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Development of a System Engineering Process for an ESTOL Transport Planning Activity

Callaway, R. K*.; Wardwell, Douglas, A.†; Zuk, John‡;
NASA – Ames Research Center
Moffett Field, CA 94035

ABSTRACT

This paper discusses the effort to develop an additional process that would assist and guide the RIA Sector Manger in planning the development of technologies that would enable an ESTOL transport. This system engineering process would be a repeatable and traceable process that would link the technologies being developed directly to the RIA Sector Vision, Vehicle System Goals and NASA's Goals and Aeronautics Objectives.

This process is being used by the RIA Sector Planning Team to define the basic functions and requirements of an ESTOL transport operating in the 2020 time frame, and then will be used to further define the ESTOL technologies to be developed in the years between now and 2020.

BACKGROUND OF VEHICLE SYSTEM PROGRAM

The NASA Vehicle Systems Program (VSP) provides the technology foundation for future aerospace vehicles[1, 2]. It develops and demonstrates advanced airframe and spaceframe technology concepts and methodologies, provides advanced validated tools and techniques, responds quickly to critical national issues, and investigates the fundamental physics underlying the aerospace disciplines. Research covers the areas of conceptual design and systems analysis; aerodynamic and structural design and development; advanced propulsion system concepts and installations; airborne systems design and testing; and flight and systems demonstrations.

The VSP currently consists of five vehicle sectors (Supersonic, Subsonic, Personal Air Vehicle, Uninhabited Air Vehicle, and Runway Independent Aircraft). These five vehicle sectors directly support the NASA Aeronautics Theme Objectives of: Protect the Environment, Increase Mobility, Explore New Aerospace Missions, and Support National Security. Each of the vehicle sectors have one or more vehicle capabilities that are used within that sector to identify new technologies that will support the vision of that vehicle sector, the Aeronautics Theme Objectives, and finally NASA's Strategic and Enabling Goals.

All vehicle sector efforts are coordinated in terms of identifying and developing technologies to enable the U.S. industry and/or DOD to implement new vehicles as desired.

Figure 1. Notional RIA ESTOL Transport

The Runway Independent Aircraft (RIA) vehicle sector currently has three vehicle capabilities, which it is using to identify technology investments within the VSP. These are the Extreme Short Takeoff and Landing (ESTOL) Transport (Figure 1), the Vertical/Short Takeoff and Landing (V/STOL) Transport—low disk loading, and the V/STOL Transport—high disk loading. Although this paper will focus on the planning efforts for the ESTOL Transport, the process presented can be applied to other efforts.

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* Member, Deputy APT
† Associate Fellow, RIA Sector Deputy Manager
‡ Member, RIA Sector Manager

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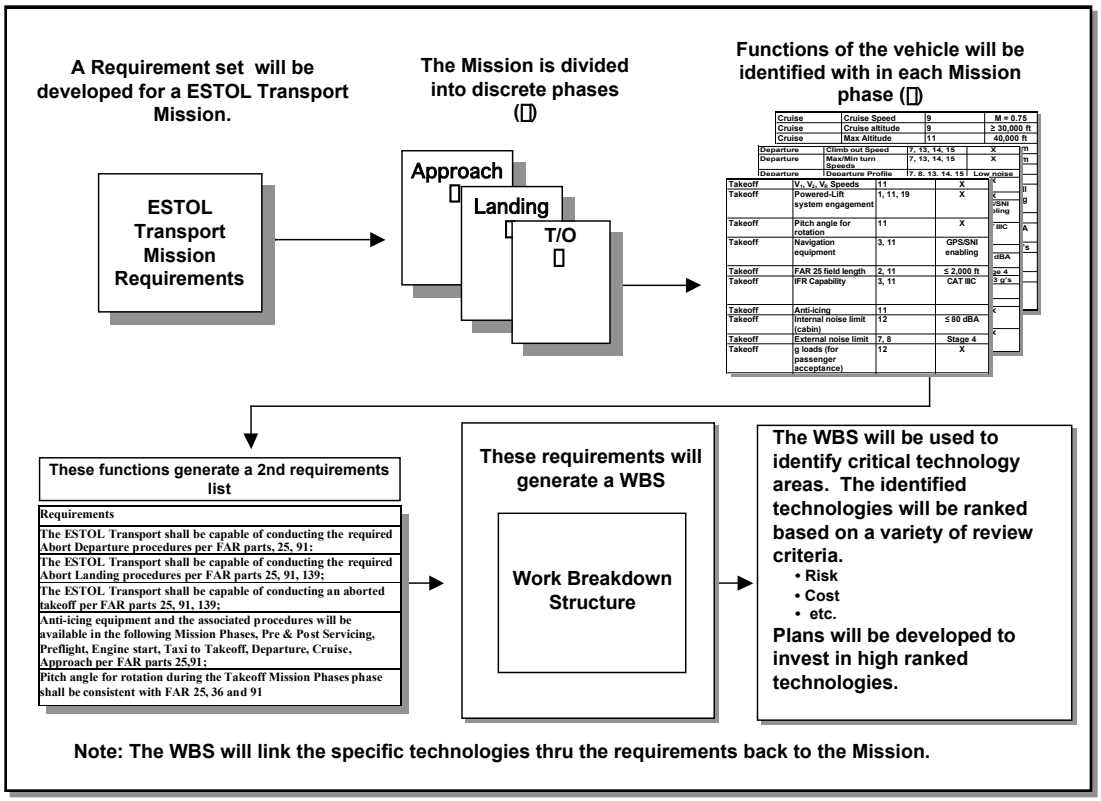

