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Certification Coordination Roadmap

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September 2019

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Executive Summary

Advanced technology holds the promise of bringing benefits to areas heretofore rife in underutilized global capacity, subsonic overland vehicles, inefficient commercial vehicles, reliance on high-carbon propulsion systems, reactive system-wide safety and traditional automation in aviation systems. These challenges require a strategic framework as we enter the second quarter of the twenty-first century.

Innovative technology that may show great promise usually has to prove itself in the context of legacy regulations. In many cases, technology developers of innovative technology attempt to conform their technologies against current regulations and certifications, and in the process either deform their innovative technologies to conform to the regulations, or attempt to rationalize the current regulations to fit their innovative technologies. Neither of these approaches is fair to the new technologies, and, in the long run, it is not fair to the body of regulations and certifications.

This dilemma results in an inappropriate justification of the relevant environment by the technology advocate or an accusation of unrealistic technology by the gatekeeper of the relevant environment.

Therefore, while it is necessary for technologists to write scholarly papers for publication in technical journals, it is not a sufficient condition for technology transfer.

The only rational accommodation to resolve the dilemma is by the technologist actively engaging in the standards process with the knowledge borne from the new technology, as well as engaging with the regulating authorities to first understand their role and then to advise on the effect that the new technology has on those regulations, and finally the technologist must engage with the manufacturing community to demonstrate the potential benefit of the technology.

This report has summarized past work within this task and identified areas that have been pioneered in certification and standards.

A model for Innovative Technology Environment consisting of the relationship of NASA technology to industry, standards development and regulatory activities is described. This tetrahedral model provides a check that all relationships are equally valued between industry, standards and regulation-certification.

A review of the needs from the standards community that are directly affected by the X-57 project are identified and a recommendation for establishing the management structure to ensure an enduring commitment by NASA is described.

It is noteworthy that nowhere else in NASA is there an equivalent level of working relationship with standards and regulatory organizations than that which is being done by the X-57 project. As such the products of the X-57 project can become an enduring technology legacy long after the project is concluded. The model that has been established for this working relationship should be applied to other advanced vehicle projects.

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1. Introduction

Advanced technology holds the promise of bringing benefits to areas heretofore rife in underutilized global capacity, subsonic overland vehicles, inefficient commercial vehicles, reliance on high-carbon propulsion systems, reactive system-wide safety and traditional automation in aviation systems. These challenges require a strategic framework as we enter the second quarter of the twenty-first century.

The days of innovating a technology as a one-off demonstration of a technical capability during the mid-twentieth century were overtaken by the development of a more systematized engineering approach pioneered in the third quarter of the twentieth century in aeronautics and aviation.

Coupled with a strategic framework, this systematized engineering approach allows for a much more complete opportunity for the technology to be validated or tested in its eventual, relevant environment.

New technology, whether a component or an entire vehicle concept should have the ability to innovate an industry sector without conforming to legacy methods of ensuring the quality attributes of non-functional requirements used to evaluate the performance of the system within which the new technology may be intending to operate. Many of these properties have heritage in long-established technology and procedures, and thus, the associated "-ilities". A precise definition of *ilities* by Olivier de Weck, from Engineering Systems[1]:

> The *ilities* are desired properties of systems, such as flexibility or maintainability (usually but not always ending in "ility"), that often manifest themselves after a system has been put to its initial use. These properties are not the primary functional requirements of a system's performance, but typically concern wider system impacts with respect to time and stakeholders than are embodied in those primary functional requirements. The ilities do not include factors that are always present, including size and weight (even if these are described using a word that ends in "ility").
>
> Over time, greater awareness of safety became characteristic of the *epoch of great inventions and artifacts*, although engineers concentrated primarily on making safety-related alterations and adjustments to artifacts (often products), they also participated in changing the underlying systems and operating environments within which they function. *Quality* was the other ility to emerge in this early epoch.

While this reference in the Engineering Systems book is focused on automotive safety, it is clear that the same systems engineering practices are applied in aerospace.

Aviation prides itself as one of the safest transportation modes. The NTSB noted in a report in 2017[2] that, of 39,339 fatalities in 2016, aviation was responsible for 412 fatalities.

