Maxim Tyan

- Associate Professor
- Dept. of Mechanical Engineering
- New Uzbekistan University

- Got PhD Degree from Konkuk University in 2015
  - Dept. of Aerospace Information Engineering
  - Advisor Prof. Jae-Woo Lee

- Worked at KADA from March 2010 till August 2025
  - Researcher, Senior Researcher,
    Research Professor, Assistant Professor

- Research Area
  - Aircraft Multidisciplinary Design Optimization
    - General aviation, Electric UAV, UAM, RAM
    - Design methodology and software development
    - Design for Certification
    - Flight Simulation and Digital Twin Systems
  - Systems Engineering

Digital Twin Technology for Aerospace Challenges and Opportunities

Maxim Tyan

Associate Professor, Department of Mechanical Engineering

New Uzbekistan University

m.tyan@newuu.uz

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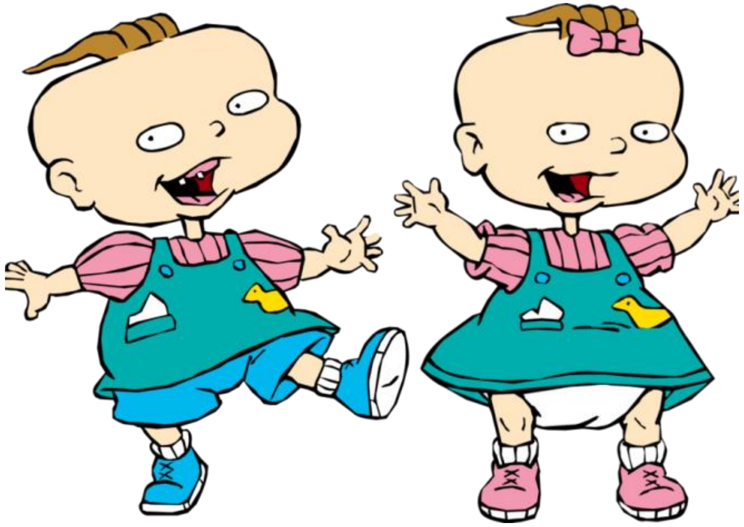
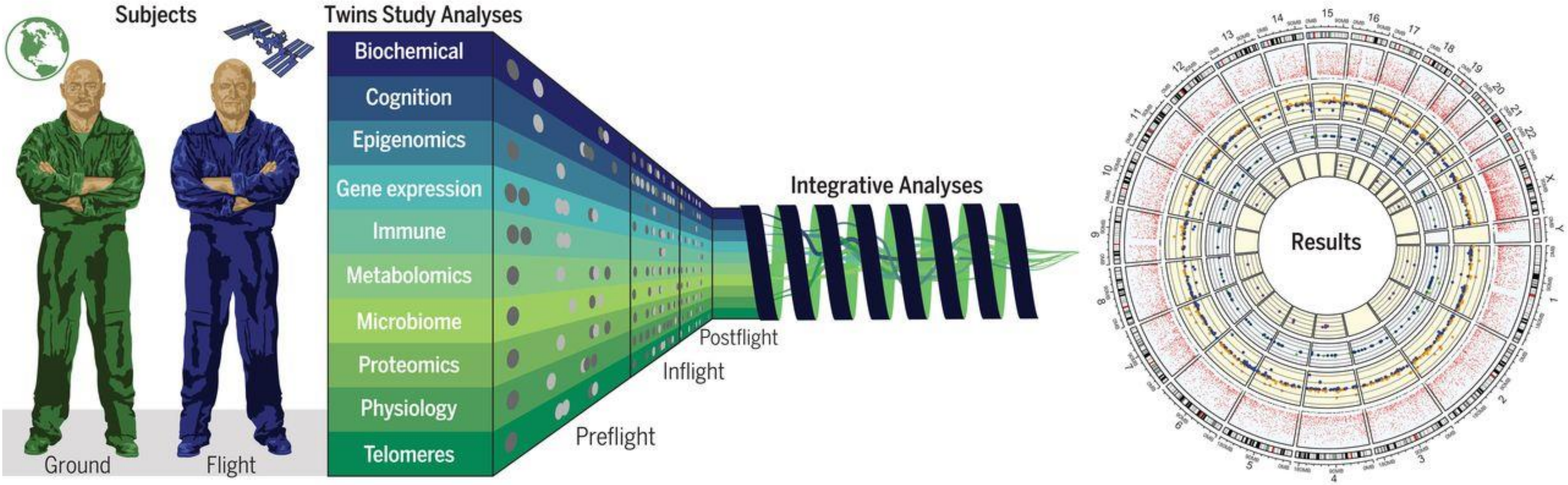
Who Are Twins?



- Genetically nearly identical
- Look alike, but usually have different temper
- Difference becomes noticeable if twins grow in different environment

Scott and Mark Kelly – NASA's Twin Experiment

- One in orbit and one on earth will help us learn how humans change when they leave the planet



Garrett-Bakelman, Francine E., Manjula Darshi, Stefan J. Green, Ruben C. Gur, Ling Lin, Brandon R. Macias, Miles J. McKenna, et al. "The NASA Twins Study: A Multidimensional Analysis of a Year-Long Human Spaceflight." *Science* 364, no. 6436 (April 12, 2019): eaau8650. https://doi.org/10.1126/science.aau8650.

Scott Kelly
@StationCDRKelly

What? My DNA changed by 7%! Who knew? I just learned about it in this article. This could be good news! I no longer have to call @ShuttleCDRKelly my identical twin brother anymore.

newsweek.com
A year in space altered this man's DNA
Seven percent of Scott Kelly's genes did not return to normal when he got home.

