“Digital Twin Center of Excellence - Collaboration Thrust Whitepaper

Acceleration of Air Force Digital Twin Adoption through a Collaborative Technology Incubator

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Concept Overview:

The importance of Digital Engineering to the United States Armed Forces is vital:

> The need to adopt digital engineering in all its forms is not only nice to have, but by any stretch, it's an imperative, it's imperative to us as industry partners to remain competitive, but more importantly, it's imperative to design and deliver the weapon systems that we do and make this available to the warfighter in a much more rapid pace.” Paul Ferraro, Vice President of Airpower at Raytheon Missiles & Defense.

The collaboration thrust of the proposed Digital Twin Center of Excellence’s mission is to facilitate partnerships between the Air Force, private sector entities, and academic institutions, as well as within each of these organizations. The goal is to help digital twin methods and technologies to grow in new areas, and to extend into adjacent areas where it is already in use. This effort will be guided both by internally driven needs from within the Air Force, as well as externally, through proposing innovative digital twin solutions from partners outside the Air Force.

The core aspect of the collaboration thrust is a Digital Twin Incubator (DTI), which will feature an agile, collaborative approach to bringing digital twin techniques into practice. Pairing the best digital twin minds in the Air Force, with the best digital twin minds in the private sector and academia, to tackle high return-on-investment projects for the Air Force will develop an ecosystem of digital twin experts that are ready to meet the Air Force’s requirements. The DTI’s Steering Committee will be responsible for overseeing the portfolio of projects such that the team is maximally responsive to Air Force needs.

The Steering Committee will facilitate collection of needs from the Air Force, as well as best practices from outside the Air Force. The larger DTI team will turn these concepts into project proposals and the most relevant projects will be selected by the DTI Steering Committee (with Air Force concurrence) to be funded and executed. This model allows for a portfolio of projects to be launched and maintained quickly, and in a coordinated fashion, to respond to near term digital twin needs of the Air Force. These projects will span from research projects that develop new digital twin techniques, to refinement of processes of existing digital twin efforts, to developing workforce development programs to support digital twin adoption by the Air Force.

The Digital Twin Incubator will be composed of members from private sector entities and academic institutions with a presence in the region around Wright-Patterson Air Force Base. These institutions have recognized capabilities in areas such as computational fluid dynamics, finite element analyses, model-based systems engineering, product lifecycle management, and systems modeling, which are the basis of digital engineering. They also have active education and training programs to serve a wide variety of needs—from technicians to post-graduate. This whitepaper was developed with input from multiple organizations, but with the academic institutions as the main contributors. It is expected that a major focus of the Collaboration Thrust of the Digital Twin Center of Excellence will be in workforce development, thus, having academia involved at the outset is critically important. Investment in this key area will further strengthen the region's ability to support the Air Force's digital twin efforts and help transition digital twin techniques into the Air Force for future use.

Digital Twin Introduction:

The Air Force frequently occupies the role of being a customer of a large, platform-level supplier of a system. In this role, they are most involved in the early stages of the system engineering "V" process (Defense Acquisition Guide) in terms of defining operational needs and requirements. These are fed into a process in which multiple entities will conduct some level of virtual and physical prototyping to demonstrate concepts, prepare a bid, etc. Upon winning the bid, the supplier takes the lead on the detailed design/build/verification. As the product nears release at the upper right of the "V", the Air Force plays a strong role in the validation of the system and assumes responsibility for the remaining lifecycle. Digital twins can facilitate early and late collaboration between government and the developer, informing both requirements and sustainment.

Digital twin is a core aspect of the DoD Digital Engineering Strategy (*Digital Engineering Strategy*, 2018). In other engineering environments, the use of digital twin techniques typically takes hold in the "design" phase of the systems engineering process. This poses a unique challenge for adoption of digital twin techniques within the Air Force. Foremost is the fact that generally, a great deal of the digital twin activity is happening outside of the Air Force. Furthermore, the suppliers of the systems view their process and digital twin artifacts as business sensitive which creates a barrier. These and other factors have greatly slowed the adoption of digital twin techniques from organically arising within the Air Force.