A major reason for this level of safety is the robust sets of engineering and operational safety regulations and aviation safety inspectors who oversee the implementation of these regulations. These engineering certification regulations have a strong foundation based on experienced engineers documenting hard lessons learned from engines, structures, aerodynamics, controls and guidance, flight systems, and assorted subspecialties. While decades of experience in internal combustion, reciprocating engines, turbine engines, metallic materials and structures,

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[1] Life-Cycle Properties of Engineering Systems: The Ilities, Chapter 4, Engineering Systems, De Weck, June 16, 2011. http://strategic.mit.edu/docs/es_book_004_proof.pdf

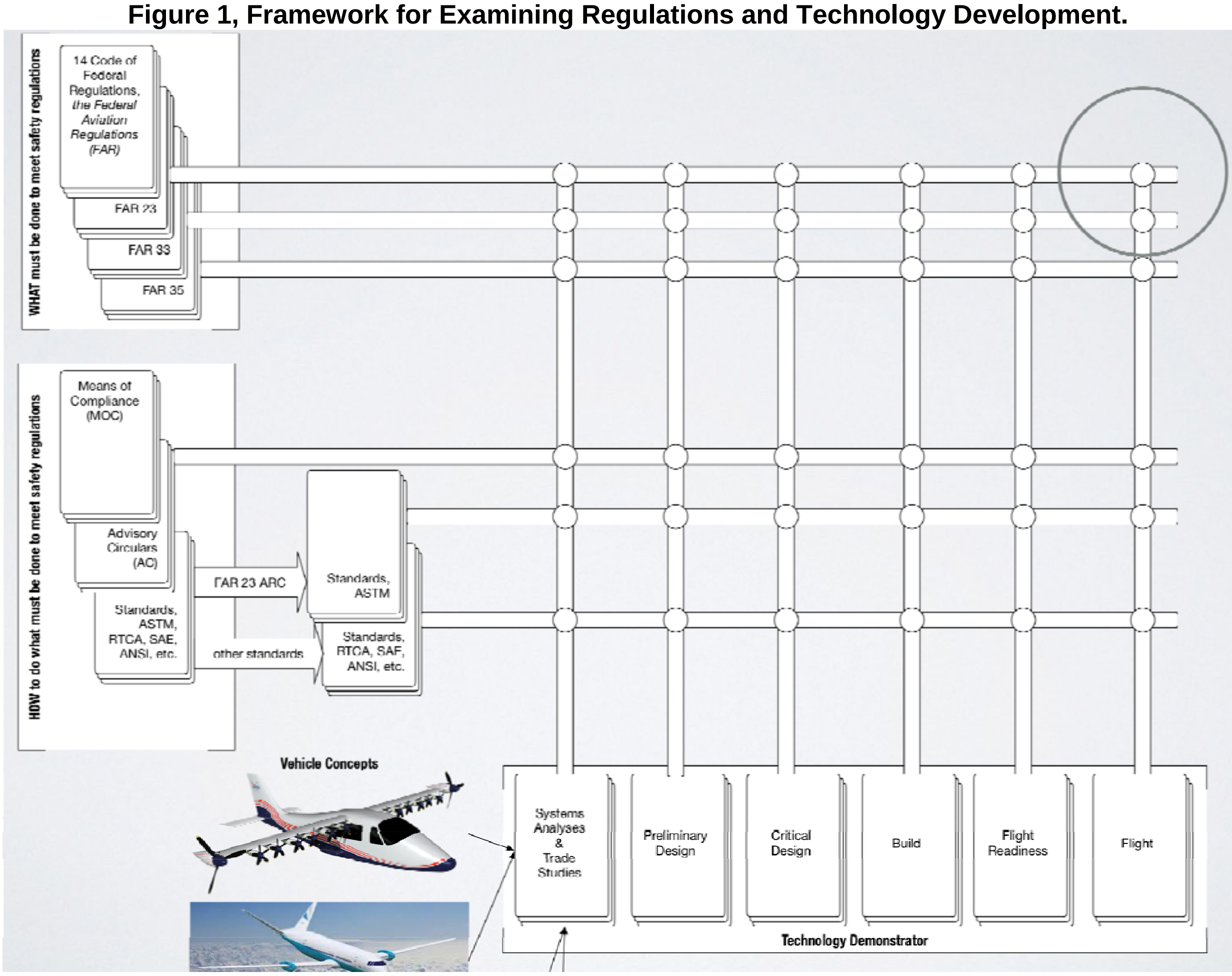
[2] https://www.ntsb.gov/news/press-releases/Pages/PR20171121.aspx

traditional terrestrially-based navigation, guidance and control, establishes excellent engineering practice, there is an unintended consequence of stymying innovation.

1.1. Developing a Framework for Assessing Innovative Aeronautics Technology and Regulations

The first report described the general methodology and applied it to the general class of electrification of aircraft propulsion systems. In particular, it looked at battery-powered, electric propulsion for both cruise and takeoff and landing configurations of an aircraft. The first report developed the concept of organizing the framework in the form of regulations and means of compliance versus the system technology development phases. Figure 1 illustrates the general framework. Each step in the Technology Demonstrator timeline reflects increasing levels of maturity. This means that as the initial means of compliance is presumed during the system analysis phase, it is reassessed at the preliminary design step, and modified, potentially, as new knowledge is developed. In the same way, as the technology demonstrator moves towards critical design, build and flight, each of those steps mature the intended standard and understanding of the applicable regulation. This shows the level of confidence increasing as the technology demonstration matures.

