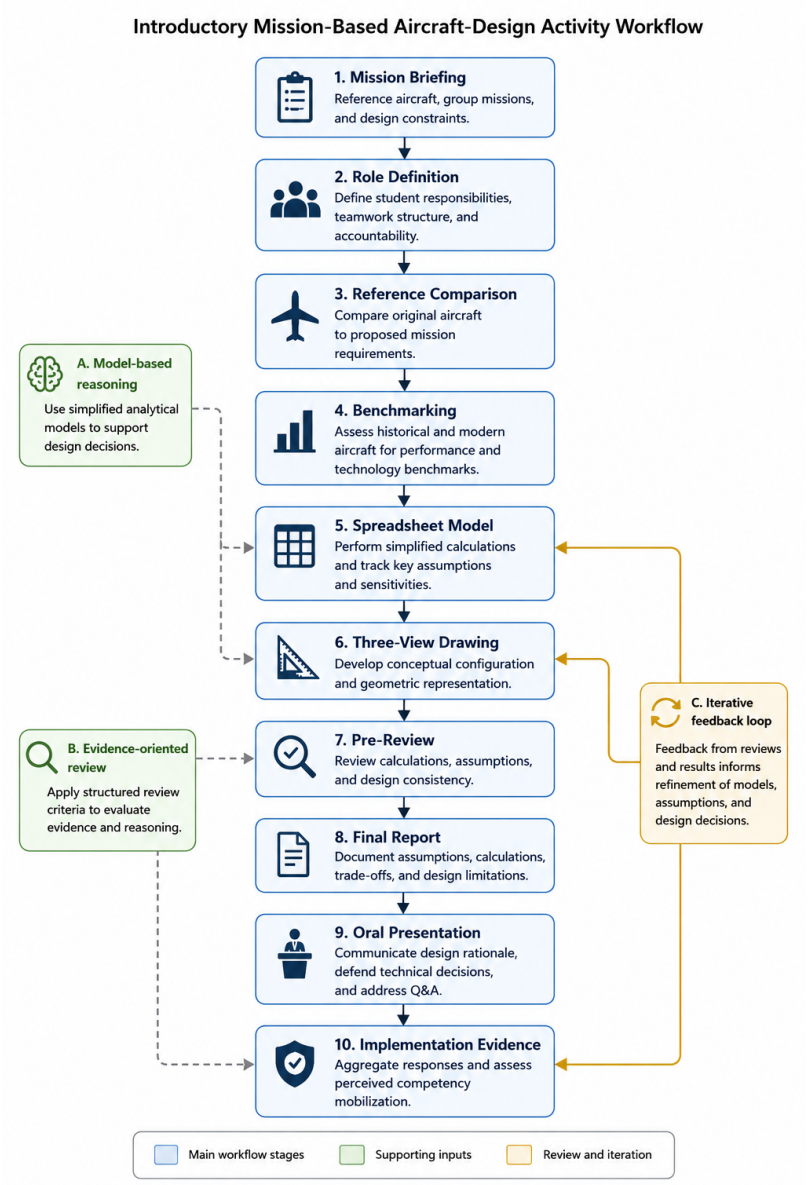


Figure 2 – Workflow of the introductory mission-based aircraft-design activity used to implement the MBSE-oriented educational framework.

that aircraft-design decisions are not only numerical choices, but may later affect manufacturability, materials, operation, maintenance, testing and verification.

This distinction is important for the educational argument of the paper. The activity represented the first conceptual layer of a broader aerospace formation pathway. At this level, students used simplified calculations, conceptual drawings and qualitative reasoning. In later stages of the curriculum, the same aircraft-system logic can be revisited through aerodynamics, structures, flight mechanics, manufacturing practice, composite fabrication, wind-tunnel testing, hangar-based activities and flight-test evidence. The introductory implementation therefore acts as an entry point into an aircraft-development culture rather than as a direct design-build-test experience.

This progression also helps students understand why simplified models must be treated carefully. A spreadsheet estimate is not a final design result. It is an educational representation that depends on assumptions, input data, validity limits and future evidence. By placing simplified models within a design-build-test context, students can begin to understand the role of verification, validation and evidence-based review before they are formally exposed to advanced testing, certification or flight-test topics.

Table 7 – Activity sequence and educational deliverables.

