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Challenges in Autonomy

The Quest for Full Autonomy in Unmanned Flight and the Integration of Unmanned Systems into the NAS

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Introduction

Explosive growth and an expanding range of applications for employing unmanned/autonomous systems, coupled with a disparate and growing list of users of autonomous systems, will continue to challenge the ability to implement a coherent and unified approach in the development, transition, and effective integration of cutting-edge autonomous systems technology safely into the National Airspace System (NAS).

The autonomy challenge in the operation and integration of unmanned systems within the NAS is composed of numerous non-trivial activities. These activities cut across a wide array of cultural, operational, and developmental lines of responsibility and span organizations from the government, industry, and academia. Recent UAS technology developments to address the growing use of autonomous systems require the aviation community to consider new, non-traditional approaches to UAS development, collaboration, integration, and transition.

Statutory and regulatory decisions will have significant impacts on the development and execution of capabilities that support systems operation and integration of capabilities into the NAS. Equally important to autonomous systems integration efforts will be the significant influence of policy, procedural, and implementation activities on the myriad of players associated with a growing global market

for unmanned systems and autonomous operations. Focus of effort will be critical in the development of capabilities that include control interfaces; link management; normal and emergency procedures; safety handling; mission planning; preflight procedures that include surface operations, takeoff (including launch), departure, and transit to operations area; flight operations; approach; landing and recovery operations; post-flight and contingency operations; and maintenance procedures, to name a few.

According to the Federal Aviation Administration (FAA), “Unmanned Aircraft Systems (UAS) come in a variety of shapes and sizes, and serve diverse purposes. They may have a wingspan as large as a Boeing 737 or smaller than a radio-controlled model airplane.” The FAA further states that “A pilot is always in charge of UAS operations.”¹ As a major developer and user of unmanned systems, the Department of Defense (DoD) then defines an Unmanned Air System as “...a system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft—that is, an aircraft that does not carry a human operator and is capable of flight under remote control or autonomous programming.”²

Until recently, the DoD approached development of autonomous systems generally across independent/ non-synchronized efforts for UAS, Unmanned Ground systems, and Unmanned Maritime systems (UMS). With the release of the FY 2009-2034 version of the UMS Integrated Road

Map, the DoD endeavors to more effectively portray the technical challenges for autonomous systems development and integration across the ground, air, and maritime domains by publishing a “truly synchronized effort that increases the focus on unmanned systems, and through interoperability with manned systems.”³ The UMS roadmap articulates a clear vision and establishes a path forward by identifying key goals and objectives to meet respective challenges in autonomy through an integrated approach over the next 25 years.⁴

During the past decade, use of unmanned systems has experienced continued growth across military and governmental agencies, industry, and academia and represents a major niche focus area in the global economic marketplace. To amplify the growing importance of autonomous systems, the White House has made Unmanned Systems a focus area within its National Aeronautics Research and Development Plan of February 2010. Within the cover letter of that plan, the Office of Science and Technology Policy Director specifically identifies that “Of particular note, this plan includes an important new goal regarding the integration of unmanned aircraft systems into the National Airspace System.”⁵ UAS are called out in the 2010 version of the NextGen implementation plan where the FAA states that “with NextGen, we must continue to advance safety as we look ahead at increasing air traffic and the introduction of very light jets, unmanned aircraft systems and commercial space flights.”⁶

The challenges created by this continued growth and expansion or incursion into the NAS of unmanned and autonomous systems are numerous and non-trivial. They include bridging technological gaps and shortfalls that have a profound impact on safety concerns resulting from autonomous systems operating within a very high density and dynamic air traffic management/air traffic control environment. Solutions are required across a wide expanse of technical need to include the paramount concern for safety, the need for certifiable trust, activities within and near the terminal area, take-off and landing, en-route and trajectory-based planning, airworthiness, command and control, communications and operations, and computer software. All these areas need measures verifiable and robust enough to actively affect the control of autonomous systems. Capabilities that support sense and avoid/see and avoid and collision avoidance require technical solutions that mirror manned platform operations in executing both visual flight rules (VFR) and instrument flight rules (IFR) activities. Finally, common definitions and logical understanding of what is

truly required will not only help to focus technical solutions, but save precious resources.