8:47 AM · Mar 11, 2018

11.6K Reply Copy link to Tweet

Read 273 replies

- Scott Kelly spent **340 days in space**, while Mark remained on Earth
- Study helped understand the **effects of long-term space travel** on the human body

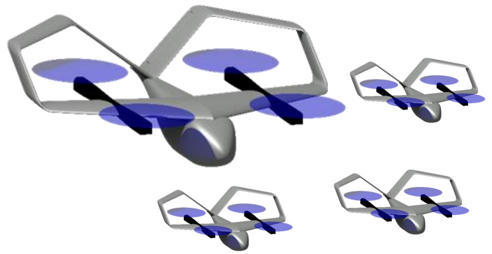
Digital Twin Definitions

- Integrated Multiphysics, multiscale, probabilistic simulation
- At its optimum, any information that could be obtained from inspecting a physical manufactured product can be obtained from its Digital Twin [2]
- By bridging the physical and the virtual world, data is transmitted seamlessly allowing the virtual entity to exist simultaneously with the physical entity
- DT is an organized collection of physics-based methods and advanced analytics that is used to model the present state of every asset in a system

[1] https://en.wikipedia.org/wiki/Digital_twin
[2] M. Grieves and J. Vickers, "Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems," in *Transdisciplinary Perspectives on Complex Systems*, F.-J. Kahlen, S. Flumerfelt, and A. Alves, Eds. Cham: Springer International Publishing, 2017, pp. 85–113.

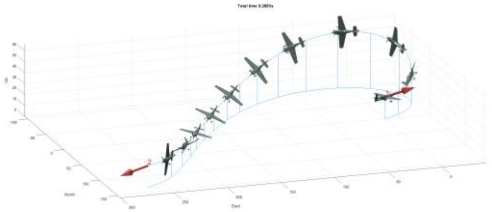
Simulation – One of The Key Components

- KDS: a flight dynamics model for UAV/UAM and other types of aircraft developed in KADA



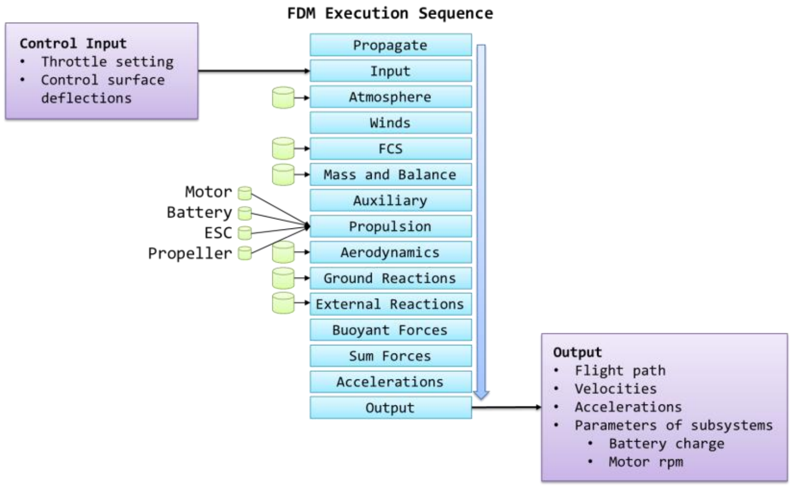
Model(s)

Environment



- Aircraft control input
  - Individual controls
  - Target flight path
- Initial conditions

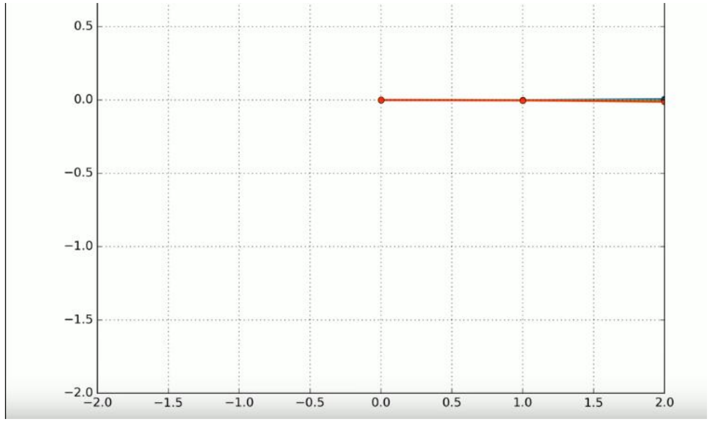
Simulation Program



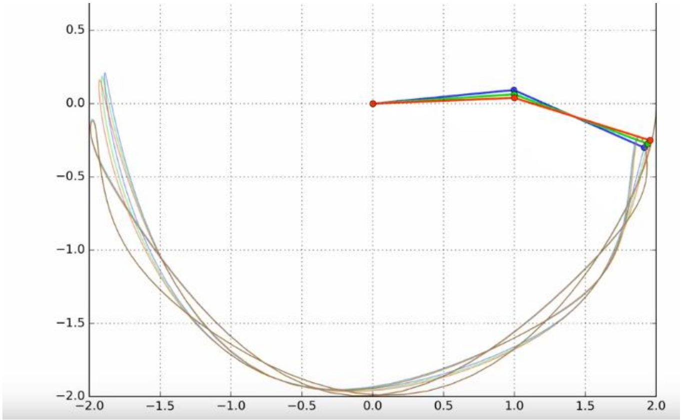
- Flight trajectory
- Dynamics data
  - Velocities, accelerations, etc.
- Subsystems
  - Motor, battery status
- Etc.