Stage	Deliverable	Educational purpose
Initial briefing	Presentation of activity, reference aircraft, groups and missions	Establish mission context and design boundaries
Role definition	Internal organization of student responsibilities	Promote teamwork, task allocation and accountability
Reference comparison	First table comparing original aircraft and proposed mission	Develop requirements awareness and baseline understanding
Benchmarking	Comparison with one historical and one modern aircraft	Support design reasoning through external references
Spreadsheet model	First version of simplified calculation spreadsheet	Introduce model-based reasoning and assumption tracking
Three-view drawing	Initial conceptual drawing of the proposed variant	Connect configuration choices to visual system representation
Preliminary report	Draft technical report and calculation summary	Develop structured engineering documentation
Pre-review	Short review with teaching monitors	Provide feedback, identify inconsistencies and improve traceability
Final submission	Final report and spreadsheet	Consolidate assumptions, calculations, trade-offs and limitations
Oral presentation	Group presentation and review discussion	Exercise technical communication and design defense

5.6 Relationship with the MBSE-oriented framework

The implementation can be interpreted directly through the framework defined in Section 3. The mission statement of each group represented stakeholder intent and initial requirements awareness. The proposed aircraft variant represented a system architecture. The spreadsheet calculations represented low-fidelity analytical models. Discussions of materials, operation, landing gear, propulsion, maintenance and mission equipment introduced physical implementation constraints. Benchmarking, comparison tables and normalized indicators represented evidence artifacts. The final report and oral presentation represented technical communication and design rationale.

Table 8 maps the implementation artifacts to the MBSE-oriented framework layers.

This mapping shows that the activity was not only a project-based exercise, but also an introductory MBSE-oriented experience. Even without formal systems-modelling software, students were required to connect mission, architecture, models, implementation constraints, evidence and communication. This is the main educational mechanism through which the activity contributes to broader aerospace systems formation.

5.7 Scope control and limitations of the implementation

The activity deliberately avoided requiring high-fidelity modelling, structural sizing, certification analysis, detailed cost modelling, validated performance prediction or experimental verification. These topics belong to later stages of aerospace engineering formation. The introductory implementation focused on conceptual reasoning, controlled modifications, simplified calculations and communication.

This scope control is essential for preserving educational coherence. If the activity demanded advanced modelling too early, students would likely reproduce formulas without understanding their meaning. By contrast, a controlled mission-based activity allows students to recognize why later courses are necessary. Aerodynamics, structures, flight mechanics, propulsion, systems engineering, manufacturing and testing become visible as future layers of the same aircraft-system problem.

Therefore, the implementation should be interpreted as the first layer of a broader formation pathway. Its value lies not in the technical maturity of the proposed variants, but in the introductory exposure to systems thinking, requirements awareness, model-based reasoning, physical-implementation awareness, trade-off analysis and technical communication.

6. Implementation Evidence and Perceived Competency Mobilization

Table 8 – Mapping between introductory implementation artifacts and framework layers.

Framework layer	Implementation artifact	Educational interpretation
Mission and requirements	Mission statement and original aircraft versus proposed mission table	Students identify operational intent, design priorities and constraints
System architecture	Conceptual variant definition and three-view drawing	Students represent how configuration choices respond to mission objectives
Analytical models	Spreadsheet calculations for geometry, weight, power, performance and related indicators	Students use simplified models to connect assumptions and consequences
Physical implementation	Discussions of landing gear, materials, propulsion, maintainability, payload and operational feasibility	Students relate design choices to manufacturability, operation and future implementation constraints
Evidence and review	Benchmark comparison, tables, figures, trade-off discussion and limitations	Students generate reviewable evidence and identify uncertainties
Technical communication	Final report, spreadsheet and oral presentation	Students communicate design rationale, assumptions, results and limitations

Table 9 – Distribution of student responses by mission-based group.

Mission-based group	Responses
Trainer	8
ISR/Monitoring	7
Eco/Efficient	7
Cross-Country	6
STOL Interior	5
Total	33

6.1 Data source and interpretation limits

To support the analysis of the introductory implementation, a post-activity response form was used as a course-level monitoring and improvement instrument. The form collected individual self-reported information on student participation, group organization, activities performed, deliverables produced, perceived task fulfilment, technical contribution quality, technical mastery, collaboration and presentation readiness. Responses were analysed only in aggregated form, without identifying students, quoting personal statements or exposing internal group conflicts.

The response form was administered after the final presentation as a course-monitoring and activity-improvement instrument. It included self-assessment items, group-functioning questions, categorical indicators of participation and reported activity types. The responses are used in this paper to assess implementation feasibility, perceived engagement and alignment between activity tasks and targeted competencies. They are not used to infer statistically significant learning gains or to compare the framework with alternative pedagogical approaches.