We can ill-afford to maintain a cold war perspective that relies on developing large-scale solutions that often take years to develop and quite often fall far short or fail altogether in meeting the technical need or requirement originally intended. It is the hope of the authors that we contribute to the identification of key focus areas that facilitates a unified, collaborative way ahead. In view of the critical nature of safety vis-à-vis autonomous systems integration into the NAS, we hope to underscore the need for a concentrated and integrated effort/approach in providing technical solutions that meet the challenges in autonomy. The exponential growth and use of unmanned systems, coupled with the need to ensure that these systems can safely be integrated into the national and global airspace, merits just that—a detailed and coordinated approach.⁷

Searching for a Common, Unifying Definition

Just what does autonomy mean when applied to unmanned systems? Is it merely another step forward, or is it a monumental leap beyond auto pilot and waypoint navigation? The inherent challenge in identifying, defining, and establishing a common understanding of autonomy is no small task. What are we looking for in a definition? Should we only factor in pilot-in-the-loop, on-the-loop, out-of-the-loop, and off-the-loop in defining the associated requirements; or should we discuss levels of control coupled with levels of autonomy; or a combination of all three? How does command and control influence autonomous operations if unmanned systems are truly operating in a fully autonomous fashion? Is a common definition even needed? We think so.

To frame the discussion, we have used representative examples that serve to identify the difficulty and complexity in obtaining a common definition for autonomy, autonomous operations, and unmanned air systems. Although these may seem relatively straightforward, there is an underlying conflict in definitions that point to a disparity in a commonly understood view towards each. This disparity underscores the significant challenge that autonomy presents with unmanned flight and the integration of unmanned systems into the NAS.

Webster’s defines autonomy as “1: the quality or state of being self-governing, especially the right of self-government 2: self directing freedom and especially moral independence and 3: a self governing state.”⁸ With respect to autonomous

systems, we point again to the FAA unmanned aircraft systems definition where they state that UAS “come in a variety of shapes and sizes, and serve diverse purposes. They may have a wingspan as large as a Boeing 737 or smaller than a radio-controlled model airplane...” and further states that “a pilot is always in charge of UAS operations.”⁹ Radio Technical Commission for Aeronautics (RTCA) in its Operational Services and Environmental Definition (OSED) for Unmanned Aircraft Systems (UAS) document of June 10, 2010 defines autonomous as being “...not controlled by others or outside forces...”¹⁰ They further define Unmanned Aircraft as “...Aircraft operated without the possibility of direct human intervention from within or on the aircraft,”¹¹ and define a UAS as an “...unmanned aircraft and its associated elements required for operation.”¹² The DoD defines a UAS as “...a system whose components include the necessary equipment, networks, and personnel to control an unmanned aircraft—that is, an aircraft that does not carry a human operator and is capable of flight under remote control or autonomous programming...”¹³ Finally, the army defines a UAS a system “...comprised of the unmanned aircraft, payload, human element, control element, weapons systems platform, display, communication architecture, life cycle logistics, and includes the supported soldiers...”¹⁴ Their definition further states that “...anything but ‘unmanned,’ the UAS tactical and operational employment absolutely requires the human element...”¹⁵ If we include all elements of the “system” into the autonomous discussion, then we must factor in all entities that, when combined, make the “system.” This would include associated segments, subsystems, components, parts, and elements, and the numbers of definitions would then arguably increase as a result. The list of example definitions could go on because the number and differences in definitions are as varied as the number of governmental, industry, and academic entities that develop, use, or operate autonomous systems.

