Digital Twins and Predictive Maintenance for Applied Teaching and Learning in Aeronautical Engineering Technology Curriculum

White Paper Report from:

The Aerospace and MRO Technology Innovation (AMT-I) Center

School of Aviation and Transportation Technology

Purdue University, West Lafayette, IN

10 May 2023

Timothy D. Ropp, Ph.D.
Clinical Professor - Aeronautical Engineering Technology
School of Aviation & Transportation Technology
Director, Aerospace & MRO Technology Innovation (AMT-I) Center
Purdue University, School of Aviation & Transportation Technology

Digital Twins and Predictive Maintenance for Applied Teaching and Learning in Aeronautical Engineering Technology Curriculum

Dr. Timothy D. Ropp, Ph.D.

Introduction

Students in technical education programs like Aeronautical Engineering Technology enter aviation, aerospace and commercial space career fields that are a hybrid of physical and digital workspaces. An international survey of aerospace and aviation companies showed knowledge of digital product definition, Industrial Internet of Things (IIoT) and other Industry 4.0 frameworks ranked nearly as high as technical skills among workforce competencies considered critical in the short term and mandatory at some level by 2030 (Ropp, et. al, 2020). Digital Twins are one example. North America specifically is known as one of the "early adopters" of this technology including company U.S. operations that include: General Electric, NASA, Bye Aerospace, Lockheed Martin and Boeing (MarketsAndMarkets Global Forecast, 2022) and this revenue market worldwide is estimated to top $70 billion by the year 2027 as companies move to radically reduce cost and repair disjointed supply chain operations still recovering from COVID disruptions.

Digital Twin Defined

Much like robotics, Digital Twin definitions vary on specifics dependent on whether you are in production or performance side of operations. While varying in particulars, they do orbit around a common theme, which IBM (2023) provides a generalized, succinct foundation summary::

> "a virtual representation of an object or system that spans its lifecycle, is updated from real-time data, and uses simulation, machine learning and reasoning to help decision making" (IBM, 2023, https://www.ibm.com/topics/what-is-a-digital-twin)

Digital Twins are more than just a model-based replica of a component, engine, or air vehicle. Using modern sensors and Digital Thread technologies like satellite links and rapid simulation. However, different than traditional simulation technologies which tend to be micro-oriented to a unique component or process, the Digital Twin becomes more like a real-time, holistic virtual character capable of real-time multi-system simulation.

The Role of Digital Twins in Aviation and Aerospace

The goal then, is to show real-time operating state of a component or its systems and more importantly, visualize and predict future failure modes (and fix them) before something breaks.

Similar to Condition Based maintenance, Predictive Maintenance (PdM) is the true outcome from which we extract the Digital Twin's value. These maintenance philosophies have similarities: They capture data to inform maintenance tasks, with the goal of failure prevention. Condition-based tends to use a data point to identify and perform critical maintenance near the precise moment required. PdM on the other hand incorporates the more comprehensive algorithms, the digital thread and virtual life-pulse of the Digital Twin to predict equipment degradation further upstream in its performance cycle using aggregate multiple sensors, data points and Big Data computing.

In some cases organizations may choose to replace what historically would be thought of as a perfectly functioning component, due to its predicted failure point earlier than planned, based on rapidly updated aggregated data and prediction models that the Digital Thread and other IIoT technologies afford. The goal is to blend both analytical and cognitive technologies to enable more accurate, positive and timely decision-making (Dorsch, 2018), even changing action plans already underway to account for new real-time and updated data pictures (Webster, 2022).