Figure 2. RIA Project Planning Team Process

HISTORICAL REVIEW OF THE RIA PLANNING PROCESS

The RIA Sector Planning Team was formed to develop an implementation plan to manage RIA technology development for future Vehicle System programs. This plan has its basis in the concept of maintenance and utilization of the four critical components of the RIA Sector: people, facilities, technology, and process. Each of these components has a contribution to make to the overall development of a healthy RIA technology Sector, and the loss of any one component will mean degradation in our ability to respond to the challenges of NASA current and future goals.

The formation of the RIA Sector Planning Team in the spring of 2003 was triggered by the realization that the then-conceived Vehicle System Program (VSP) did not have a plan for future RIA technology development. This group, led by NASA Ames Research Center's Aeronautical Programs and Projects Office, recognized that to insure a cost effective technology development project, a fully integrated plan would be needed.

A key aspect of the RIA Sector Planning Team activity was that any plan developed had to be based on a rational vision for future potential mission, and that any plan had to be requirements-based. This allowed the team to develop a plan based on the "functions" that a future RIA vehicle will have to accomplish in a given future mission. Though missions may change, these basic "phases" are unlikely to drastically change. Membership of the RIA Sector Planning Team was/is open to the entire Aerospace community: government, industry, and academia. It is felt that good management of this Sector requires input from the entire community, not only to mitigate biases in any one discipline or institution, but also to take advantage of all the ideas that may be available for new approaches to addressing RIA technology development needs.

RIA SECTOR PLANNING TEAM ACTIVITIES

The purpose of this effort was to develop an additional process that would assist and guide the RIA Sector Manger in planning the development of technologies that would enable an ESTOL transport.

Table 1. ESTOL Level One Requirements

1.	Uses powered-lift technology.
2.	FAR Part 25 field length ≤ 2,000 ft. *(CEI operations for T/O and landing)*.
3.	CAT IIIC capable.
4.	Level 1 handling qualities with CEI.
5.	100 passengers (nominal. May vary by ± 50).
6.	Range between 1,400 nm. and 2,000 nm.
7.	Approach/departure operations to provide simultaneous non-interfering (SNI) operations with SOA CTOL transports.
8.	Minimize the ground noise footprint (FARs 36, 150, 161) as compared to SOA CTOL transports.
9.	Cruise speed at least Mach 0.75 at 30,000 ft. altitude.
10.	Unless specified differently, design aircraft to use minimal (capitalize on existing unused or underutilized) airport infrastructure/airspace.
11.	Vehicle shall meet all applicable FARs.
12.	Cabin environment (noise, g loading, etc.) equivalent to SOA CTOL
13.	Assume GPS/DGPS/WASS/LASS is available for vehicle/ATM operations.
14.	Approach/Departure noise footprint contained within airport boundaries.
15.	Turn radius in terminal area ≤ 1/2 nm (under 2,000 ft altitude).
16.	Unless specified differently technology shall comparable to SOA civil production CTOL aircraft.
17.	Final approach/decision height speeds on the order of 65 knots.
18.	Provides a transportation system benefit.
19.	Assume FAR's will be developed to support certification of new technologies and vehicles.
20.	Assume passengers supported equivalent to industry standard.

It was felt that basic systems engineering practices[3, 4] (Figure 2) had to be the cornerstone of this effort, such that a repeatable and traceable process would link the technologies being developed directly to the RIA Sector Vision and the Vehicle System Goals.

The primary objectives of the RIA Sector Planning Team were to define the basic functions that would be placed on an ESTOL transport operating in the 2020 time frame, and to define the technologies to be developed in the years between now and 2020.

To start the process we developed the following RIA vision using Vehicle Systems Program Themes and NASA's Goals and Aeronautics Objectives as guidance.