In searching for a definition, we do think that it is important to also factor in activities and actions that include systems operation, control interfaces, link management, normal and emergency procedures, safety handling, mission planning, preflight procedures, takeoff and transit to operations area, flight operations, recovery and landing, post-flight and contingency operations, and maintenance procedures to name just a few. We need to ensure that as we move forward, we have a comprehensive understanding of how autonomous systems operate and influence the NAS and how their operations affect airspace classifications and requirements, air navigation facilities, equipment and services; airport and

landing areas; aeronautical charts and symbols; aeronautical information services and sources and applicable rules, regulations and procedures.

Common Framework for Identifying the Autonomous Domain and Levels of Autonomy

Although autonomous systems development spans the air, ground, and maritime domains, for purposes of this paper, we feel that it is important to address the increasingly complex implications that arise specifically in developing solutions across the air and ground domains. Similar to the search for a definition, we believe it is as equally important to have a comprehensive foundational understanding of the complexity presented by ever-increasing levels of autonomy for unmanned systems and their impact and influence on NAS operations.

Currently, unmanned systems operate largely within the realm of military aviation, and yet they are experiencing significant growth and use within industry, academia, and the civil market place. The desire to integrate autonomous systems into the NAS reflects a realization that these systems have become more than a mere novelty; they have become an economic reality within both a growing domestic and global niche market. As a result there is increasing stress on airspace activities within civil and general aviation for unencumbered transparent autonomous systems operations. This stress is being increasingly felt within both regulatory and non-regulatory airspace, with implications spanning controlled, uncontrolled, special use, and other airspace. Within this paper our focus is oriented on the air and ground domains and the associated implications that arise with NAS integration.

To better frame the air/ground picture, we believe it is important to clearly articulate where these systems operate within each respective domain. Like their manned counterparts, autonomous systems will operate within an environment that includes terminal area operations (both ground and air), launch and recovery, and en-route/trajectory planning and operations. Activities will influence surface operations, takeoff, departure, en-route, approach, and landing operations. Critical to these activities will be technologies that afford safe operations and include sense and avoid, speech recognition, separation assurance and conflict avoidance, communications, multi-modal interaction, autonomous systems interface and interoperability, and the need for

certification/certifiable trust and verification and validation of associated technologies.

With a general operational framework in mind, we think it equally important to understand how the levels of autonomy impact and influence the development of relevant technologies, policies, and procedures associated with autonomous systems and their NAS integration. In dealing with these levels, having an accurate understanding of terminology will be critical. Not unlike the need for a clear and unambiguous definition, we believe that understanding the terminology used to describe the levels of autonomy is essential and can have significant impact on development activities if terminology is not clearly articulated and used in a precise manner. Although similar, the different columns of Table 1 all identify 10 levels of autonomy, but do so in different ways.

Are these merely subtle nuances or substantive differences, critical to the discussion and challenges at hand? When dealing with autonomous systems integration into the NAS, do these different explanations of the levels apply equally, or is one more suited to the use of unmanned systems than the others?

Take for example the three interpretations in our examples for level one. The description found in Column A appears to be straightforward, “the computer offers no assistance, and humans do it all”. In Column B, however, the use of the phrase “remotely guided” indicates or implies that operating or control occurs from a distance (American Heritage Dictionary). In Column C, the use of “manual control” may imply some variation of automation is already extant within a system through some form of describing function that approximates certain tasks performed by a human operator.

At the other end of the spectrum, each example describes level 10 differently. Column A identifies that “the computer decides everything and acts autonomously, ignoring the human;” Column B indicates ability for “fully autonomous swarms,” while Column C indicates merely “full automation.” Again, in Column A, the description appears to be fairly straightforward. The computer does everything with no human intervention or activity. In Column B however, the definition becomes more difficult to ascertain what actions occur to facilitate “fully autonomous swarms” transitioning from fairly simple independent entities to the more complex emergent behaviors associated with swarms and