Double Pendulum System

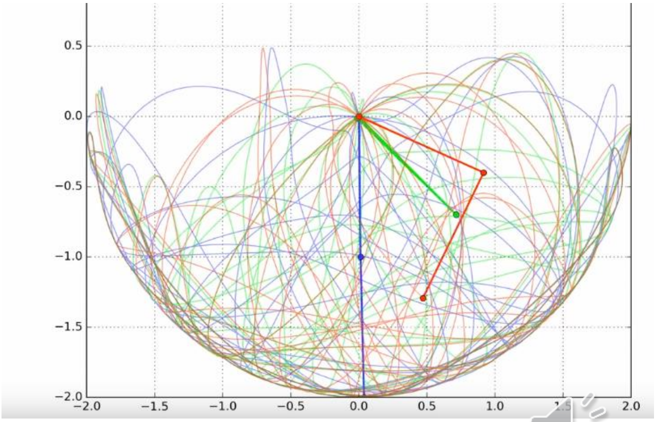
- Some deterministic dynamical systems may be highly sensitive to initial conditions (IC)



Time = 0 sec



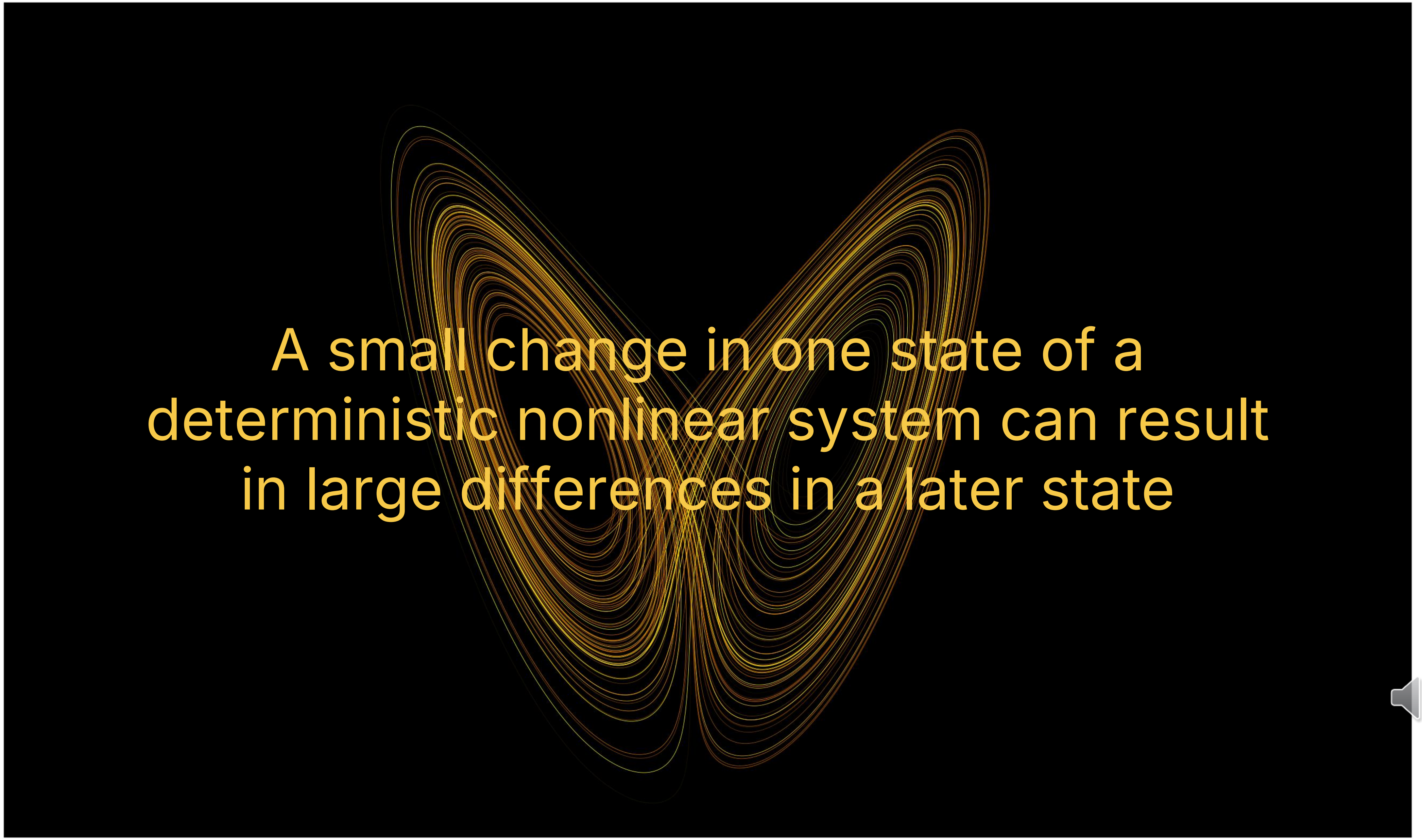
Time = 10 sec



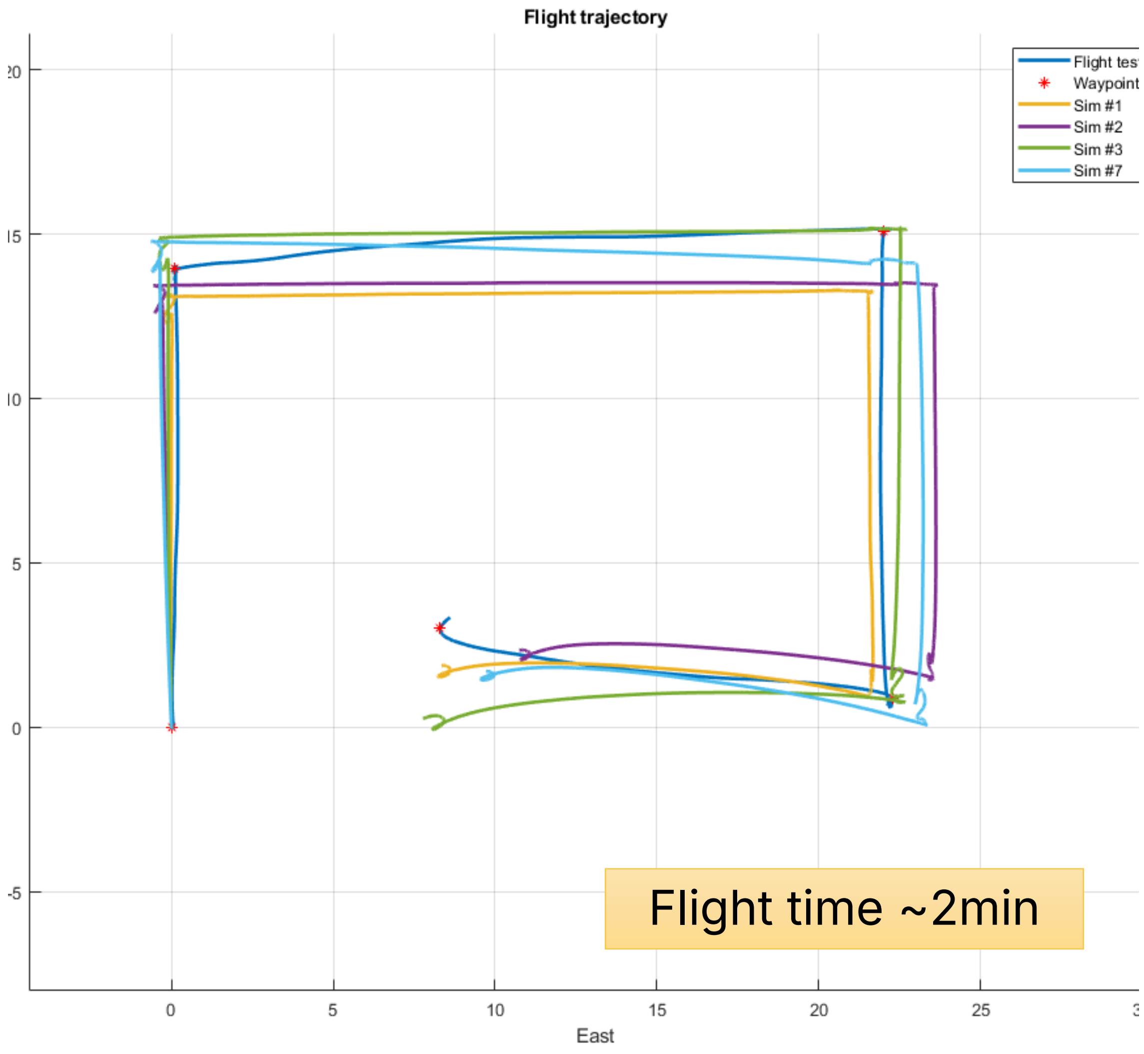
Time = 60 sec

https://www.youtube.com/watch?v=pEjZd-AvPco