Digital Twin Benefits and Challenges:

The use of digital engineering methods has been identified as a key component in the Department of Defense's modernization strategy. The DoD defines digital engineering as "an integrated digital approach that uses authoritative sources of system data and models as a continuum across disciplines to support lifecycle activities from concept through disposal" (*Digital Engineering Strategy*, 2018). The goal is not simply using models, but in creating a digital environment where challenges can be identified and solved virtually across the lifecycle. Digital Engineering will enable engineers throughout the Air Force community to become more agile and responsive, while complexity and uncertainty continue to grow (*Digital Engineering Strategy*, 2018).

To arrive at this state of Digital Engineering, a Digital Transformation process needs to occur. There is a transition from the traditional linear process to a digital engineering process, which incorporates new methods and tools that will fundamentally change engineering problem-solving approaches (*Digital Engineering Strategy*, 2018). Although modern engineering tools are readily available, the growth in the use of digital engineering (DE) tools and methods is hindered by (a) the lack of engineers proficient in applying these tools to solve engineering problems (Magana & Silva Coutinho, 2017; NSF, 2006) and (b) the significant disruption that is needed to the product development process to initiate and sustain the transformation (Kraft, 2018), as well as the limitations that currently exist within the DoD acquisition and sustainment communities. Technological development is an obvious driver, but technology alone will not bring about the full potential of Digital Engineering. To fully bring about Digital Engineering through a Digital Transformation plan, the workforce and the work environment must be able to adapt to the rapid pace of change brought about by technological advancements (Kane & Phillips, 2019; Schwab, 2016).

An Agile Digital Twin Collaborative Incubator:

Developing a sustainable digital twin approach requires development in three key areas:

1) Digital Twin Processes: Well-understood digital twin techniques to meet Air Force needs more effectively than current approaches
2) Digital Twin Competencies: that have the requisite training and education to execute the digital twin processes
3) Digital Twin Infrastructure: IT infrastructure to support the needs of the people and process

Each of these areas are related and represent a conundrum: one needs the digital twin process to develop the competencies in staff and one needs both to have requirements for the IT infrastructure to support it. Executing a digital twin process is not about software alone—it is about the right software, the right training, applied to the right problem, in the right context within the organization to be useful. The goal of this thrust is to help unwind the problem to accelerate the adoption of digital twin techniques within the Air Force. The formation of a Digital Twin Incubator (DTI) Team will address the complex and complicated nature of these organizational challenges.

What follows is a condensed process for how projects will be centrally evaluated and funded through this effort. The expectation would be there is an annual process for launching projects with ample opportunities for collaboration between the Air Force and external partners to allow better understanding of needs and capabilities.

1) Identify Air Force Digital Twin Needs: To be relevant, ideas need to be sourced from within the Air Force itself. To be maximally forward looking, additional ideas need to be sourced from organizations outside of the Air Force. These project concepts are captured and moved forward to the DTI Steering Committee.
2) Evaluate Proposals by DTI Steering Committee: The project ideas are evaluated by the DTI steering committee and high-potential, high-impact ideas are presented to the larger DTI Team. The DTI steering committee will select concepts to move forward which best meet Air Force needs, as well as provide overall strategic value to the overall goal of a comprehensive digital twin process.
3) Develop Proposals to Meet Air Force Digital Twin Needs: For each Air Force requirement, the project specific team develops collaborative proposals with the Air Force customer to address the concepts from the previous step. These are refined through an iterative process and finalized in a formal proposal that returns to the DTI Steering Committee for review and to the Air Force customer for approval and funding.
4) Select Proposals to Maximize Impact: The DTI Steering Committee reviews the proposals and selects those that provide the most impact to the overall Digital Engineering strategy of the Air Force. These may be selected as high-risk, high-reward projects or be very process-driven to solve

a near-term need. The DTI Steering Committee will balance the portfolio of recommended projects based on feedback from the Air Force customer.

5) Assessment of Projects Against Air Force Needs: Projects funded through this effort will be formally reviewed against milestones by the DTI Steering Committee and appropriate Air Force customers. This will ensure high-quality results and that project team is identified and aligned. Each specific project funded will have a dedicated project manager and be planned and conducted as a project as opposed to a classical university grant.