The class included 35 students, of whom 33 submitted responses, corresponding to a response rate of 94.3%. The respondents were distributed across the five mission-based groups as follows: eight in the Trainer mission, seven in the ISR/Monitoring mission, seven in the Eco/Efficient mission, six in the Cross-Country mission and five in the STOL mission. Table 9 summarizes the response distribution.

These data are interpreted as implementation evidence rather than as a formal measurement of learning gains. The activity did not include a pre-test/post-test design, a validated psychometric instrument, an external evaluator, a control group or a longitudinal assessment. Therefore, the results should not be interpreted as proof that the framework caused measurable learning gains. Instead, they provide descriptive evidence that the activity engaged students in tasks aligned with the competencies targeted by the MBSE-oriented framework and help identify limitations to be addressed in future offerings. This cautious interpretation is consistent with the broader educational literature, which emphasizes that active and project-based learning should be supported by clear evidence,

Table 10 – Aggregated student-response indicators from the introductory implementation.

Indicator	Scale	Mean	Interpretation
Self-assessed individual participation	0–10	8.58	High perceived individual engagement
Participation in meetings and group discussions	1–5	3.97	Generally positive, with some uneven participation
Fulfilment of agreed tasks	1–5	3.91	Most tasks were fulfilled, but delays or gaps occurred in some groups
Technical quality of group contributions	1–5	4.15	Contributions were generally perceived as technically adequate
Technical mastery of group members	1–5	3.94	Most students perceived adequate mastery, but not always by all members
Collaboration and collective responsibility	1–5	4.03	Collaboration was generally positive, with local imbalance in effort

reflection and assessment design [22, 23, 15, 16].

6.2 Participation, task fulfilment and group functioning

The response form indicates that students generally perceived themselves as active participants in the project. On a scale from 0 to 10, the average self-assessment of individual participation was 8.58, with a median of 9.0. Most students therefore reported substantial involvement in the work, although the distribution also indicates that participation was not perfectly uniform across the class.

Table 10 summarizes selected quantitative indicators from the student responses. The 1–5 scale items refer to group-level perceptions, where higher values indicate more positive evaluations. One response was missing for the collaboration and collective-responsibility item; therefore, that average is based on 32 responses.

Categorical responses reinforce this interpretation. Regarding the fulfilment of agreed tasks, 20 students reported that they had fully fulfilled their commitments and 11 reported that they had fulfilled them to a large extent. Regarding work distribution, 17 students considered the division balanced and 14 considered it reasonably balanced. Thus, most responses indicate that the activity produced a functional teamwork structure.

At the same time, the responses reveal important educational limitations. Sixteen respondents indicated that at least one group member had participated little or delivered less than expected, while nine were uncertain and eight did not report this problem. In addition, eight respondents reported that parts of the work had to be redone and four reported that this occurred partially because of insufficient, delayed or inadequate contributions. These findings do not invalidate the activity. On the contrary, they show that open-ended aerospace projects expose students to a realistic aspect of engineering practice: technical results depend not only on calculations, but also on coordination, accountability, communication and review.

Table 11 summarizes selected categorical indicators related to group functioning.

6.3 Activities performed and artifacts generated

The activities reported by students were consistent with the intended scope of the framework. The most frequently reported activities included definition of the problem and objectives, bibliographic research, reading and summarizing references, calculations, spreadsheet development, analysis of results, text writing, communication with monitors and preparation of presentation material.

Table 12 summarizes the most frequent types of activities reported by students. Because students could select multiple activities, totals exceed the number of respondents.

These results indicate that the activity generated a broad set of educational artifacts, not only a final presentation. Students reported producing or contributing to comparison tables, benchmark

Table 11 – Selected categorical indicators of group functioning.

Question topic	Response category	Responses
Fulfilment of agreed tasks	Fully fulfilled	20
	Fulfilled to a large extent	11
	Partially fulfilled or little fulfilled	2
Perceived work distribution	Balanced	17
	Reasonably balanced	14
	Partially unbalanced or uncertain	2
Low participation or under-delivery by at least one member	Yes	16
	Uncertain	9
	No	8
Need to redo work due to insufficient, delayed or inadequate contribution	No	18
	Yes	8
	Partially	4
	Uncertain	3

Table 12 – Most frequent activities reported by students.