https://youtu.be/6z4qRhpBlyA?t=64

The Butterfly Effect

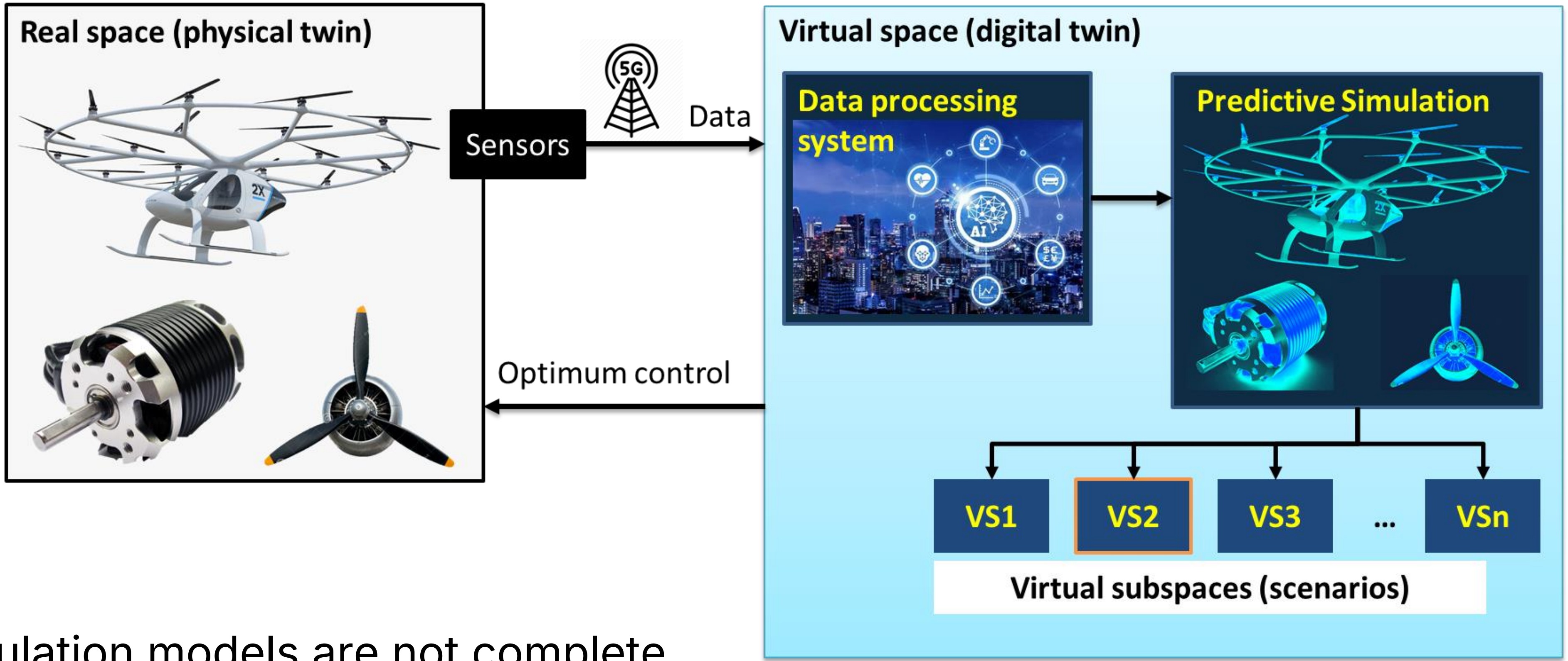


Example of Chaotic Dynamic Behavior of a Drone Simulation



- Flight simulation is a chaotic dynamic system
- The system is deterministic
- A tiny difference in initial conditions may lead to a large error at the end

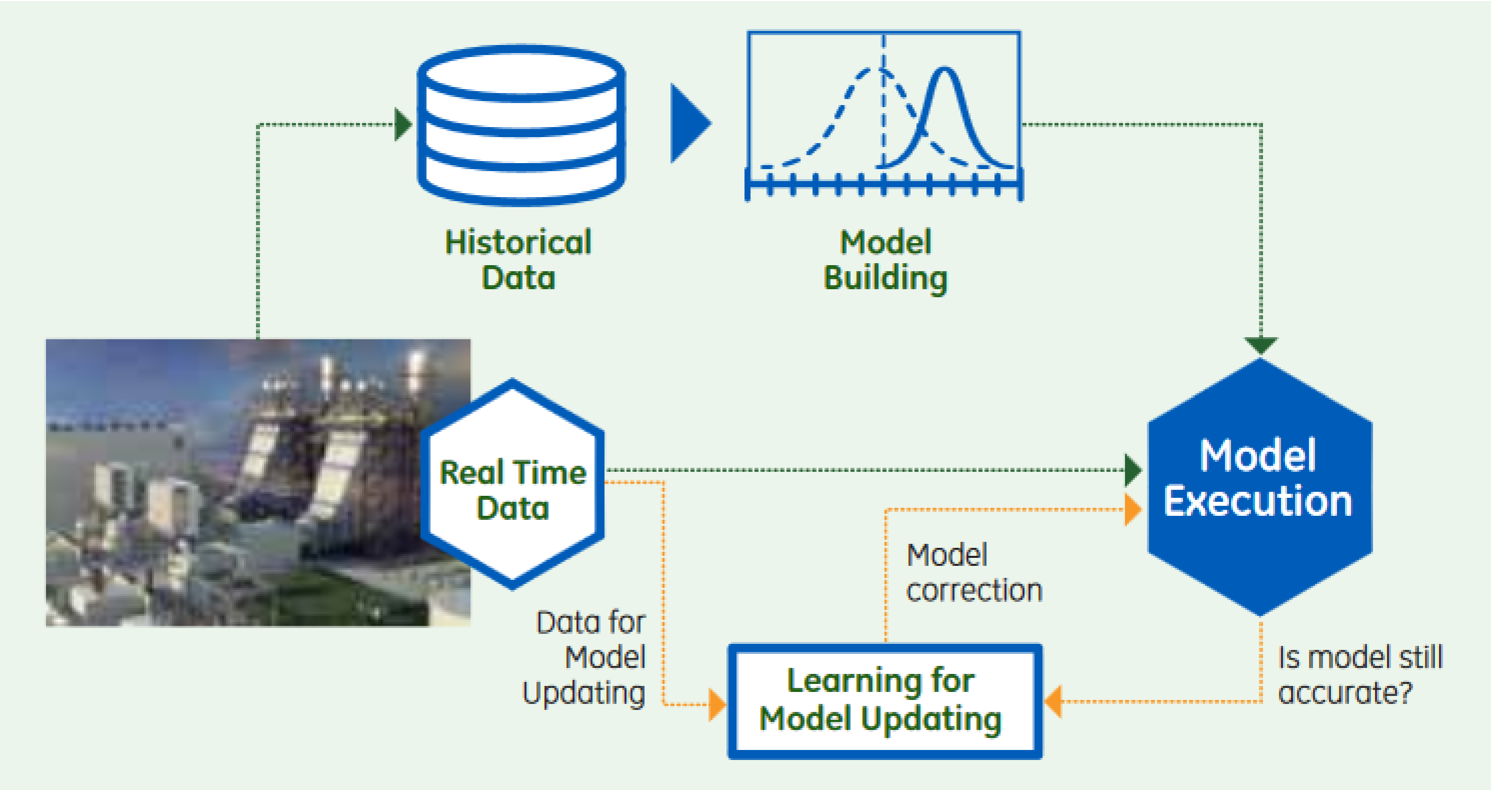
Digital Twin Needs a Real-World Data Supply



- The simulation models are not complete
  - We cannot simulate absolutely everything (other vehicles, weather, people, aircraft component degradation, battery self discharge, effect of temperature, etc.)
  - Measurement precision is limited
- Execution cannot be 100% accurate during long period of time