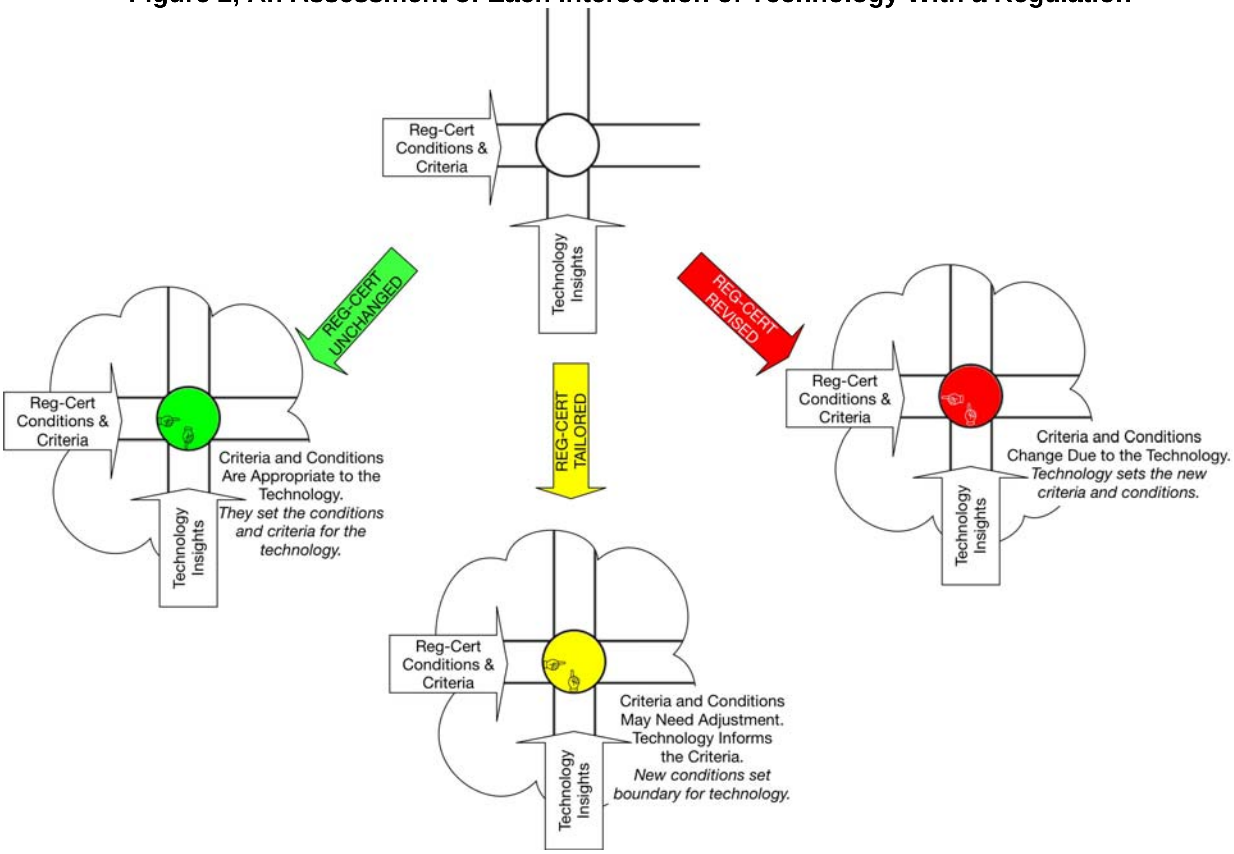
Figure 1, Framework for Examining Regulations and Technology Development.



Given the framework, the intersections of each regulation and means of compliance with its associated system technology phase, offers a unique opportunity to assess the relationship of the regulation and as the technology matures through its technology demonstration phase.

Figure 2 shows a three-part assessment, based on the appropriateness of the regulation to inform the technology or the technology to inform the regulation, an assessment of whether the regulation is unchanged in the presence of the technology, that the regulation is informed by the technology (and thus the regulation is tailored to the technology), or that the regulation is changed due to the technology (where the regulation is revised, either in whole or in part).