Reported activity	Responses	Share of respondents
Definition of the problem and objectives	24	72.7%
Bibliographic research	23	69.7%
Reading and summarizing references	22	66.7%
Calculations	20	60.6%
Analysis of results	18	54.5%
Text writing	18	54.5%
Spreadsheet development	18	54.5%
Communication with monitors or instructor	14	42.4%
Formatting of the final document	13	39.4%
Preparation of oral presentation	11	33.3%
Technical review of the text	10	30.3%
Organization of methodology	10	30.3%
Organization of group meetings	10	30.3%
Preparation of slides	9	27.3%

material, calculation spreadsheets, plots, report sections, drawings, slides and technical summaries. This supports the interpretation that the implementation operated as an MBSE-oriented educational activity: mission reasoning, analytical models, evidence artifacts and communication records were all present, even though no formal MBSE software was used.

The distribution of activities also suggests that the project encouraged role specialization. Students frequently described responsibilities related to aerodynamics and wing geometry, propulsion and performance, structures and materials, systems and operation, landing gear, sustainability, sensors, leadership, integration, report editing and presentation. This specialization is pedagogically useful because it mirrors multidisciplinary engineering work. However, it also reinforces the need for integration mechanisms to ensure that students understand the aircraft as a complete system rather than only their assigned subsystem.

6.4 Indications of targeted competency mobilization

The student responses provide indications that the activity engaged several competencies targeted by the framework. Systems thinking was addressed through the requirement to relate mission intent to configuration changes, performance consequences and operational constraints. Requirements awareness was introduced through the comparison between the original reference aircraft and the proposed mission. Model-based reasoning was exercised through spreadsheet calculations and simplified performance or configuration estimates. Physical-implementation awareness appeared in dis-

cussions of landing gear, materials, propulsion, maintainability, payload and operational feasibility. Technical communication was exercised through reports, tables, drawings, slides and oral presentations.

These indications should be interpreted cautiously. They show that students reported participating in activities associated with the intended competencies, but they do not independently measure the depth of individual learning. For example, a student may have contributed to spreadsheet development without fully mastering the aircraft-level implications of the model. Similarly, participation in report writing or oral presentation does not guarantee homogeneous understanding across all group members. The evidence therefore supports the interpretation that the activity created opportunities for competency mobilization, not that all students achieved the same level of competence.

The evidence also indicates development needs related to teamwork and engineering accountability. Most students reported that work distribution was balanced or reasonably balanced, and most reported full or large fulfilment of agreed tasks. Nevertheless, the presence of reported participation imbalance is educationally relevant. It shows that future implementations should include stronger intermediate review checkpoints, clearer individual accountability mechanisms and explicit rubrics connecting individual contribution to group deliverables.

Presentation readiness revealed both strengths and limitations. Eighteen respondents considered that the oral presentation would make individual participation evident, while eight answered partially and seven were uncertain. Regarding technical mastery, 10 respondents reported that all members had adequate mastery and 17 reported that the majority had adequate mastery. This suggests that the activity promoted technical engagement but did not guarantee homogeneous understanding across all members. For an MBSE-oriented educational framework, this is an important finding: integration reviews should not only check whether the final artifact exists, but whether students can explain assumptions, interfaces, trade-offs and limitations beyond their individual task.

6.5 Implications for the framework

The response data support the interpretation that the introductory implementation functioned as a feasible entry point into aerospace systems education. Students were not merely asked to reproduce calculations. They had to define mission priorities, organize roles, construct simplified models, compare alternatives, produce technical artifacts, discuss trade-offs and present their reasoning. These activities correspond directly to the framework layers of mission and requirements, system architecture, analytical models, physical implementation, evidence and review, and technical communication.

At the same time, the data show that the framework requires deliberate instructional controls. Open-ended projects can generate uneven participation and fragmented technical mastery if the integration process is not explicitly supervised. In future implementations, the framework should therefore include individual checkpoints, short design reviews, assumption logs, integration rubrics and presentation formats that require each student to explain not only their assigned task, but also how it connects to the aircraft-level mission.

Overall, the aggregated student responses provide preliminary implementation evidence that the proposed MBSE-oriented framework can structure an introductory aerospace design activity and create opportunities for systems thinking, model-based reasoning, multidisciplinary communication, physical-implementation awareness and technical accountability. The findings are not sufficient to establish learning gains, but they are useful for assessing feasibility, identifying instructional risks and guiding future improvements in assessment design. Therefore, the student-response data should be interpreted as evidence of activity implementation and perceived competency mobilization, rather than as direct measurement of individual competency development.