The initial set of projects will be selected to span the above three key areas to drive greater understanding of the needs in both Digital Twin Competencies and Digital Twin Infrastructure. As these needs are defined, projects can be initiated that investigate these areas by way of developing training programs or studying IT systems that enable adoption of these techniques.

Connection to Other Program Thrusts:

The other thrusts of this effort are larger scale projects focused on specific topics. The goal of the Collaboration Thrust Area is to transition the digital twin techniques used in these activities throughout the Air Force, help mature these techniques for use within the Air Force, and to address other needs within the Air Force that fall under the Process, Competency, and Infrastructure areas described above. The other four thrusts of the Digital Twin Center of Excellence Program are:

1) Joint All-Domain Command and Control
2) Sustainment, Modifications, and Upgrades
3) Agile Air Mobility
4) Attritable, Autonomous, Collaborative Platforms

Within each of the above thrusts, the Collaboration thrust will have visibility into the activities, and seek to make connections to other thrusts, entities, or activities. It will seek to leverage work that happens within these thrusts and transition it into the Air Force to solve other challenges. Where necessary, the Collaboration thrust can take high-value processes and spin off additional project work to address competencies by developing training or educational content. The goal is to maximize the investment being made in these cutting-edge research activities by bringing the digital twin techniques back into the Air Force as a defined process.

Sample Project Paths:

A potential path to a project undertaken in this group could be a digital twin technique derived from one of the other thrust areas. For instance, the Attritable, Autonomous, Collaborative Platforms thrust might utilize a promising digital twin technology to model the behavior of UAVs. Because these thrusts are largely driven by research goals, the Collaboration thrust area could create a project around this for a particular Air Force customer to transition the digital twin technology into the Air Force. This could include further research of the technology for a specific Air Force application, digital twin process improvement, or development of training for Air Force staff. A second path could be through an individual or group within the Air Force which has identified an area in which they need support for engaging the Digital Twin Incubator to develop and mature a digital twin technique to meet their needs. In both cases, the funding, contracting, project management, and other logistical issues would be handled by the DTI process. This allows for quick response solutions to be provided to the Air Force.

Conclusions:

The concept of digital twins has enormous potential for improvements in cost, schedule, and innovation for the lifecycle of major system investments. To see these returns, a comparable investment in these technologies and an organization capable of aligning stakeholders and thought-leaders is warranted. This proposed effort aims to begin identifying the areas where digital twin methods can have an immediate impact and serve as beachheads for organic growth of the techniques. The Digital Twin Incubator concept is designed to identify areas where digital twin technology can enhance existing or future Air Force activities and link this to a team that can help identify and mature a process to the need. This gives the Air Force ready access to a team of academic and private sector entities who are ready to collaborate via a defined structure and process. The structure of this effort will be designed to be agile such that the Digital Twin Incubator can be highly responsive to Air Force needs.

References:

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Digital Engineering Strategy, Hyperlink to Reference , Accessed 4/1/2022

Magana, A. J., & Silva Coutinho, G. (2017). Modeling and simulation practices for a computational thinking-enabled engineering workforce. *Computer Applications in Engineering Education*, *25*(1), 62–78. https://doi.org/10.1002/cae.21779

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AUTONOMOUS, ATTRITABLE, COLLABORATIVE DIGITAL TWIN CENTER OF EXCELLENCE

Technology Overview for Component-Oriented Acquisition and Software Confidence on Cyber-Physical Systems

John Launchbury and Aaron MIller

Background

In the context of this document, autonomy is the manifestation of the intersection of sensors, platforms, software and the introduction of artificial intelligence. Autonomy requires the use of data which is generated and used by a collection of sensors operating on computer infrastructure that is integrated into a system. As such, we can think of autonomy, as a collection of often complex software. To effectively deploy autonomous capabilities (i.e., software) on our systems, we must utilize emerging trends in digital engineering and digital twins to find cost effective, time efficient solutions to develop, acquire, maintain, and sustain autonomous, attritable, and collaborative systems.