Table 1: Comparison of 10 Levels of Autonomy

Factors Influencing Autonomy			
Levels of Autonomy	A. Sheridan and Verplank's 10 Levels of Automation	B. Wise, Garland, and Hopkin's Handbook of Aviation Human Factors	C. Endsley and Kaber
1	Computer offers no assistance, human must do it all.	Remotely guided	Manual Control (MC)
2	Computer offers a complete set of action alternatives, and...	Real time health/diagnosis	Action support (AC)
3	Narrows the selection down to a few, or...	Adapt to failures and flight conditions	Batch processing (BP)
4	Suggests one, and...	Onboard route replan	Shared control (SHC)
5	Executes that suggestion if the human approves, or...	Group coordination	Decision Support (DS)
6	Allows the human a restricted time to veto before automatic execution, or...	Group tactical replan	Blended decision making (BDM)
7	Executes automatically, then necessarily informs the human, or...	Group tactical goals	Rigid system (RS)
8	Informs him after execution only if he asks, or...	Distributed control	Automated decision making (ADM)
9	Informs him after execution if it, the computer decides to.	Group strategic goals	Supervisory control (SC)
10	The computer decides everything and acts autonomously, ignoring the human.	Fully autonomous swarms	Full Automation (FA)

intelligence activity and cognitive action. Finally, Column C underscores full automation. According to the Britannica Concise Encyclopedia, automation was a “term coined about 1946 by a Ford Motor Co. engineer, used to describe a wide variety of systems in which there is a significant substitution of mechanical, electrical, or computerized action for human effort and intelligence. In general usage, automation can be defined as a technology concerned with performing a process by means of programmed commands combined with automatic feedback control (see control system) to ensure proper execution of the instructions. The resulting system is capable of operating without human intervention.”¹⁶

Key Direction

The White House, in its National Aeronautics Research and Development Plan of February 2010, indicates that in order “to meet the aviation needs of our Nation now and in the future, the Federal government must continue to advance U.S. technological leadership in aeronautics by fostering a vibrant and dynamic aeronautics community that includes government, industry, and academia.”¹⁷

It further states that “of particular note, this plan includes an important new goal regarding the integration of unmanned aircraft systems into the National Airspace System.” In addition, this R&D Plan:

- Supports the coordinated efforts of the Federal departments and agencies in the pursuit of stable and long-term foundational research;
- Ensures U.S. technological leadership in aeronautics for national security and homeland defense capabilities;
- Advances aeronautics research to improve aviation safety, air transportation, and reduce the environmental impacts of aviation;
- Promotes the advancement of fuel efficiency and energy independence in the aviation sector; and
- Spurs the development of innovative technologies that enable new products and services.”¹⁸

The FAA’s NextGen Implementation Plan of March 2010, however, pays little attention to the importance and influence that unmanned systems integration activities will have on the NextGen operating environment through a somewhat ill-defined approach under the NextGen Demonstration budget. Found on page 73 of the plan, UAS are only discussed in terms of the 4D Trajectory Based Demonstration

with further explanation only of the “conduct of Integrated UAS demonstration plan activities between FY09-FY15.”¹⁹

Within the June 10, 2010 Operational Services and Environmental Definitions (OSED) for Unmanned Aircraft Systems (UAS) document serves to “provide a basis for assessing and establishing operational, safety, performance, and interoperability requirements for UAS operations in the NAS.”²⁰ This document uses an iterative process based on the RTCA DO-264 process flow of collecting, describing, assessing, and documenting information and requirements.²¹

The DoD Unmanned Systems Integrated Road Map identifies eight broad goals that are intended to help in fielding transformational capabilities, establishing joint standards, and controlling costs. These goals establish clear direction aimed at improving integration and collaboration; support research and development that will help to increase both the levels of automation and autonomy in unmanned systems; and achieve greater interoperability and the development of policies, standards, and procedures that facilitate safe and effective operations.²²