7. Discussion: Industry-Informed Aerospace Systems Formation

7.1 From aircraft-design tradition to systems formation

The results discussed in this paper suggest that the CEA-UFMG light-aircraft design-build-test tradition can be interpreted as more than a historical institutional asset. It can also function as a structured foundation for aerospace systems formation. The distinctive aspect of this tradition is not only the existence of aircraft projects, but the continuity between conceptual design, analytical models, technical

documentation, fabrication resources, experimental infrastructure, hangar-based work and flight-test culture.

This continuity gives educational meaning to the MBSE-oriented framework proposed in the paper. Mission definition, reference-aircraft analysis, simplified calculations, physical-implementation awareness, evidence generation and technical communication are not isolated educational components. They represent different views of the same engineering system. This is aligned with the central educational value of MBSE: making relationships among objectives, requirements, architectures, models, assumptions, evidence and decisions explicit [21, 24].

The introductory implementation described in Section 5 represents only the first layer of this formation pathway. Its technical fidelity is intentionally limited, but its systems logic is important. By working with controlled variants of a reference aircraft, students were exposed to the idea that a change in mission affects geometry, propulsion, payload, operation, maintainability, performance and communication. This experience creates a conceptual bridge to later courses, where the same aircraft-system relationships can be revisited with more advanced aerodynamics, structures, flight mechanics, manufacturing, testing and systems-engineering tools.

7.2 Educational value of early aeronautical-culture immersion

A central implication of the proposed framework is that early exposure to aeronautical culture can play a formative role in aerospace engineering education. In the CEA-UFMG context, students can be introduced to an environment in which aircraft are not only objects of study, but engineered systems connected to reports, drawings, workshops, composite manufacturing, wind-tunnel activities, hangar operations and flight-test reasoning. This type of exposure helps students understand why models and calculations matter.

The expression “early immersion in aeronautical engineering culture” is used here to describe this process. It does not mean that first-year students should immediately perform advanced design, fabrication or testing tasks. Rather, it means that they should understand from the beginning that aerospace engineering connects abstract models to physical systems and operational evidence. This is consistent with project-based learning, CDIO-oriented education and aerospace design-build-test experiences, in which students progressively move from conceptual reasoning to implementation and evaluation [7, 8, 9, 10].

For this reason, the introductory activity should not be evaluated only by the technical maturity of the aircraft variants proposed by students. Its educational value lies in the formation of engineering habits: defining a mission, comparing references, documenting assumptions, building simplified models, recognizing trade-offs, preparing technical artifacts, responding to review and communicating limitations. These habits are compatible with the type of reasoning expected in more advanced aerospace projects and in professional engineering environments.

7.3 Relevance to industry-facing competency development

The academic-industrial perspective adopted in this paper reinforces the importance of competencies that are not always developed explicitly in traditional discipline-centered curricula. Early-career aerospace engineers are increasingly expected to communicate across domains, understand interfaces, connect models to evidence, document assumptions and participate in review processes. These expectations are also reflected in systems-engineering and MBSE-oriented practices, where traceability, model consistency, verification logic and decision rationale are central elements [25, 21].

The proposed framework addresses these competencies without requiring proprietary industrial data, company-specific processes or specialized commercial tools. This is important for academic environments. Universities can prepare students for modern aerospace practice using non-proprietary aircraft projects, simplified models, historical design reports, laboratory infrastructure and structured educational artifacts. The result is not an industrial training program, but an academic formation model that speaks a language compatible with contemporary aerospace systems engineering.

The involvement of industry-facing authors in this work should therefore be understood as a contribution to the definition of relevant competencies and to the strategic framing of the educational problem. The implementation remains academic and UFMG-based. Its broader relevance lies in showing how

a university with a strong aircraft design-build-test tradition can organize its educational assets into a scalable framework for aerospace systems formation.
The industry-informed perspective is used to frame relevant competencies and educational expectations, not to validate the educational effectiveness of the framework or to represent a company-specific training process.