Figure 2, An Assessment of Each Intersection of Technology With a Regulation



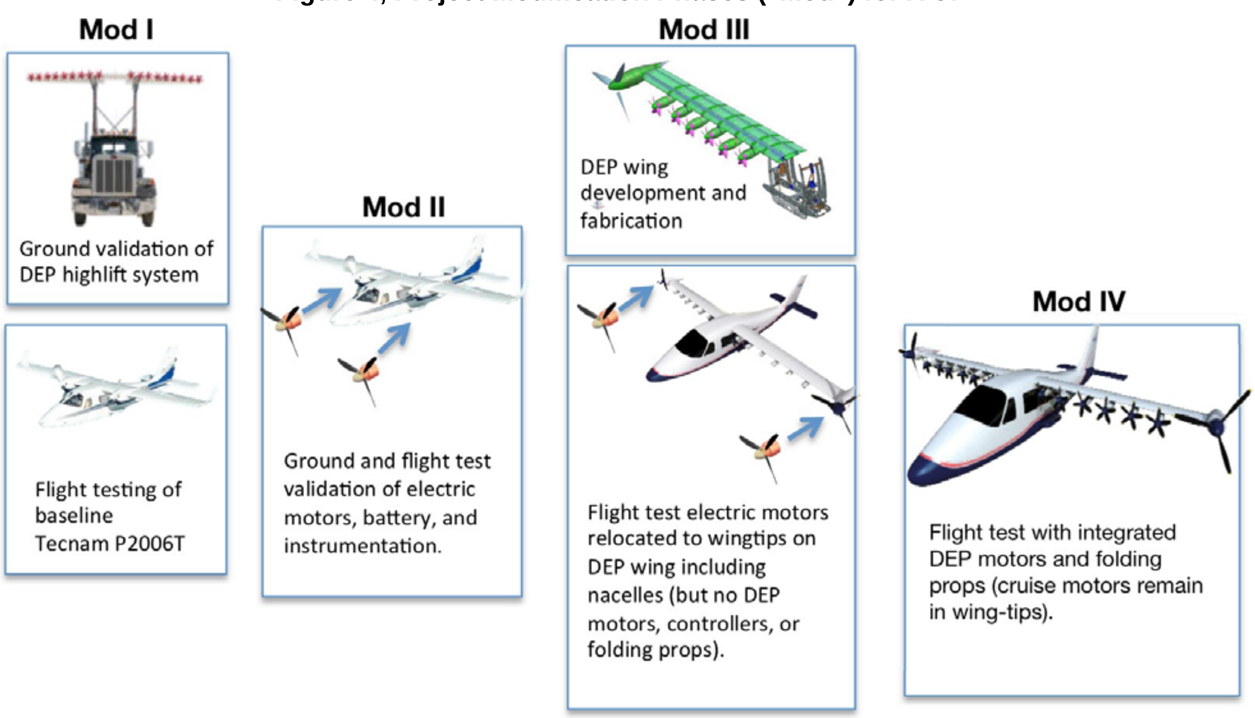
1.2. Evaluating the Framework Against an Exemplar Vehicle Concept, the X-57

The second report described the application of the framework against an example case, the X-57 project. This experimental aircraft demonstrates distributed electric propulsion for both cruise, as well as take-off and approach to landing. It uses onboard batteries to power two wingtip cruise motors and an additional set of leading edge motors. The X-57 “Maxwell” is built around a modified Tecnam P2006T with a considerable modification of the wing to accommodate the electric propulsion system, and the fuselage to accommodate the battery compartment. The aircraft is piloted by one NASA Flight Research pilot. An illustration of the concept vehicle is shown in Figure 3.

Figure 3, The X-57 "Maxwell" Vehicle Concept

There are four modification states through which the X-57 will evolve. These are shown in Figure 4. Each of these modification phases increments the technology from the flight testing of the baseline Tecnam P2006T until Modification 4 with the flight research of the integrated DEP motors.

Figure 4, Project Modification Phases ("Mod") for X-57



As a result of this incremental approach to flight research of the concept vehicle, the framework in the first report was updated for this second report to change the generic system technology phases as the column in the framework to the four modification phases in the X-57 project.

While the X-57 is an experimental aircraft, it does not require compliance with 14 CFR 23, 33 or 35 for flight. The aircraft will only be flown within the Dryden Area Test Range under the direction of the NASA Armstrong Flight Research Center, there are safety and program requirements that must be met to ensure safety of flight and effective project management.

For the purposes of the report's assessment, however, a simulation of a certification compliance matrix was used to reflect the assessment of the regulations to the X-57 technology. In addition to the regulations, the associated ASTM, International, standards (both draft and approved) were shown for each regulation paragraph. The last four columns of the framework were reserved to show the requirement, specification or analytical report associated with the appropriate regulation and means of compliance.

With the "Proposed Compliance Matrix" (PCM) in place for Federal Aviation Regulation Parts 23 (Normal Category Airplanes), 33 (Engines) and 35 (Propellers), a gap analysis was constructed that shows where shortfalls exist in the regulations that can be structured and populated by the fruits of the X-57 technology demonstration. It also shows where the X-57 will not respond to regulations (these are predominantly in icing — the Tecnam P2006T is not certified for flight into known icing conditions — and lightning). However, in areas of electric motor technology there will be significant data to contribute to the regulations, standards and, thus, industry. The X-57 battery technology design, specifications, and lessons learned will likewise contribute immeasurably to battery standards for aviation applications.