Digital Pedagogy: Digital Twin and PdM as Teaching and Learning Tools

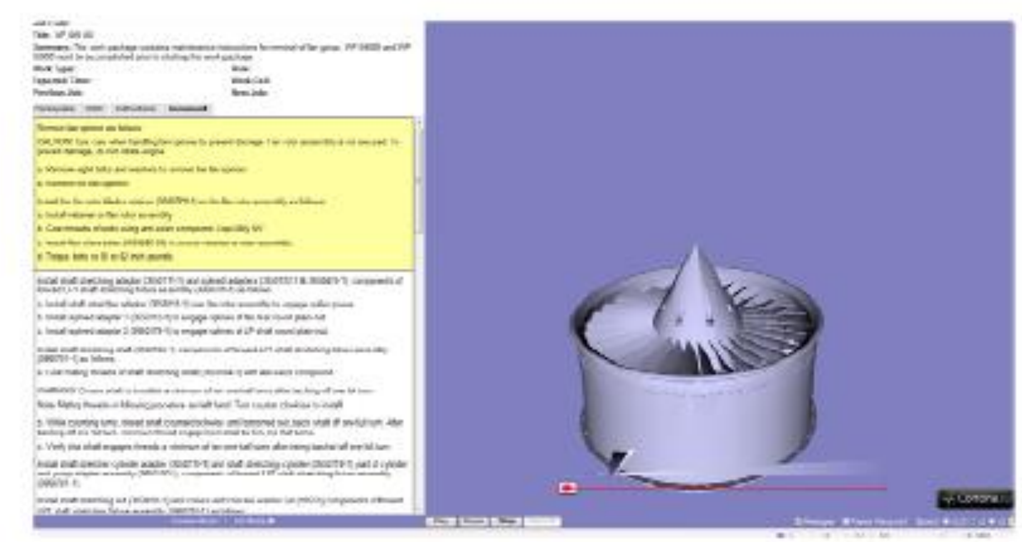
Learning with, not just *about* digital twin environments is crucial for learning outcomes. Learning in context, producing graduates who can rapidly transfer digital competencies to the industry (Ropp et. al, 2020). In their writing on the fifth wave evolution of American universities, Crow & Dabars (2020) emphasize the need for pedagogical innovation. They call for transformation of traditional academy practices to be more deliberately outward facing resources accommodating needs for retraining and upskilling existing workers as well as new entrant graduates.

The aviation and aerospace industries have been continuously integrating Industrial Internet of Things (IIoT), Big Data frameworks, automation and robotics in various forms into daily operations for several years. But rapid advances in computing and sensor power have enabled concepts like the digital thread, digital twin, edge computing, machine-to-machine learning (M2M), and Artificial Intelligence (AI) to become ubiquitous data science tools of the trade. In the realm of aviation and aerospace, techniques for extracting and analyzing large volume, high velocity data, using multiple sources and tools, and compiling it into some meaningful, visual, *actionable* and useful knowledge is paramount (Brodie, 2019).

A prominent use case in aviation and aerospace operations is the broadening use of real-time predictive machining (Webster, 2022) and predictive maintenance (PdM), in which the monitored system can rapidly simulate its own mission cycles - modern air vehicles like the A350 generate upwards of 400,000 datapoints on a single flight (Read, 2018) - assess emerging failure modes further upstream, and suggest tailored repair or maintenance interval strategies.

Digital Twin Development for Aeronautical Engineering Technology Curriculum

The Aerospace and MRO Technology Innovation Center (AMT-I) at Purdue began exploratory assessment and testing of hybrid teaching and learning approaches incorporating the use of Digital Twins, Mixed and Augmented Reality technologies in 2013, evaluating 3D interactive model use in teaching and learning laboratories (Hartman & Ropp, 2013).



From: International Federation of Information Processing, 2013. Hartman & Ropp, (2013). *Examining the use of model-bae work instructions in the aviation maintenance environment*.

In 2016, a learner acceptance assessment on use of early Augmented Reality in active learning labs for turbine engine component ID and task assistance was tested with positive results in learner acceptance of digital learning technologies (Wang, Anne & Ropp, 2016).

2016 AR Turbine Engine Component Task. AMT-I Center, Hangar of the Future, 2023

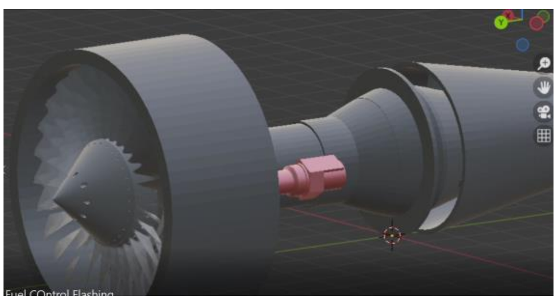
In 2021, a Digital Twin of the School's large jet flight deck and an immersive mixed reality training program were created to test speed of learning and task accuracy for starting a jet engine, with notable task learning efficacy (Borgen, Ropp & Weldon, 2021).

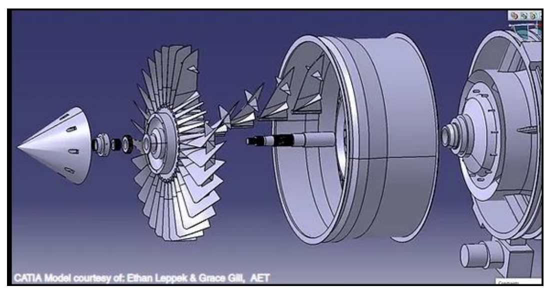
Digital Twins and Predictive Maintenance for Applied Teaching and Learning in Aeronautical Engineering Technology Curriculum

Dr. Timothy D. Ropp, Ph.D.

From: International Journal of Aerospace Psychology, 2021. Borgen, Ropp & Weldon, 2021. *Assessment of Augmented Realty technology's impact on speed of learning and task performance in Aeronautical Engineering Technology education*.