During August 2010, NASA underscored the challenge of integrating unmanned systems into the NAS in a briefing to the National Science Council entitled UAS Integration into the NAS project. Within that briefing, NASA indicates that there is a combination of complicating factors that are influencing routine UAS operations within the NAS. These include a lack of definition and an integrated or broadly accepted plan, a conflict between the “as is” FAA architecture/enterprise and that of the “to be” Next Gen operating environment, disparate certification standards, and an expansive performance environment that is much different than that found with existing manned aircraft.²³

Specified or implied, a fundamental theme for each is the need for clearly articulated direction that enhances unity of effort, provides commonly understood direction, and ensures a fully collaborative approach to interoperability and integration. Arguably, much of that does not currently exist. In order to ensure that safe, suitable, and sustainable progress is made in the realm of autonomous systems research, development, and integration, we must commit to an approach that maximizes the development of relevant technologies in a well coordinated manner that ensures technological leadership, advances research activities, and spurs the development of new products and innovative technologies. Any activity in the future must ensure success by instituting economical and fiscal measures that reward collaborative development and shared understanding for the way ahead, orienting all activi-

ties in a manner that will ensure safe integration of autonomous systems into the NAS.

Critical Challenges and Enablers

The continued autonomous systems expansion within the current aviation domain and expected increased utility of these systems within the planned NextGen NAS environment are creating unparalleled strain on both the Government and industry's ability to seamlessly incorporate systems into the operational framework.

The paramount challenge associated with integrating autonomous systems in the NAS is that of safety. To meet this critical challenge, introduction of capabilities which maximize the development of open systems architectures, which ensure airworthiness through effective reliability and maintainability, and which provide effective measures for certifiable trust must occur across all development, integration, and operational activities. As previously discussed, challenges include ill-defined definitions and terminology; a less than clearly articulated or agreed understanding of the autonomous domain and desired levels of autonomy; confusion in assessing and interpreting key direction in major policy for R&D; and a less-than-adequate approach to meet the critical procedural, oversight, and support actions required to develop and integrate necessary enabling technologies. These challenges span both air and ground domains and include operations in the terminal area, take off and landing, en-route/trajectory operations, automated separation and assurance, conflict avoidance, robust communications, systems interfaces, and standardized safety and certification measures and procedures.

The lack of stable/approved requirements compound these challenges as does an insufficient emphasis on reliability and maintainability for autonomous systems, the clash of cultures between manned and unmanned communities, and inefficiencies resulting from duplicative activities for similar functions. With the explosive growth of unmanned systems, coordination across government, industry, and academia is not robust. Often times, key stakeholders from a widely diverse organizational base are unaware of other activities or efforts being conducted by each other due to parochialism, bureaucratic inertia, and a lack of incentive to coordinate.

If safe operations are to occur in a coordinated fashion, Government and industry alike must ensure that measures are in place that ensures trust in autonomous operations through effective and impartial certification, integration, and interoperability. Detailed understanding of the operational

domain must address more fully actions and requirements for autonomous systems operating in the terminal area, the critical need for sense and avoid, separation assurance and conflict/collision avoidance, take off and landing, en-route/trajectory planning, command and control, and a more robust and integrated approach to verification and validation.

In light of the explosive growth in use of autonomous systems and the effect that an expanding user base (national security and defense; emergency management; commercial applications ranging from law enforcement, border control, and agriculture; academia; and the scientific community) is having on current NAS operations and those of the future NextGen environment, we must place more emphasis on laying an effective foundation.

Regulations for file and fly access, the critical need for enhanced see and avoid capability, and air traffic regulatory requirements that orient on a do-no-harm approach to conformance and precedence setting are critical in establishing a unified approach to the integration challenges presented by autonomous systems. Other factors including reliability, air worthiness, and crew qualification/training will be equally important in the development of technologies that afford transparency in operations. As safety will undoubtedly remain the key concern for integration of autonomous systems into the NAS, we must endeavor to ensure proper focus and unity of effort occur across developmental, integration, and operational activities.