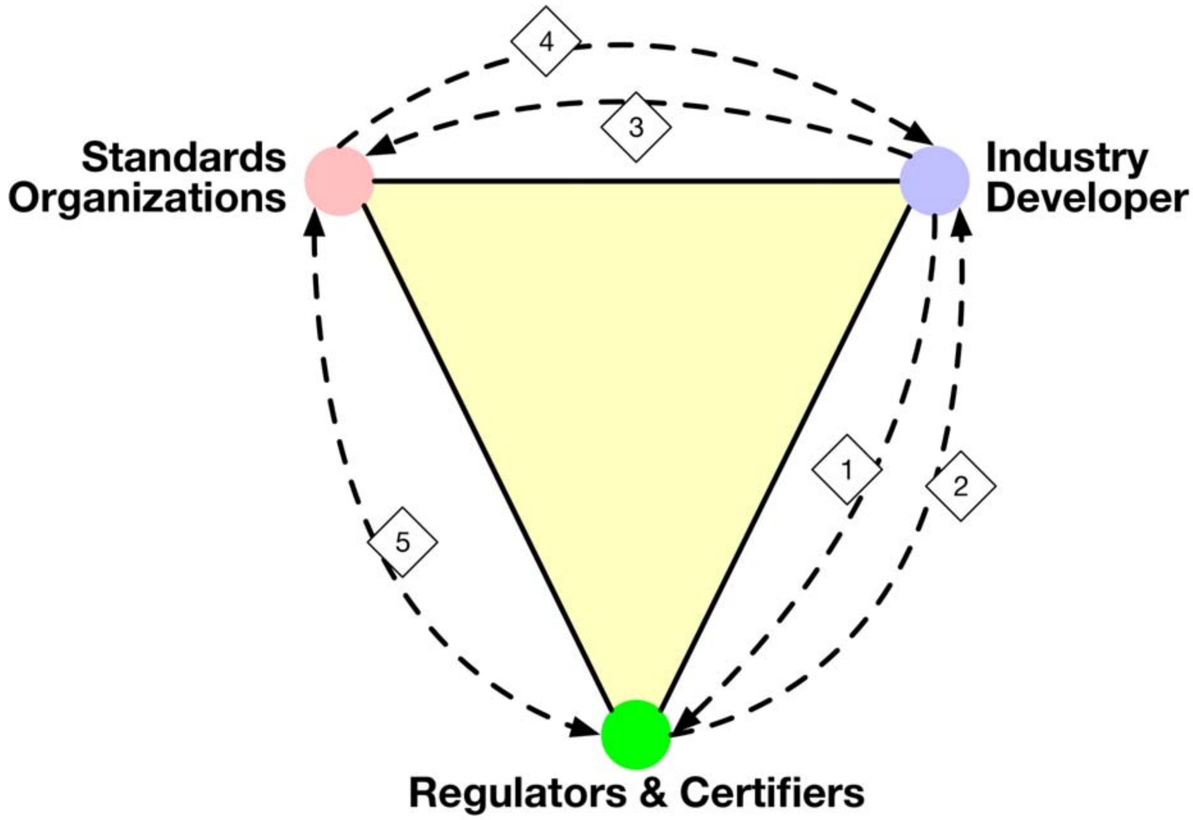
The result of the second report was a framework that shows the role that NASA Aeronautics Research can play in the context of not only industry, but also with civil aviation authorities (in the US, the FAA), and international standards organizations.

This report is the third and final report in a series of reports that describes potential frameworks and roadmaps for development of standards and regulations related to innovative, emerging aerospace technologies.

2. Coordination Between NASA, the Regulators and the Standards Bodies

Figure 5 shows the relationships between an industry developer, the regulator and the standards organizations in an established technology environment. As a simplified illustration, an industry developer goes to the FAA with a development certification plan (path 1), and the FAA validates that the cited regulations in the certification plan are appropriate and approved (path 2). The industry developer goes to the standards organization to develop the means of compliance to the certification plan (path 3) and works to ensure that the standards are appropriate for their technology. In many cases, changes to the standards are suggested by the industry developer to the standards organization and a consensus process begins to develop the new standards (path 4). Of course, the industry developer needs to be circumspect in the details of the rationale for the changes, lest the proprietary technology becomes exposed. In this environment, the FAA, as a member of the standards organization seeks to ensure that the new standards can continue to be a valid means of compliance to the associated regulations (path 5).

Figure 5, Roles Within an Established Technology Environment



A significant portion of any certification program is a solid knowledge of the means of compliance (MOC) to each paragraph within the regulations. These MOCs are traditionally done by FAA Advisory Circulars to their respective sections of the FAR. However, a number of MOC are better done by industry-accepted standards. Aviation standards organizations such as ASTM, RTCA, SAE (and others) build their standards, typically, through consensus of industry and Government technical specialists gathering to develop their standards.

Of particular note for general aviation is that the ASTM has built the Committee F44 on General Aviation Aircraft, and Committee F39 on Aircraft Systems. These committees are actively contributing to the standards body of knowledge on electric propulsion, in particular.