Learning Model

- DTs are continuously created, validated, monitored, and updated in near real-time
- Performance of Digital Twins is constantly monitored and both continuous and incremental learning techniques are applied to update the Digital Twin



https://www.ge.com/digital/sites/default/files/download_assets/Digital-Twin-for-the-digital-power-plant-.pdf

A Digital Twin in The Pocket

$C_{current}, P_{drain}$

Math Model (simulation)

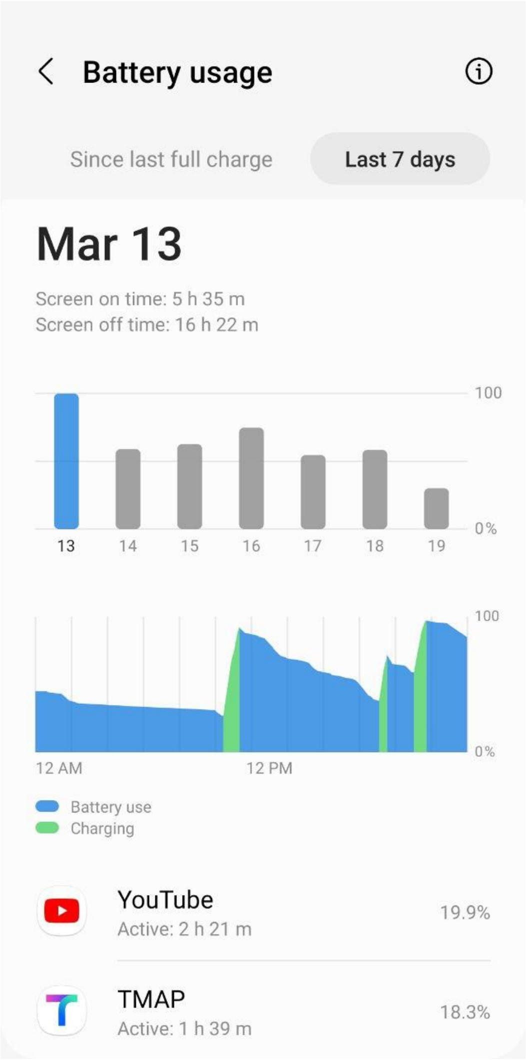
$$time_{left} = \frac{Charge_{current}}{Power_{drain/charge}}$$

Predicted battery life

System Monitoring
(AI, Data Analytics)

Apps used
Power consumption

The Smartphone Battery Digital Twin Can:



- Predict (simulate) the remaining battery lift
- Estimate time required for full charge
- Identify apps that consume most energy
- Monitor battery health and degradation
- Optimize battery usage
- Suggest energy-saving settings
- Provide insights on charging habits to extend battery lifespan
- …

Attributes of a Digital Twin

- **Individual**
  - DT is applied to individual asset, tracking history, and performance over the lifetime
- **Adaptable**
  - Transfer to another asset class, or adapt to new scenarios or factors
- **Continuous**
  - Continuously updated as the physical system is operated. At any time, DT represents a faithful representation of the current state of the system.
- **Scalable**
  - When hundreds of similar systems have a DT, it learns from other similar DTs

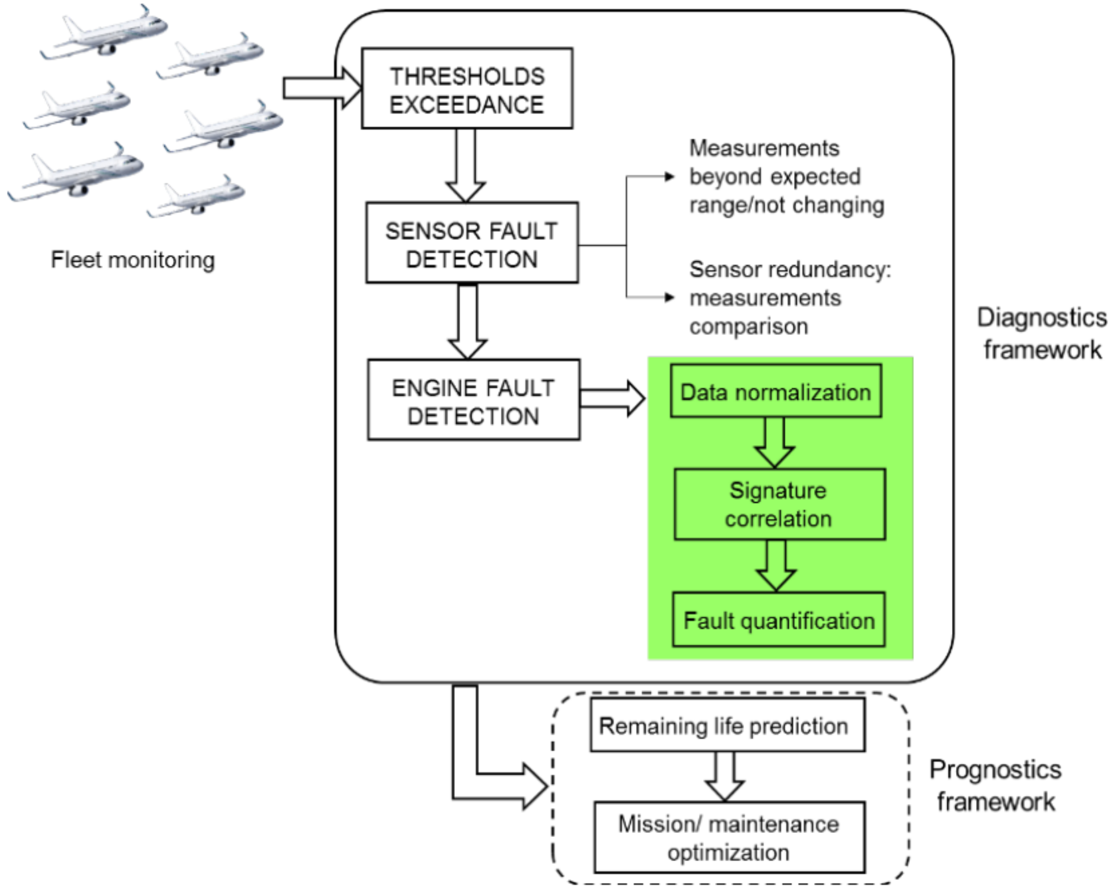
Rolls-Royce – One of the pioneers of commercial DT