– Develop the technologies needed that will enable the building and operation of a 50 to 150 passenger powered-lift transport within the Air Transportation System. This class of vehicle will be able to operate simultaneously and non-interfering with the current transports while using unused or underutilized airport ground structure and airspace.

Subsequently, a set of level one requirements (Table 1) was derived for the ESTOL transport mission. The next step of the process was to compile a list of vehicle functions that would be required in all the mission phases. Each mission phase represents a change in the operational conditions. Each phase also may have a different set of nominal and contingency conditions. The mission phases are listed in Table 2.

These functions of each mission phase were then used to derive level two requirements. Each level two requirement is intended to formalize the expression of a particular vehicle function that was identified in the function matrices. This then evolved into a RIA vehicle WBS. This WBS will be then serve as a jumping off point for identifying key technology areas that the RIA sector will investigate for further development.

Table 2. Mission Phases

1.	Pre-Servicing	9.	Approach
2.	Preflight	10.	Landing
3.	Loading	11.	Taxi to terminal
4.	Engine Start	12.	Shutdown
5.	Taxi to takeoff	13.	Unloading
6.	Takeoff	14.	Post Flight
7.	Departure	15.	Post-Servicing
8.	Cruise		

EXAMPLE OF PROCESS

The following is an example on how this process works. From the NASA's Goals and Aeronautics Objectives we recognized that noise concerns around airports would require the new vehicle to conduct terminal operations near or over the airport property. This lead us to establish the level one requirement

Table 3. ESTOL Vehicle WBS

1. **Airframe Structures,**
   - 1.1. basic structure -- wing, empennage, fuselage,
   - 1.2. fuel tanks
   - 1.3. Landing gear
2. **Aero/Propulsion Integrated System**
   - 2.1. High-Lift systems
   - 2.2. Powered lift systems
   - 2.3 Propulsion system
3. **Flight control systems**
   - 3.1. Central Computer, the master data processing unit(s).
   - 3.2. Software for Vehicle
   - 3.3. Data Display and Controls,
   - 3.4. On-board mission planning systems
   - 3.5. Intelligent Flight Control,
4. **Navigation System**
   - 4.1. Radar, or other essential navigation equipment
   - 4.2. Navigation/guidance function.
5. **Other Vehicle Systems**
   - 5.1. IVHM/PHM
   - 5.2. APU
   - 5.3. Auxiliary Equipment.
   - 5.4. Maintenance Systems
   - 5.5. Furnishings -- crew, cargo, passenger, troop, etc.,
6. **Operations**
   - 6.1. Vehicle
   - 6.2. Airport
   - 6.3. ATM
7. **Propulsion/ Airframe Noise/vibration**
   - 7.1. Airframe
   - 7.2. Propulsion
   - 7.3 Internal Cabin

(1.15) "Turn radius in terminal area ≤ 1/2 nm (under 2,000 ft altitude) (may define a cone shape and/or non-circular pattern)."

Evaluation of the breakdown of the mission phases (as well as other level one requirements, runway length, etc.) identifies the need for controlled slow flight during terminal operations. This enabled derivation of the following level two requirement, "The ESTOL Transport shall be capable of operating at a low Approach Speed (Nominal Value 75 knots)".

From the derived level two requirements the initial ESTOL vehicle Work Breakdown System (WBS)/ technology areas was developed:

1. Airframe Structures,
2. Aero/Propulsion Integrated System
3. Flight Control Systems
4. Navigation System
5. Other Vehicle Systems
6. Operations
7. Propulsion/ Airframe Noise/ Vibration

Each area was further divided into sub-areas as delineated in Table 3.

It is recognized that whenever you break a system into what appears to be an arbitrary manner or a specific WBS you will have disagreements on whether or not it is the correct breakdown.

This current breakout of technology and sub-technology areas are not the only way to organize the proposed RIA Sector, but they will serve as first attempt to communicate what work needs to be accomplished.

TECHNOLOGY MATURITY ASSESSMENT

A 9-step technology readiness level and or research readiness level (Table 4) will be used to assess the maturity of the RIA technologies. This assessment will become one of the primary steps in determining which parts of the Sector need funding in order to have technology ready by the 2020 time frame.

Assessing the technology or research readiness of a particular sub-technology area will be done with respect to these readiness levels and the concept that we are assessing, not whether each area is at a particular desired level today, but whether it will be at the desired level in 2020 (or some other defined timeframe).

Each of these sub-areas is also meant to serve as bins for grouping individual RIA technology development projects. At any given time, there are a number of technology development projects being funded that are associated with RIA technology areas. The funding sources for these projects may be diverse, ranging from institutional research and development programs, to programs developed and funded under specific NASA Enterprises, to collaborative efforts with industry or other DOD agencies. One of the goals is, by planning well, resources will be spread around more efficiently, and duplication of technology development will be reduced to a minimum.