2.1. Resolving the Dilemma of Introducing Innovative Technology into Established Technology Environments

Innovative technology that may show great promise usually has to prove itself in the context of legacy regulations. In many cases, technology developers of innovative technology attempt to conform their technologies against current regulations and certifications, and in the process either deform their innovative technologies to conform to the regulations, or attempt to rationalize the current regulations to fit their innovative technologies. Neither of these approaches is fair to the new technologies, and, in the long run, it is not fair to the body of regulations and certifications.

This dilemma results in an inappropriate justification of the relevant environment by the technology advocate or an accusation of unrealistic technology by the gatekeeper of the relevant environment.

Therefore, while it is necessary for technologists to write scholarly papers for publication in technical journals, it is not a sufficient condition for technology transfer.

The only rational resolution to the dilemma is by the technologist actively engaging in the standards process with the knowledge borne from the new technology, as well as engaging with the regulating authorities to first understand their role and then to advise on the effect that the new technology has on those regulations, and finally the technologist must engage with the manufacturing community to demonstrate the potential benefit of the technology.

NASA has a unique tradition of pushing the state-of-the-art in aeronautics research and technology (R&T). In many cases the R&T is focused on discipline-focused advances. Some times the opportunity arises for multi-disciplinary, systems technology R&T, which can give rise to a flight demonstration project. These unique opportunities offer great insights for the entire aeronautics community. When coupled to industry initiatives such as on-demand mobility (ODM) and urban air mobility (UAM), where the state-of-the-art is pushing the state-of-technology, NASA has a role that is unlike any other Government organization.

NASA's X-57 project is in a unique position to inform the entire aeronautics community, as well as the *nouveau-aeronautics* community that is investing in the ODM-UAM experience. In fact, the *nouveau-aeronautics* community has the least experience in the rich heritage of aeronautics and aviation safety procedures and standards, and stands to gain the most knowledge from NASA's experience.

NASA has a responsibility, therefore, to populate the standards and regulatory knowledge base.

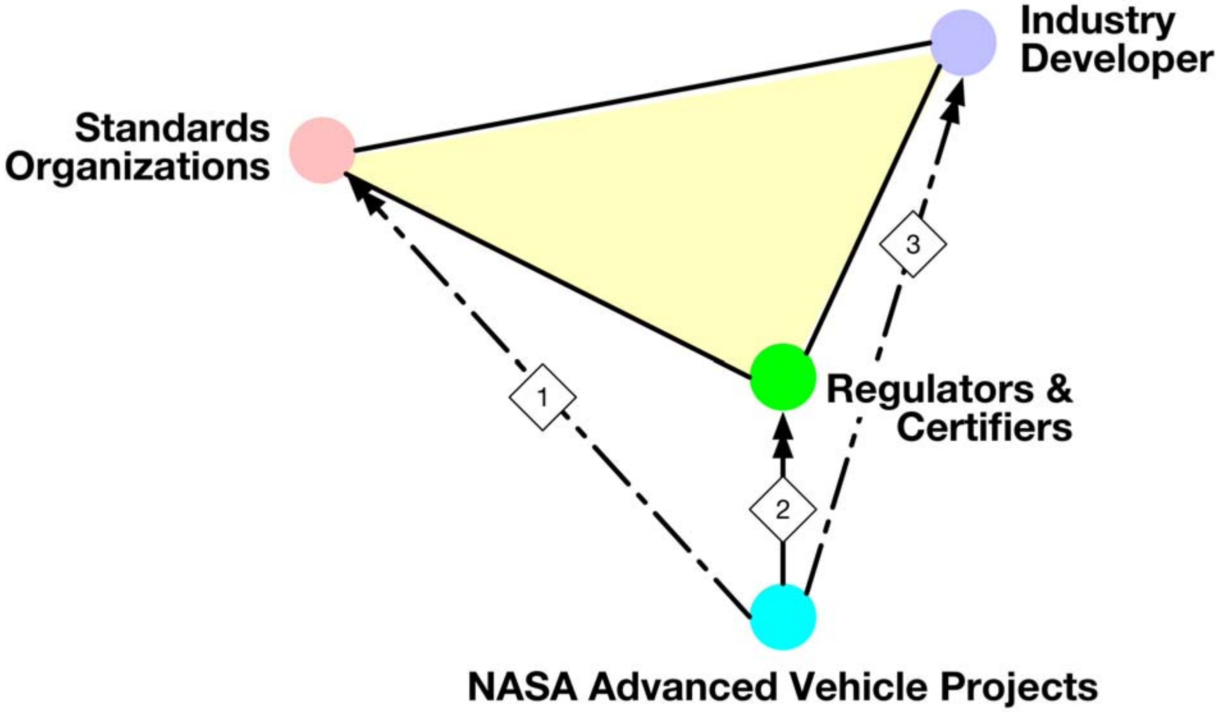
NASA involvement with the regulators and standards bodies is openly encouraged, and forms a unique ability to ensure contribution of NASA technology to the industry.