When Safety is Paramount (The Need for an Integrated Solution)

When developing critical technologies that facilitate and support integration of autonomous systems into the NAS, we can ill-afford to continue down a path of disparate, stove-piped development across U.S. Government, industry, and academia. Not only is that approach counterproductive and wasteful, it is unsustainable. What is needed is a hybrid approach to autonomous system integration that aggressively seeks out technical solutions for an expanding user base while facilitating unity effort.

To underscore the critical need for safety, Henry Krakowski, the Chief Operating Officer, Air Traffic Organization for the FAA, made the following statement before the Senate Committee on Commerce, Science, & Transportation, Subcommittee on Aviation Operations, Safety, & Security on Field Hearing on the Integration of Unmanned Aircraft Systems (UASs) Into the National Airspace System (NAS):

Fulfilling Imminent Operational and Training Requirements on September 13, 2010.

With regard to unmanned aircraft systems (UAS), the FAA sets the parameters for where a UAS may be operated and how those operations may be conducted safely in the NAS. Our main focus when evaluating UAS operations in the NAS is to avoid any situations in which a UAS would endanger other users of the NAS or compromise the safety of persons or property on the ground. The FAA acknowledges the great potential of UASs in national defense and homeland security, and as such, we strive to accommodate the needs of the Department of Defense (DoD) and Department of Homeland Security (DHS) for UAS operations, always with safety as our top priority.

When new aviation technology becomes available, we must determine if the technology itself is safe and that it can be operated safely. Whether the technology is to be used by pilots, operators or air traffic controllers, we determine the risks associated with putting that technology into the NAS. Once the known risks are mitigated, we move forward with integration in stages, assessing safety at each incremental step along the way. Unforeseen developments, changing needs, technological improvements, and human factors all play a role in allowing operations within the civil airspace system.

The FAA is using this same methodology to manage the integration of the new UAS technology into the NAS. While UASs offer a promising new technology, the limited safety and operational data available to date does not yet support expedited or full integration into the NAS. Because current available data is insufficient to allow unfettered integration of UASs into the NAS—where the public travels every day—the FAA must continue to move forward deliberately and cautiously, in accordance with our safety mandate.²⁴

Achieving balance across multiple activities and environments will create significant challenge for systems engineering, configuration management, verification and validation, testing and evaluation, transition, integration, and active/unencumbered operational activities. To support any balanced approach, we must significantly improve our ability to conduct integrated technical planning, requirements analysis, functional analysis and allocation, synthesis, and verification and validation efforts. In the quest for safety, this balance must enhance and provide certifiable trust in autonomous systems operations.

Krakowski went on further to state that “Unmanned aircraft systems are a promising new technology, but one that was originally and primarily designed for military purposes. Although the technology incorporated into UASs has advanced, their safety record warrants caution. As we attempt to integrate these aircraft into the NAS, we will continue to look at any risks that UASs pose to the traveling public as well as the risk to persons or property on the ground. As the agency charged with overseeing the safety of our skies, the FAA seeks to balance the security, defense, and other public needs of our partner agencies with the safety of the NAS. We look forward to continuing our work with our partners and the Congress to do just that.”²⁵

In view of Mr. Krakowski’s comments, we believe that the time is now to implement an integrated approach in addressing longstanding and critical inefficiencies in the research, development, and integration of technical solutions for unmanned systems. These inefficiencies have been created in large measure by often-times duplicative activities and functions that cross multiple lines of responsibility with government, industry, and academia. Coordination must be improved to ensure that we effectively cross parochial boundaries that impede full and open understanding and collaboration within the field of autonomous systems. A positive step forward, Krakowski’s closing comments underscore the critical need to ensure that there is a consistent and focused approach to safely integrating unmanned/autonomous systems within the NAS. ✈

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The graphic features a large image of an airport tarmac with a person in a high-visibility vest and a large commercial airplane. Below the main image are several small, square thumbnail images showing various scenes related to air traffic control and aviation.

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