However, the Department of Defense has long suffered from an outdated acquisition construct that no longer keeps pace with the speed and sophistication of evolving threats to our national security. An aging fleet, the growing cost of new weapon systems, and the rise in rapid technology insertion, specifically in the domain of autonomy and artificial intelligence, make it impossible to build systems under the same 10-30 year acquisition paradigm. Today's weapon systems are made up of embedded computer systems and software which comprise of Cyber Physical Systems. Cyber Physical Systems have capabilities where the hardware and software "are deeply integrated and actively connected to the physical world."[1] Integrating software with hardware greatly extends the capabilities of cyber physical systems and introduces a new level of complexity to their development.. The systems engineering process of today makes systems expensive to maintain and upgrade. It is time consuming, leading to deployments of obsolete capabilities and offering limited reconfiguration of legacy systems.

This issue is a priority of senior leadership within the Department of Defense. Former Under Secretary of Defense for Acquisition and Sustainment, Ellen Lord, reworked the DoD Instruction 5000.02 to address evolving present-day threats and introduced new 6.8 funding lines supporting the acquisition, maintenance and sustainment of software. Former Secretary of the Air Force for Acquisition, Technology, and Logistics, Dr. Will Roper, amended acquisition processes for software and systems to address goals of creating processes to build trusted, reliable software in the Air Force for technological advancements in current and future weapon systems.

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[1] *American Innovation and Competitiveness Act* (AICA) (P.L. 114-329)

Underlying technologies still limit the effect of the rapid acquisition and the ability to acquire software incrementally against specifications and the Department's approach to software acquisition still trails current industry standards. Modern development approaches to eliminate artisan and craft concepts of software development have the potential to dramatically improve both speed and correctness of software acquisition in the DoD. Critical techniques include the use of digital first approaches in systems engineering and the use of digital twins to support rapid development, test, and deployment approaches. Additionally, principles of software-hardware codesign utilizing digital first approaches offer promise based on recent DARPA programs such as SSITH, HACMS, CASE, VSPELLs and Symbiotic Design of Cyber Physical systems. These digital first approaches offer the ability to speed up both production of new capabilities and the opportunity to inject effective upgrades into legacy systems while also reducing cost. One thing that holds true is Dr. Roper says that "Artificial intelligence (AI) will fundamentally change the character of warfare, so future Airmen must have systems that learn faster than their enemies. To harness this technology from the commercial industry, we must design, acquire, and update software like them."

Through research conducted at DARPA and the DoD services, a new type of acquisition and integration process for software enabled Cyber Physical Systems is possible. In this paper we will discuss how the use of open architectures and standards enables component-oriented acquisition and retrofit with software confidence, how new research in machine learning for runtime assurance and composable system builds is necessary, and the impacts of policy on the implementation of component-oriented engineering.

State of Now

Rapid acquisition has been attempted with mixed success over the years, while we have increased the speed of acquisition, we are incurring significant operations and maintenance costs as well as long-term systems engineering debt when past designs cannot be efficiently reused. A recent use case for the P-8A Poseidon, which was designed to replace the Navy P-3, demonstrates this concern. The Poseidon focused on rapid acquisition using existing Commercial Off the Shelf (COTS) subsystems, basing the Poseidon airframe entirely off of the Boeing 737 aircraft and its supporting infrastructure. A Naval Postgraduate School report finds, "The supportability issues will likely not come from the hardware on the P8; the challenge will be in the software sustainment and software upgrades for the on-board systems supporting a weapon system scheduled to be in the Navy inventory for 20+ years".[2]

Another example is found in the development of the Global Hawk. The Global Hawk yielded quick-to-field prototypes that, while successful, suffered costly overruns in areas of software design and airworthiness certification. In a report studying the results of the Global Hawk Advanced Concept Technology Demonstration (ACTD), it was cited that the Global Hawk ACTD

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[2] Brad Naegle and Diana Petross. P-8a Poseidon multi-mission maritime aircraft (mma) software maintenance organization concept analysis. Technical report, NAVAL POSTGRADUATE SCHOOL MONTEREY CA GRADUATE SCHOOL OF BUSINESS AND PUBLIC …, 2010.

achieved prototype to production status in a very short time, yielding 10 low rate production aircraft from the initial prototype in 1998 to 10 block 10 aircraft by 2006. However, the ``military airworthiness certification process was very rigorous and took three years and 77,000 man-hours to achieve''.[3] Thus, of the eight year acquisition process, three years were spent in airworthiness certification.