Innovative NASA Aeronautics Research Advanced Vehicle projects must demonstrate the ability to be an equal contributor to the industry developer, the standards organization and the FAA regulator and certifier, as illustrated in Figure 6.

The model is intended to be 3-dimensional in its structure, as the relationship between any three parties is unique. For example, the unique relationship between the industry, standards organizations, and FAA regulations and certification (as is shown in Figure 5), is a normal relationship that does *not* need an active NASA contribution in cases where emerging technology is *not* involved. This is the normal case of development and certification of mature technologies. When NASA supports an innovative technology project, NASA's role is manifest. However, the normal relationship between industry, standards and civil aviation regulators must be recognized and respected.

However, when new technology is being demonstrated in a system technology advanced vehicle project, NASA enters a relationship with the standards organizations (see path 1 in Figure 6) and the FAA regulators and certifiers (see path 2 in Figure 6) to help build effective means of compliance and to assess the regulations for their ability to be affected by the technology, based on the experience learned by NASA in the pursuit of the flight demonstration. It is the lesson-learned (not just a dry systems engineering artifact) that form the knowledge foundation for the new technology and its associated role in the form of a handbook (or practices within a standard) that becomes the legacy to the entire industry (see path 3 in Figure 6). This is a fundamental difference between a discipline-level R&T effort and a multidisciplinary, system-level R&T advanced vehicle project, in that for a discipline-level R&T effort, publication in a professional journal is sufficient. For a multidisciplinary flight project, publication is in the form of standards is absolutely necessary (path 1 in Figure 6).

Figure 6, NASA's Role in Emerging Technology Environments



NASA also enters a relationship with the industry developer and the standards organization to build feasible standards based on knowledge of the technology push, as well as understanding the industry technology roadmap (paths 1 and 3).

Finally, NASA enters a relationship with the industry developer and the FAA regulator to build robust technology assessment (paths 2 and 3). In this case, NASA needs to assess the value of its technology innovation on the regulations, by assessing NASA's technology against the industry state of the art.

The path lengths, in this model, between the four entities must be demonstrated to be equal value to ensure the entry of the emerging technology is adopted.

2.2. Evaluating X-57 in the Innovative Technology Environment

Based on the development of the task, the NASA X-57 has participated in each of the corners of the Innovative Technology Environment.

In the case of the very unique position occupied by the NASA X-57 project, a very unique series of events has unfolded that is unlike anything in recent history.

As part of the challenge to general aviation, the FAA has begun a review of its certification and regulations regarding 14 CFR 23, Normal Category Airplanes, in 2009. This review and evaluation focused on ensuring that the regulations were performance-based in nature, rather than the historically proscriptive regulations.

In addition, the General Aviation Manufacturers Association (GAMA), in response to its members' interests, began the Electric Propulsion Innovation Committee (EPIC), which seeks to enable the design and operation of hybrid and electric aircraft in key aviation markets around the world.

As the GAMA EPIC project proceeded and GAMA members were beginning to engage the FAA in potential (and real) certification projects, the FAA realized that its efforts needed to not only move to a performance-based construct, but the FAA also began to consider how some of the regulations would be affected by electric and hybrid propulsion systems. Since many of the concepts from EPIC were focusing on ODM-UAM transportation models, the role of near-vertical-take-off-and-landing vehicles were being considered that would leverage electric propulsion based on experience form recent unmanned aircraft system (UAS) vehicle concepts. Now the specialists in regulatory policy for Normal Category Airplanes (14 CFR 23) were facing some attributes of vertical flight requirements that were in Normal Category Rotorcraft (14 CFR 27), but these were not normal rotorcraft. Some of these were vehicle concepts that have extremely short take-off and landing that act like rotorcraft in landing and takeoff, but are much more normal category airplanes in cruise.

The FAA reorganized its certification organization from what they described as a stovepipe organization into a more adaptable organization model that could accommodate not only the traditional certification programs, but also accommodate the new vehicle and systems coming forward. This new organization, the Policy & Innovation Division, reports directly to the Executive Director for Aircraft Certification Service, and supports aerospace innovation by creating novel means of compliance, develops and maintains FAA Certification regulations, and manages the staff of Chief Scientist and Technical Advisors (CSTA).

One such team within the Policy & Innovation Division is focused on understanding the implications of these new vehicle technologies on the FAA regulations. The Future Aviation Safety Team (FAST) composed a technical paper that assessed the effect of new technology on the 14 CFR 23 regulations, and was composed of policy experts in normal category airplanes, rotorcraft and engines. As a result, the paper provides some insights to the X-57 project that goes to the core of the X-57 flight project objectives of not only electric propulsion, battery management and safety, but also to high-lift devices, such as the Distributed Electric Propulsion. These three areas are of fundamental importance to the future of FAA regulations and, with the information from the NASA X-57, the ability to transition to a more accommodating regulatory environment for these new vehicle concepts will be ensured.