In attempting to assess where our capabilities are in the seven (WBS) technology areas, the team will encounter a number of difficulties.

The first will be developing a consensus in the community about the maturity level of a particular

Table 4. Description of Technology Research Levels (TRL)

1.	Basic principles observed and reported (Basic Technology Research)
2.	Technology concept and/or application formulated (Research to Prove Feasibility)
3.	Conceptual design tested analytically or experimentally (Research to Prove Feasibility)
4.	Critical function demonstrated in lab(Technology Development)
5.	Components/breadboard tested in a relevant environment (Technology Demonstration)
6.	System/subsystem model or prototype tested in a relevant environment (Technology Demonstration)
7.	Validation model demonstrated in a relevant environment (System/Subsystem Development)
8.	Actual system completed and "qualified" through test and demonstration - simulation or actual environment (System Test and Operations)
9.	System "proven" through successful operations (Operations)

technology. For example, if one individual determines that a particular technology is at a level 6, and another determines that it is at a level 4, does this mean that overall, the technology is at a level 5? No. Consequently, we face the problem of not having a good yardstick to measure the level of maturity of different levels of RIA technology.

These technology assessment levels were not designed for use by multiple investigators, or for general assessments of a whole technology area. The lack of definition of whether the list is logarithmic or geometric can lead to misinterpretation.

It was also recognized that this list is qualitative vice quantitive. Again this is obvious, but to manage this development process efficiently we need to be able to have measure of our progress throughout the development process (We recommend that we work toward developing a more complete and quantifiable system for evaluating RIA technologies).

The second problem concerned the feeling that no matter how "mature" a technology is, a flying demonstrator may still be required because of the very conservative nature of the Aerospace Industry. If this is true, then this means a demonstrator vehicle project must be developed, which would be managed differently than a technology development project.

EVOLUTION VS. NEW TECHNOLOGY

There is considerable discussion as to whether the next generation system will be evolved from a present vehicle or developed from a completely clean sheet of paper. The resolution to this question is obviously complex, and is rooted in economic considerations as much as engineering ones. The military has faced it on many occasions: when is it reasonable to add new engines and avionics to an old airframe (e.g., B-52), and when is it necessary to build something new (e.g., the B-2). Clearly, there are some missions that can be accomplished using upgraded equipment, but there are many times where it is not possible to make a silk purse out of a sow's ear. For instance, no amount of avionics or engine upgrade can turn a C-130 into a V-22. The RIA Sector Planning Team took the approach that it is necessary to have continuous development of RIA technology, regardless of the system into which it will be deployed. By the same token, the plans would recognize that periodically an integrated demonstration of a suite of RIA technologies makes sense. The present process is designed to provide periodic demonstration opportunities as the technology being developed reaches the appropriate maturity level.

MANAGEMENT PROCESS

Every NASA Project is guided by NPG 7120.5b[5]. This document provides guidelines how each project will execute their planning and implementation activities. The major areas in a project implementation process are listed below:

1. Project Control.
2. Customer Advocacy.
3. Requirements management.
4. Designs, Develops, and Sustains.
5. Deliver Products and Services.
6. Capture Knowledge.

Key facets of these integrated planning processes are that they do not simply generate mounds of documents, but are tools to allow for the development of consistent, defendable near term RIA Sector goals against established Vehicle System Program goals.

The sector plan, in particular, will describe an optimum plan for a 5-year focused research and technology development effort. However, this plan also supplies the manager with a tool to understand how these development efforts will respond to low budget years, and how to plan out-year activities to respond to changes in budgets. In effect, this plan will eliminate the need for "shoot from the hip" activity and budget planning, and will allow an understanding of the consequences of different budget scenarios to be consistently evaluated. Yearly progress will be judged against projected technology and research development goals, which will in turn be based on the RIA community's assessment of the level of development it needs to reach within a given period of time. The intent of this plan is to also have very clear "Go – No Go" criteria for a decision to build a technology demonstrator.

SUMMARY

Managing the technology development for an ESTOL Transport will require a mix of scientific and engineering disciplines that are linked by a requirements-driven planning process.

This paper discussed an effort to develop a repeatable and traceable process that would link the technologies being developed directly to the RIA Sector Vision, Vehicle System Goals and NASA's Goals and Aeronautics Objectives.

This process is being used by the RIA Sector Planning Team to define the basic functions and requirements of an ESTOL transport operating in the 2020 time frame, and then will be used to further define the ESTOL technologies to be developed in the years between now and 2020.

The active participation of all members of the RIA community (government, industry, and academia) will be necessary to ensure that all avenues are explored and new and innovative ideas are examined.

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