- Advanced Simulation at the core
  - check how engine will perform under various conditions
- IoT and Sensor data analytics
  - Monitor health
  - Predict maintenance needs in real-time
- Machine learning
  - To refine the simulation accuracy

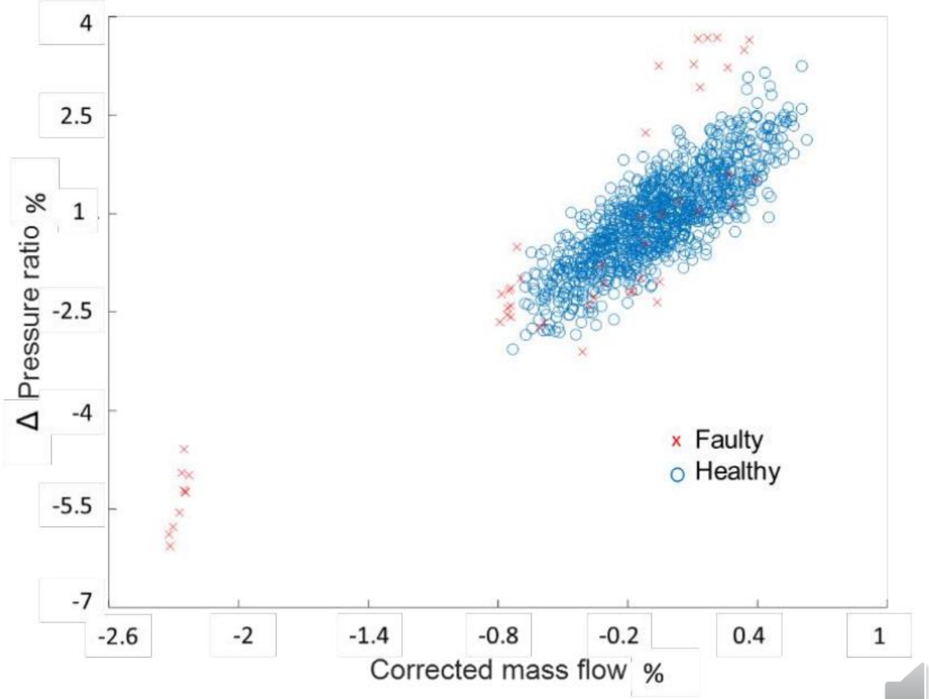
- Applications
  - Predict potential failures
  - Optimize maintenance schedule
  - Improve engine design for future iterations

