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Impact of Virtual Modelling in Building Space Ecosystem

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The intricacy of aerospace systems is growing at a rate that is much faster than traditional development methods. The cost of typical aerospace tasks, such as physical prototyping, physical testing, and proximity/periodic maintenance, will keep rising due to the increased complexity of these systems. Reduced costs are possible with virtual capabilities that can imitate physical environments with increased fidelity, speed, and granularity. The idea of a 'digital twin' is one such virtual ability[1].

A digital twin includes all stages of the product lifecycle and is a virtual copy of the physical asset connected to it. What makes it valuable is the ability to move work from a physical location into a virtual or digital one, as well as the ability to predict asset circumstances when they become physically undesirable. As a result, the resources required to design, construct, and maintain aeronautical assets are significantly reduced.

As new space-focused businesses enter the market, particularly in the commercial low-Earth orbit space sector, the satellite industry is undergoing a rapid digital transformation. India has made significant strides, especially since the central government announced reforms in 2020 to increase the private sector's participation in the sector. Digital twin technologies have considerable promise for the rapidly growing space industry, particularly in areas such as satellite production, space exploration, and space infrastructure[2].

By creating virtual versions of satellites and other space-related assets, digital twin can increase productivity, reduce risks, and promote innovation in the space industry.

Satellite Development and Operations

Design Optimisation

With digital twin, engineers can test and simulate satellite designs. This allows them to optimise each component's weight, balance, and configuration before it is manufactured. Better satellite performance and reduced development costs could result from this.

Mission Planning

By simulating satellite orbits, communication links, and payload performance, digital twin can aid mission planners in optimising launch windows, ground station coverage, and other mission characteristics.

Predictive Maintenance

By monitoring the health and performance of satellites in orbit, digital twin can help identify potential issues before they become serious and enable prompt maintenance or adjustments to extend the satellites' lifespan.

Space Exploration

Planetary Science

The ability to create virtual representations of celestial bodies, such as the Earth, planets, moons, and asteroids, is possessed by digital twin[3].These models can aid in the development of future missions and scientific investigation into their geology, climate, and capacity to support life.

Spacecraft Design and Testing

Digital twins are able to mimic how spacecraft operate in a variety of conditions, such as microgravity, high temperatures, and radiation exposure. This can help engineers increase the accuracy of their designs, reduce risks, and increase the possibility of meeting mission objectives.

Astronaut Training and Mission Simulation

Astronauts can train and perform their duties in a safe, virtual environment by using digital twin to imitate real-world mission scenarios.

Space Infrastructure

On-orbit servicing and manufacturing

Digital twins are able to model complex relationships between satellites, space stations, and servicing vehicles. This makes it easier to optimise robotic operations and reduce risk when performing manufacturing and servicing tasks while in orbit.

Space Traffic Management

Digital copies of spaceassets and the orbital trajectories that correspond with them can be used to simulate and predict potential collisions, improving the effectiveness of space traffic management and reducing the likelihood of orbital accidents.

Space-based Communication Networks

In order to ensure the best possible coverage and bandwidth efficiency, digital twins can be used to optimise the design, deployment, and operation of space-based communication networks, particularly satellite constellations.

Recommendations

A collaborative pursuit of the following priority areas and activities will be required for broader enterprise-benefit realisation from selected digital twin applications in order to expedite value generation from the deployment of digital twins.

Business & Transactional

The advantages of a digital twin are still not well understood or conveyed in a way that promotes and helps define 'win-win' business models and the application of best practices for contracting in the public and private sectors[4].