The examples of the P-8A and the Global Hawk demonstrate that rapid acquisition is here to stay with the goal to enable systems to be designed and built within a fraction of the time. However, these examples also show that the need for quick solutions for fielding warfighter capability often yields design compromises, short circuiting systems engineering best practices and resulting in software that is not composable, defined or able to be reused. The manner in which we utilize systems engineering processes and tools to reuse and build software for weapon systems must change, and we must adapt the methods we use to gain certification to keep up with this rapid acquisition model.

As software becomes more prolific within interconnected cyber physical systems, reconfiguration to meet new mission needs equates to "reusing" software in new contexts and environments. We must find ways to enable the warfighter to reconfigure their systems to achieve mission success with confidence through our acquisition cycle. We must find ways for highly coupled, integrated systems that contain software to perform in new contexts, under new conditions, at all times. Current rapid acquisition models are necessary but faulty. For rapid acquisition to be successful at a broad level, it is necessary to embrace the implicit notion that software, like hardware, must be defined, described and reusable. Just as physical materials and integrated circuits have "data sheets" that describe standard fitness for use, every component of software must also come with an equivalent notion of a "data sheet". As software can change faster than physical components, static data sheets are infeasible. The current acquisition system of software enabled systems lacks the engineering tools and methods to rapidly argue the fitness for use of that software within new contexts.[4]

State of the Future

Historically, the whole-system focus of embedded software system designs has been critical to designing trustworthy and efficient systems while also managing the limitations of on-board compute resources. Engineers have been able to rely on very tightly integrated hardware and software to perform a specific role within a specific platform, knowing that the systems will be operating in well-defined and isolated contexts. Now that we can no longer accept the cost and extended development timeframes of this approach, we need to upgrade our engineering processes to enable us to build safe and secure systems that are both highly connected and adaptable to evolving mission needs.

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[3] Bill Kinzig et al. Global hawk systems engineering case study. 2009.

[4] Nancy G Leveson and Kathryn Anne Weiss. Making embedded software reuse practical and safe. In ACM SIGSOFT Software Engineering Notes, volume 29, pages 171–178. ACM, 2004.

Suppose,for example, that a warfighter needs a more capable targeting subsystem for an unmanned aerial system (UAS). Ideally, the squadron commander could authorize a weapon system upgrade and directly purchase and install the new targeting subsystem. However, there is a list of engineering obligations that need to be met. It may be that the new targeting subsystem had been designed for a different UAS with different software attributes, requiring its software to be reconfigured to talk to the new UAS. The new targeting subsystem may have different computational characteristics (timing, error rates, etc), raising issues regarding the overall behavior of the integrated system. In another scenario, the new targeting subsystem software may have a different cybersecurity profile from the previous one, raising questions as to how secure the new integrated system will be.

The State of the Future lies in addressing these kinds of challenges. If we had strong technological approaches to all of these engineering concerns, the warfighter could upload the reconfigured software as a software patch for the existing UAS with confidence that the resulting system will exhibit predictable behaviors, even in a cyber-contested environment. Additionally, ongoing quality control would include warfighter feedback, sharing how the component worked in the field and how it did not, allowing them to upgrade systems only when upgrades are needed and will be successful. This would drive higher efficiency on sustainment and maintenance.

This is a vision of component-oriented systems. Component oriented systems are systems that can be iteratively built and adjusted by replacing components of the system (software and/or hardware). The use of digital engineering and digital twins advances and enables the premise of component oriented engineering. The most promising approach to achieving this vision is a component-oriented systems engineering approach where individual pieces of functionality are created with minimal external dependency and a strong understanding of the attributes of the component itself. Properties of high cohesiveness (clear single purpose) and low coupling (minimal external dependencies) make for a good design of a component and increase its flexibility for reuse and repurposing.

The component-oriented mindset builds on the excellent progress the DoD has made so far with Modular Open Systems Architecture (MOSA), and it takes the next step by adding significant technological automation. Specifically, the behaviors as well as the interfaces of the various components should be well-defined (or learned), and smart integration tools should know what components are available and how to combine them. With effective machine-assisted component-oriented systems engineering we will be able to build composable systems with confidence the software is correct.