8. Limitations and Future Work

8.1 Limitations of the present study

The present study has limitations that must be made explicit. First, the introductory implementation was based on one course offering and one cohort of students. Although the response rate was high, the evidence should be interpreted as preliminary and contextual. The results indicate that the activity mobilized relevant competencies, but they do not establish generalizable learning gains.
Second, the student-response data were self-reported. Self-assessment is useful for understanding perceived participation, group functioning and student engagement, but it is not equivalent to independent measurement of technical learning. The activity did not include a formal pre-test/post-test design, a validated psychometric instrument, a control group or longitudinal tracking of competency development.
Third, the aircraft variants produced by students were not intended to be technically validated designs. They were educational artifacts generated through simplified calculations, spreadsheet models and conceptual reasoning. Therefore, the technical results should not be interpreted as aircraft-design recommendations or as validated performance predictions.
Fourth, the implementation did not include fabrication, wind-tunnel testing or flight testing. These elements are part of the broader CEA-UFMG educational ecosystem and of the design-build-test formation pathway, but the specific introductory activity discussed in this paper remained at the conceptual and low-fidelity model level. The link to physical implementation and experimental evidence was therefore educational and prospective, not experimental within the activity itself.
Finally, the proposed MBSE-oriented framework was not implemented using a formal MBSE software environment. This is consistent with the pedagogical goal of the paper, but it also means that future work is needed to evaluate how the framework can be translated into more formal model-based representations, requirements structures, traceability matrices or systems-engineering tools in advanced courses.

8.2 Future work

Future work should proceed in four directions. The first direction is assessment improvement. Future offerings should include explicit rubrics for individual contribution, group integration, assumption tracking, model quality, trade-off reasoning and technical communication. Such rubrics should separately assess mission-to-requirement translation, assumption documentation, model consistency, configuration rationale, trade-off quality, evidence use, individual technical understanding and communication clarity. Short intermediate design reviews should be used not only to correct technical errors, but also to verify whether students can explain how their subsystem-level work connects to the aircraft-level mission.
The second direction is longitudinal evaluation. The framework should be evaluated across multiple course offerings and, ideally, across different stages of the aerospace engineering curriculum. This would make it possible to investigate whether early mission-based aircraft reasoning helps students later in aerodynamics, structures, flight mechanics, design, manufacturing, testing or systems-engineering courses.
The third direction is model formalization. At the introductory level, spreadsheets, tables and drawings are appropriate educational artifacts. At later stages, these artifacts could be connected to more formal MBSE representations, including requirement structures, functional decompositions, architecture views, interface definitions, verification logic and evidence traceability. The objective should remain educational: formalization should support reasoning and communication, not become tool training detached from engineering understanding.

The fourth direction is stronger integration with the physical and experimental ecosystem. Future implementations could connect student artifacts to demonstrations in workshops, composite manufacturing, wind-tunnel visualization, hangar activities or flight-test data interpretation. Such integration would strengthen the design-build-test pathway and reinforce the central message that aircraft are systems whose models must eventually be related to physical implementation and evidence.

9. Conclusion

This paper presented an MBSE-oriented educational framework for aerospace systems formation grounded in the CEA-UFMG light-aircraft design-build-test tradition. The framework was motivated by the need to connect disciplinary aerospace education with systems thinking, model-based reasoning, physical-implementation awareness, evidence-based review and technical communication.

The central argument of the paper is that the CEA-UFMG tradition provides a distinctive educational foundation because it connects complete aircraft projects, historical design reports, fabrication resources, wind-tunnel culture, hangar-based work and flight-test awareness. When interpreted through an MBSE-oriented lens, this tradition can be organized as a scalable formation pathway linking mission definition, system architecture, analytical models, physical implementation, evidence and communication.

An introductory implementation was discussed through a mission-based aircraft-design activity with first-year aerospace engineering students. The activity used controlled conceptual variants of a complete reference aircraft and required students to define mission priorities, compare aircraft references, develop simplified spreadsheet models, prepare three-view drawings, write technical reports and present their design rationale. Aggregated student-response evidence indicated high perceived engagement and suggested that the activity created opportunities for the mobilization of systems-thinking-related behaviours, requirements awareness, model-based reasoning, multidisciplinary communication, physical-implementation awareness and technical accountability.

The study also identified important limitations. The evidence is preliminary, self-reported and based on a single implementation. The student variants were educational artifacts rather than validated aircraft designs, and the introductory activity did not include fabrication or experimental testing. These limitations define the next steps: stronger rubrics, longitudinal assessment, formalized traceability, and progressive integration with manufacturing, wind-tunnel, hangar and flight-test activities.

Overall, the paper contributes by translating a classical aircraft design-build-test educational tradition into a contemporary MBSE-oriented framework for aerospace systems formation. This translation preserves the practical and institutional strengths of the CEA-UFMG context while providing a language compatible with modern aerospace systems engineering and industry-informed competency development.

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