- Economic Impact: Reviewing the financial implications of digital twin techniques is necessary in order to make better decisions about product development, manufacturing, and maintenance while maintaining the Aerospace Industrial Base's financial stability. Specifically, the upfront costs associated with creating and managing digital twins must be weighed against the anticipated financial benefits and return on investment.
- Cybersecurity and Intellectual Property: Furthermore, these new approaches will need to match strategies related to cybersecurity, intellectual property management, and its preservation in order to support the usage of data with digital twins for cross-life cycle and cross-supply chain value realisation.
- Contractual Language: Ultimately, in order to create the right terms, conditions, and incentives for quickening the realisation of value from digital twin capability, contract language needs to be reviewed in light of improved understanding and alignment with value, economic impact, and intellectual property considerations. Numerous governmental and professional organisations are working hard in this area, but frequently in isolated, disorganised ways within their own systems of view.

Technological and Analytical

While some members of the aerospace industry have made significant progress in applying digital twin capacity to realise benefits, a number of technological and analytical issues are preventing digital twins from being widely adopted and used.

- Standards: Suitable standards and/or standard operating procedures must be created in order for digital twins to communicate with one another throughout the supply chain and life cycle. There is a lack of coordination and awareness among the numerous professional societies that are currently in existence that are working to standardise across industry sectors. The establishment of suitable foundational open standards (e.g., data and models) and life cycle architecture frameworks could yield significant benefits and enhance collaboration.
- Toolsets and Methods: To advance the quality and practice of digital twin usage across the broader Aerospace community, more advancements in tools and methods are needed, including multi-physics modelling and the development of probabilistic frameworks. The use of artificial intelligence and machine learning to advance configuration management and reduce manual labour while increasing connectivity could be explored. Besides, a system for

verification, validation, accreditation, and certification, as well as the uncertainty quantification of digital twins[5] is also required.

- Data Curation: Given the security, export, and intellectual property sensitivity of the digital twin models, industry-accepted solutions for the location and management of digital twin storage and maintenance must be found. Furthermore, since a digital twin cannot exist without a linked physical asset, access to and curation of 'twin data' such as field performance, reliability, and failure data is crucial in addition to the storage and upkeep of models and simulations.
- Infrastructure: Large industries and government partners have set up substantial IT infrastructure to facilitate the internal implementation of digital twin and digital enterprise capacity. Meanwhile, small and medium-sized aerospace companies lack the capacity to do so. This is further highlighted by new and developing requirements for cybersecurity, such as harmful data threat-aversion systems.

Engagement of National Geospatial Policy 2022and National Space Policy 2023 is of prime importance as it gives a road map for the activities undertaken by public and private entities. Policies also provide a roadmap for public-private collaboration in the space domain. The government is more than keen to involve technology inclusion in this domain as it remains a disruptive and ever-developing one. Various benefits to start-ups, an increase in FDI, and delimiting governmental control are the basics of these policies.

Way forward

The Aerospace Industry needs the establishment of a digital twin 'Centre of Excellence' for cooperation between academia, industry, government, and pertinent certification authorities in light of the aforementioned issues, needs, and challenges. This centre may be used to clearly define and agree upon the value of the digital twin and encourage initiatives aimed at bridging the aforementioned business, technological, and cultural gaps. It may also be used for a shared understanding of value and gap analysis, providing guidance for government procurement policy and investment thereby act as a reliable source to develop and disseminate best practices, standards, and lessons learnt. It is also recommended to act as a reliable source for determining the 'Maturity Level' and other aspects of the digital twins' verification, validation, and accreditation for the purpose of managing the quality process and to promote workforce development and curricula at school level.

(Disclaimer: The views and opinions expressed in this article are those of the author and do not necessarily reflect the position of the Centre for Air Power Studies [CAPS])

Notes:

[1] "Digital twin: Definition & value", *An AIAA and AIA Position Paper*, December 2020, https://www.aiaa.org/docs/default-source/uploadedfiles/issues-and-advocacy/policy-papers/digital-twin-institute-position-paper-(december-2020).pdf. Accessed on October 28, 2023.

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[5] Danette Allen, "Digital Twins and Living Models at NASA", November 03, 2021, https://ntrs.nasa.gov/api/citations/20210023699/downloads/ASME%20Digital%20Twin%20Summit%20Keynote_final.pdf. Accessed on October 31, 2023.