To know how to combine components, smart integration tools should leverage the network effect across the DoD enterprise. As components are reused, they will be integrated in new settings. If that information can be learned by the integration tools, it will be able to repeat the task in additional related settings.

To gain understanding of the behaviors of individual components, multiple testing and verification approaches must be leveraged, including verifiable code generation, software verification, traditional test and evaluation, and run time assurance techniques. No single behavioral method is a silver bullet, but smart integration tooling will combine multiple techniques to gain deep understanding of the newly integrated system capabilities and risk profile.

In a future state with component-oriented systems engineering, the needs of the combatant forces on the front lines can directly be translated into rapid acquisition at the highest level. If a system is designed with a modular open architecture involving software and hardware, the combatant forces closest to the mission will be positioned to address a new threat as it emerges incrementally, rather than waiting for the next “block” upgrade. As our warfighters are the most experienced users of our acquired capabilities and tools, we already seek their needs and suggestions to address the most near-term needs. Often these needs are lost in bureaucracy and acquisition of large systems. In a new world of component-oriented systems, our warfighters could rapidly access a market place, search for a specific weapon system, and view the available components that could be installed on this system to achieve the mission utilizing smart integration tooling.

How Do We Get There

While a clean sheet approach is helpful for designing highly trustworthy, and composable software enabled systems, in reality, this approach is not feasible. Most systems are built with existing software that is reused or modified, and often not fully understood. We live with a legacy of large monolithic systems with limited componentization. Component-oriented modularity often takes a backseat to production and deployment deadlines leaving a significant technical debt to be incurred in post-deployment fixes and sustainment.

To realize the future of rapid acquisition at the hands of the warfighter, engineering modernization efforts and additional focused applied research is required. An initial set of proposed projects includes:

- **Legacy Systems Modernization:** Reduce cost and shorten system upgrade cycles by automatically generating assured MBSE models that allow for rapid modification and certification of Airworthy software components. Additionally, the software components can be retrofitted to support Modular Open Systems Architecture guidelines such as Open Mission Systems (OMS) that enable for technological insertion of increasingly complicated autonomy packages. These packages, which require high levels of trust before fielding and use in combat operations, include extensive test artifacts, documentation, and ease the integration of hardware in the loop (HWIL) and software in the loop (SIL) simulators. By leveraging SIL/HWIL and a common Modeling Simulation, and Analysis environment, these capabilities can be rapidly tested, updated, and retested to increase trust in system functionality and behavior.

- **High Confidence Composability Research:** Conduct applied research on leveraging machine learning to aid in increasing confidence rapidly composing systems. The next generation of technologies for composable systems engineering will include advances in the areas of software confidence via self testing, automated decomposition, run time assurance and emergent collective behavior of components.
- **Advancements in Tooling and Techniques:** Develop, prototype, and make available cutting edge and emerging tooling that enables modern digital engineering and digital twinning concepts to support the implementation of complex software such as autonomy into new and legacy systems. This requires an environment to make systems engineering tools and demonstrations accessible to potential users:
    - Develop tools and a process that would allow for the automated assessment of software evidence and provide justification for a software's level of assurance that is understandable. [5]
    - Advance the idea that mathematical models and abstractions of software and hardware components should be used to characterize behaviors, and that reusable system components should be contained in a model-based library. Search functions over this library would leverage cloud-based machine learning to optimize the use of these components in new environments.
    - Create capabilities to verify neural networks in cyber-physical systems by continually monitoring a system's developing behavior which has become an ASTM standard (American Society for Testing and Materials) and is recognized by the FAA as a viable option for the certification of components of unknown provenance.[6] [7]
    - Leveraging advances in machine learning, advance the research for continuous component-oriented confidence, where ongoing monitoring of components enables auto-argumentation and behavioral modeling continuously. A future state must exist where components are embedded with assurance tools and run-time monitors such that the pedigree or technical readiness level of a component automatically increases as it is used; first in the research laboratories, next in test and evaluation, in rapid prototyping and finally in sustainment. This future reduces the burden of manually modeling and verifying systems and leverages a "network-effect" of confidence across different platforms and environments.