In Spring 2023, more capable 3D Twins and animations were developed, and initial testing began along this continuing R&D track.





AMT-I Center, Hangar of the Future 2023

Digital Twins and Predictive Maintenance for Applied Teaching and Learning in Aeronautical Engineering Technology Curriculum

Dr. Timothy D. Ropp, Ph.D.

Current R&D Focus

With a robust baseline of digital workspace test development and industry feedback, the AMT-I Center's next step trajectory targets developing intuitive Digital Twin learning suites, tailored to a user's learning style, level, and ancillary cognitive factors, facilitated by use of AI-assisted learning tracks in an end-to-end digital learning laboratory.

AMT-I Center, Hangar of the Future 2023

Task-specific learning modalities include component nomenclature, guided positioning, function, predictive and simulated failure modes, and guided maintenance tasks will be developed for students to visualize and assess, then transfer this immersive experience directly onto physical air vehicle and powerplant laboratories. The ongoing research goal is to evaluate Digital Twin learning and competency transfer efficacy specific to:

1. Learning outcome (KSAs and Technical Data Competencies)
2. Speed of learning
3. Use of digital twins in education to create virtual capacity to improve learner throughput

Conclusion

Graduates entering the modern workforce are expected to possess at minimum cursory knowledge and cross-over skills incorporating these IIoT/AI and Digital Twin frameworks (Crow & Dabars, 2020). Traditional pedagogy and applied learning approaches for a new age of digital fusion of modern technologies into legacy aviation/aerospace operations occurring within the industry must evolve to encompass digital thread technologies as tools (Ropp, et al, 2020).

Graduates from Part 147 maintenance schools as well as broader spanning aeronautical engineering technology programs are being hired into sectors across the aviation, aerospace and commercial space industries utilizing digital thread and digital twin technologies. These tools therefore must be incorporated into curriculum beyond just introduction. Digital Twins must be a part of the learning cycle if graduates are to enter the workforce “industry-ready”.

<This space intentionally left blank>

References

Borgen, K.B, Ropp, T.D. & Weldon, W.T. (2021). Assessment of Augmented Reality Technology's Impact on Speed of Learning and Task Performance in Aeronautical Engineering Technology Education. *The International Journal of Aerospace Psychology*, 19 February, 2021. https://www.tandfonline.com/doi/full/10.1080/24721840.2021.1881403 DOI: 10.1080/24721840.2021.1881403

Brodie, M.L. (2019). What is data science? In book: *Applied Data Science. p*p. 101-130. June 2019. DOI:10.1007/978-3-030-11821-1_8

Crow, M.M. & Dabars, W.B. (2020). T*he Fifth Wave: The evolution of American higher education*. Johns Hopkins University Press: Baltimore. ISBN: 9781421438023.

Dorsch, J. (2018, May 30). *IIoT and Predictive Maintenance*. Semiconductor Engineering online. May 30, 2018. https://semiengineering.com/iiot-and-predictive-maintenance/

Hartman, N. W., & Ropp, T. D. (2013). *Examining the use of model-based work instructions in the aviation maintenance environment.* Nantes, France: PLM13, tech.purdue.edu/facilities/hangar-of-future.

IBM (2023, May 4). *What is a digital twin?* IBM Topics webpage. https://www.ibm.com/topics/what-is-a-digital-twin

MARKETSandMARKETS (2022, June 30). *Digital Twin Market*. Global Forecast to 2027. https://www.marketsandmarkets.com/Market-Reports/digital-twin-market-225269522 Digital Twin Market by Enterprise, Application (Predictive Maintenance, Business optimization), Industry (Aerospace, Automotive & Transportation, Healthcare, Infrastructure, Energy & Utilities) and Geography.

Read, B. (2018). Digital Takeover. *Royal Aeronautical Society online.* https://www.aerosociety.com/news/digital-takeover/ 20 March 2018.

Ropp, T.D., Pirateque, J.E., Aurenas, J.M., Minarik, K & Lopp, D. (2020). Hangar of the Future 2030: Challenges for MRO, Aerospace and Aviation Education. Research presentation on survey results of workforce competency needs in MRO and Aerospace, 2020. *Aviation Week - MRO Latin America.* International conference, Hilton Cartagena, Cartagena, Colombia. Jan. 22-23, 2020.

Wang, Y.[G], Anne, A.[G], & Ropp, T. (2016). Applying the Technology Acceptance Model to Understand Aviation Students' Perceptions Toward Augmented Reality Maintenance Training Instruction. *International Journal of Aviation, Aeronautics, and Aerospace*, *3*(4), 11., http://www.commons.erau.edu/ijaaa/.

Webster, P., (2022). Digital Twins for the Machining Process. *Manufacturing Engineering, Vol. 168*,(6). June 2022.