2.3. The Potential Areas Where X-57 Must Affect Standards

Based on the development of the task, the NASA X-57 has participated in each of the corners of the Innovative Technology Environment as illustrated in Figure 6. There are three key areas that are of immediate interest and need by the ASTM F44 and F39 committees. These are:

- Electric Propulsion Units (EPU),
- Electrical Storage System (ESS) and
- Distributed Electric Propulsion (DEP).

Each of these three areas have active working groups within the committees and are of utmost urgency for NASA to contribute their experiences to the standards development.

For example, the ESS subcommittee is examining the application of an esoteric appendix of DO-311 for a battery containment system that is an excessive constraint based on analysis and limited testing. The experience that X-57 has gained in its battery containment practice would be a dramatic improvement and would add to the dialog in the standards subcommittee responsible for ESS.

And while there are three major areas of urgent interest by the ASTM F44 and F39 committees, there are other areas that have been successfully embedded into the F44 community. In particular, Flight Performance has been a very richly informed by NASA expertise. Structures has had some participation, as well.

And, thus, it is important not only to have technical participation, it is equally important to have NASA maintain its oversight of the standards and regulatory support environment. The X-57 management must be embedded into the ASTM as part of the Executive Committee acting as Liaison by NASA to the ASTM. In this role, the NASA Executive can coordinate across all of the appropriate committees to understand real needs and requirements from the committees and subcommittees, as well as manage NASA's standards products to the F44 and F39 committees and subcommittees. This role means that the NASA ASTM Executive will need to engage the project with new standards development requirements that are as accountable as new project and technical requirements.

2.4. A Collaborative Structure Developed By X-57 as Pathfinder

Previous reports in this task have identified the generic means for assessing new technology against its regulatory environment. A method has been demonstrated for doing such and using the X-57 as an example to confirm its validity. A second report has examined the Certification Gap Analysis of the X-57, highlighted areas where real gaps exist in the regulations, identified the means of compliance associated with the regulations, and then highlighted the appropriate validation methods that the X-57 project will use in an association with the regulation and means of compliance. This report also leveraged the FAA's Future Aviation Safety Team (FAST) white paper for the 14 CFR 23 portion, which fundamentally highlighted the urgency of the X-57 knowledge to the development of standards in ASTM.

In the process of performing these reports the task team has met with the FAA FAST members and shared information. The team also coordinated with the GAMA and its role in leading the F44 and F39 standards development. During the ASTM F44 committee meeting in Washington DC in October 2018, the NASA team collaborated with the FAA and GAMA to host a workshop to highlight the results to-date. All of these events have been met with support by the members of the community.

While the face-to-face meetings of the ASTM F44 and F39 committees are an important activity every six months, and while staffing the role of ASTM NASA Executive is critical, it is equally important to ensure that the NASA management hierarchy is engaged with its counterparts in ASTM and FAA.

3. Next Steps

3.1. Establish the ASTM NASA Executive

Identify and formally assign NASA technical experts to support ESS, EPU and DEP standards activities.

3.2. Establish an Executive Standards and Regulations Review Group

This would begin focusing on X-57 ASTM Standards. This does not interfere with the established X-57 flight project and program management process. Rather, this takes the standards activities and ensures that the NASA leadership team is aware of the state of standards development. And, as such, provides a foundation for future projects to be judged based on their standards planning compared to the X-57 as pathfinder in standards development.

There are two levels in the standards and regulations review group:

- The first level is at the NASA Center level, and for the FAA would include the Innovation & Policy Division Director, as well as the new lead for innovation from the FAA.
- The executive is composed of the NASA ARMD leadership (AA and DAA), ASTM F44 leader, and the FAA Associate Administrator for Aviation Safety and Executive Director for Aircraft Certification.

These meetings ensure the pathfinder work that X-57 has pioneered will endure and become a pillar of future aeronautics flight projects.

4. Conclusion

This report has summarized past work within this task and identified areas that have been pioneered in certification and standards.

It has identified a model for Innovative Technology Environment consisting of the relationship of NASA technology to industry, standards development and regulatory activities. This tetrahedral model provides a check that all relationships are equally valued between industry, standards and regulation-certification.

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14. ABSTRACT
Innovative technology has to prove itself in the context of legacy regulations. The knowledgeable technologist must engage standards process and regulating authorities to understand their roles and to advise the effect of new technology, and with manufacturers to demonstrate technology benefit. A model for Innovative Technology Environment relating NASA to industry, standards and regulation is described. The needs of the standards community of the X-57 are identified, and a NASA standards structure is described. No NASA project works with standards and regulatory organizations like the X-57.

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