Impact on Community

The Dayton Region, Ohio and the Midwest is poised to advance the concepts of component-oriented software-based engineering to the fielding of autonomous capabilities in

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[5] Graydon, Patrick J., and C. Michael Holloway. "An investigation of proposed techniques for quantifying confidence in assurance arguments." *Safety science* 92 (2017): 53-65.

[6] Clark, Matthew, et al. *A study on run time assurance for complex cyber physical systems*. AIR FORCE RESEARCH LAB WRIGHT-PATTERSON AFB OH AEROSPACE SYSTEMS DIR, 2013.

[7] ASTM International. Astm f3269-17, standard practice for methods to safely bound flight behavior of unmanned aircraft systems containing complex functions. Technical report, ASTM International,West Conshohocken, PA, 2017.

cyber physical systems. Component-oriented software-based engineering utilized principles of mathematical modeling such as those used to build physics based systems. The engineering mindsets, our academic institutions and the demand for rigor resides within our region. The Department of Defense (DoD) led by the Air Force is leading the charge to deploy cutting edge digital first approaches to implement autonomy in CPS. This leadership position evolves from the premise that autonomous, software-based systems operating in contested environments require more rigor than those used in traditional commercial practices.

Dayton is home to the research, development, and acquisition of Air Force systems. Building workforce, companies, and capabilities in the region that will launch the next wave of software deployment in the region protects the value of Wright Patt and the Air Force Materiel Command. Through collaborations with regional academic institutions, businesses and nonprofits, the region is poised to offer the cutting edge capabilities by leveraging our far reaching ecosystem. By serving as the thought leader in the next generation of software, component-oriented engineering for CPS, the region will:

- Build a workforce through collaboration with academia to make relocation attractive for companies looking to build correct CPS capabilities
- Enable additional startups through the commercialization of emerging tools, protocols and procedures created in the region
- Support the growth and modernization of existing businesses and Air Force partners by providing expertise and leadership in CPS assets
- Create opportunities for research and applied learning opportunities for academia in the area of digital, systems engineering.

Digital Engineering Center of Excellence: Advanced Air Mobility Focus Area White Paper: April 1, 2022

Background and Need: Recent years have seen the rapid development of Unmanned Aerial Systems (UAS) technologies, including the advancement of Urban Air Mobility (UAM), Regional Air Mobility (RAM), and Advanced Air Mobility (AAM) Concepts of Operations (CONOPS) through the efforts of the National Aeronautics and Space Administration (NASA), Federal Aviation Administration (FAA), and the Department of Defense (DoD). There have also been advances related to civil Type Certificate (TC), Airworthiness Certificate (AC), Production Certificate (PC), and maintenance requirements for unmanned and optionally manned systems, driven by research, regulatory development, and establishment of industry standards. Related to AAM, which is forecasted to be the next radical revolution in transportation, a broad range of emerging technologies are being designed to promote safety, cost-effectiveness, and consumer-friendliness. According to the Deloitte Advanced Air Mobility Survey (2021), by 2035 the industry will be valued at $115 billion and create over 280,000 high-paying jobs. As UAS in general, and larger electric Vertical-Takeoff-and-Landing (eVTOL) systems capable of significant cargo or passenger transport are designed, tested, and commercialized, approaches including digital engineering capabilities will quickly transition from obscure concepts to requirements for design, test, manufacture, and operation of certified systems.

The goal of Digital engineering is to change the order of the production process from design-build-test to design-test-build by moving much of the testing phase to the digital domain, providing an opportunity to optimize the design before investing resources to build a prototype or production model. It produces records for products that might otherwise not exist, or would not be as easily accessible, enabling review and approvals for certification or production and an ability to reliably manufacture at varied locations or times. These benefits result in massive savings of time and resources throughout the lifecycle of complex systems like those found in the aerospace industry. Digital engineering focuses on digital twins and digital threads modeling. Digital twins are computer models and relevant data associated with real objects that embody all physical attributes and are useful for computer simulated testing or other analyses across the lifecycle of an object. Digital threads can represent each individual decision that went into manufacturing a separate product, potentially including blockchain data, or managing an asset, preventing wasteful redundancy and enhancing communication between teams working on different aspects of the same project.

The development of aircraft and associated supporting technologies and systems able to enjoy the future benefits of AAM will necessitate a formalized and professionalized approach to UAS or eVTOL design, manufacture, and operations. The majority of such systems will require TC, AC, and PC approvals from the FAA through the guidance of the Title 14 CFR Part 21 regulations, or how they may be further modified to enable AAM capable aircraft. From design, testing, and production standpoints, this requires a high level of accuracy and professionalism in the initial design, documentation, manuals, and training requirements. Likewise, ongoing operations and maintenance of these systems will require the same level of rigor as commercial aircraft as it appears maintainers will be Maintenance, Repair, and Overhaul (MRO) services, as defined in the Title 14 CFR Part 145 regulations.

Solution: The formation of a ***Digital Engineering Center of Excellence*** (COE) with a focus on AAM is of paramount importance to ensure the complexities of digital engineering as related to this new domain of aviation are integrated from its foundation to ensure safety, efficiency, and compliance, while enabling economic development and commercial success. The State of Ohio generally, and southwest Ohio specifically, is uniquely suited to form and operate such a COE given existing world-class capabilities. The COE will provide a formalized structure through which existing resources will be organized, new capabilities will be created, and vital industry and government needs will be addressed.

Although it is east to only focus on the aircraft and integrated technologies (i.e., airframe, propulsion, navigation, sense and avoid), a holistic approach also considering integral support infrastructure including electrical charging or refueling solutions, launch and recovery facilities (e.g., vertiports), and ground-based Unmanned Traffic Management (UTM) solutions and other factors is required. To enable industry to meet current and future requirements of AAM capable systems, support mechanisms are needed to address multiple focuses including Research and Development, Commercialization, Testing and Certification, and Workforce Development. Each of these focuses are vital and part of an integrated whole that should be considered and supported together through a comprehensive and coordinated solution. The initial primary focuses as led by Sinclair College will center on Testing and Certification and Workforce Development.

Testing and Certification: As activities move past the research and development phase, testing and certification activities are required to validate technologies and ensure compliance with regulations and standards. Southwest Ohio is well positioned to support these activities through testing facilities and organizations including: *Sinclair College National UAS Training and Certification Center, Ohio Department of Transportation - Fly Ohio, Springfield-Beckley Municipal Airport, Dayton Aerospace,* and *ONEIL*. Having a robust ability to support ground and airborne testing, along with development of documentation (e.g. manuals, drawings) meeting regulations and standards is key, not only to produce quality and safe products, but also to meet the requirements for TC, AC, and PC from the FAA. Applying digital engineering best practices is necessary to ensure compliance and success in testing and certification efforts leading toward product commercialization.

Workforce Development: A strong workforce development capability able to address the requirements for AAM and associated digital engineering is critical. Institutions with leading capabilities for the development and implementation of salient academic certificate and degree programs, as well as non-academic credit workforce development training include: *Sinclair College National UAS Training and Certification Center, Wright State University, University of Cincinnati, University of Dayton,* and *The Ohio State University*. New academic programs and non-credit offerings must be developed and implemented to address the specific requirement of a digital engineering enabled workforce operating in aerospace and AAM domains. These institutions will take a leading role in the coordination of efforts, partnering with other academic, government, and industry organizations to ensure alignment.

Timeline and Next Steps: Many existing facilities and resources are already in place at the noted organizations that will support the COE and can be directly applied to envisioned activities, thereby reducing risk and overall costs. However, given the cutting-edge nature of AAM and digital engineering, investments are needed to not only create the structure of the COE and coordinate resources, but also develop new capabilities and content. The aims of the COE will be realized though a multi-phase approach beginning in 2023 with COE formation, establishment of partnerships and collaborations, documentation of requirements, and architecture of support services. From 2024-25, testing and certification, as well as academic and workforce training curriculum will be created and refined. Activities from 2026-29 will expand testing and certification capabilities and increase academic and workforce offerings and enrollments. Efforts will continue from 2030 to expand and mature in alignment with industry needs. Starting from the foundation of the COE, efforts will be coordinated with primary stakeholders to ensure alignment of requirements and outcomes, with partners having a direct role in contributing to COE success through their areas of specialized capability or support.