https://www.rolls-royce.com/innovation/digital/digital-twin.aspx

Aircraft Fleet Diagnostics using Engine DT

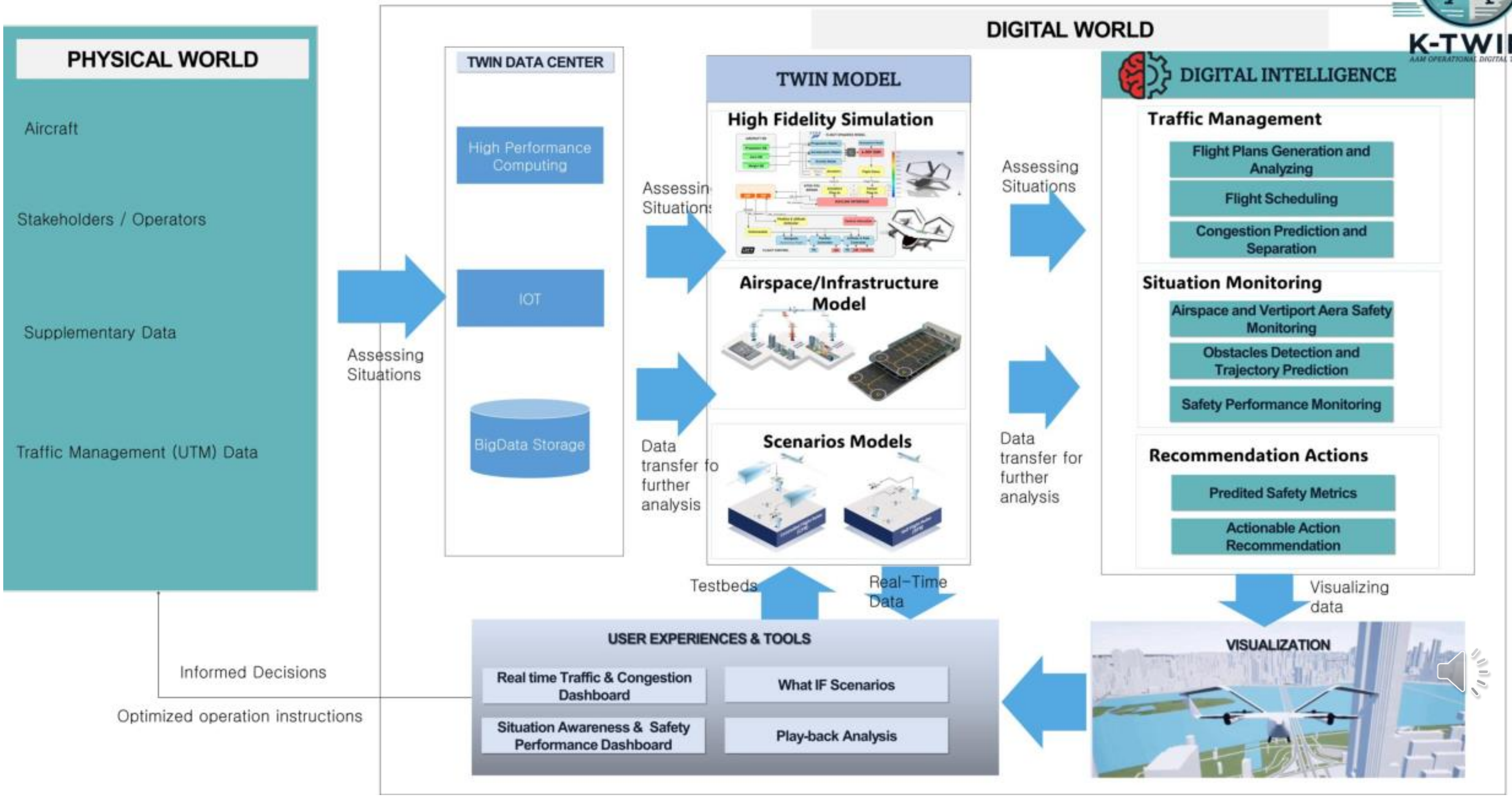


- Utilize advanced data analytics
- Compare findings with simulation results
- Detect performance anomalies more quickly.



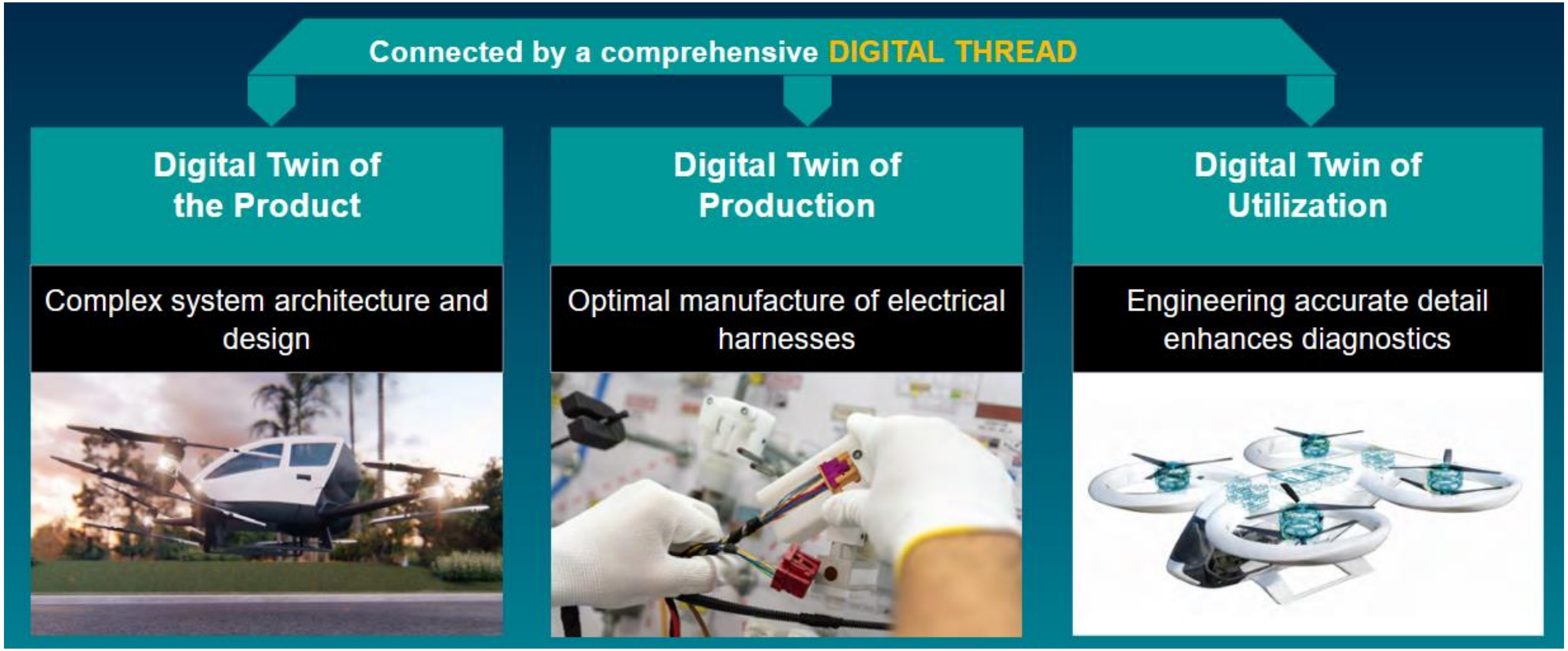
Zaccaria, Valentina, et al. "Fleet Monitoring and Diagnostics Framework Based on Digital Twin of Aero-Engines." In *Volume 6: Ceramics; Controls, Diagnostics, and Instrumentation; Education; Manufacturing Materials and Metallurgy*, V006T05A021. Oslo, Norway: American Society of Mechanical Engineers, 2018. https://doi.org/10.1115/GT2018-76414.

KADA OPERATIONAL DIGITAL TWIN (ODT)



Siemens' Model Based Approach

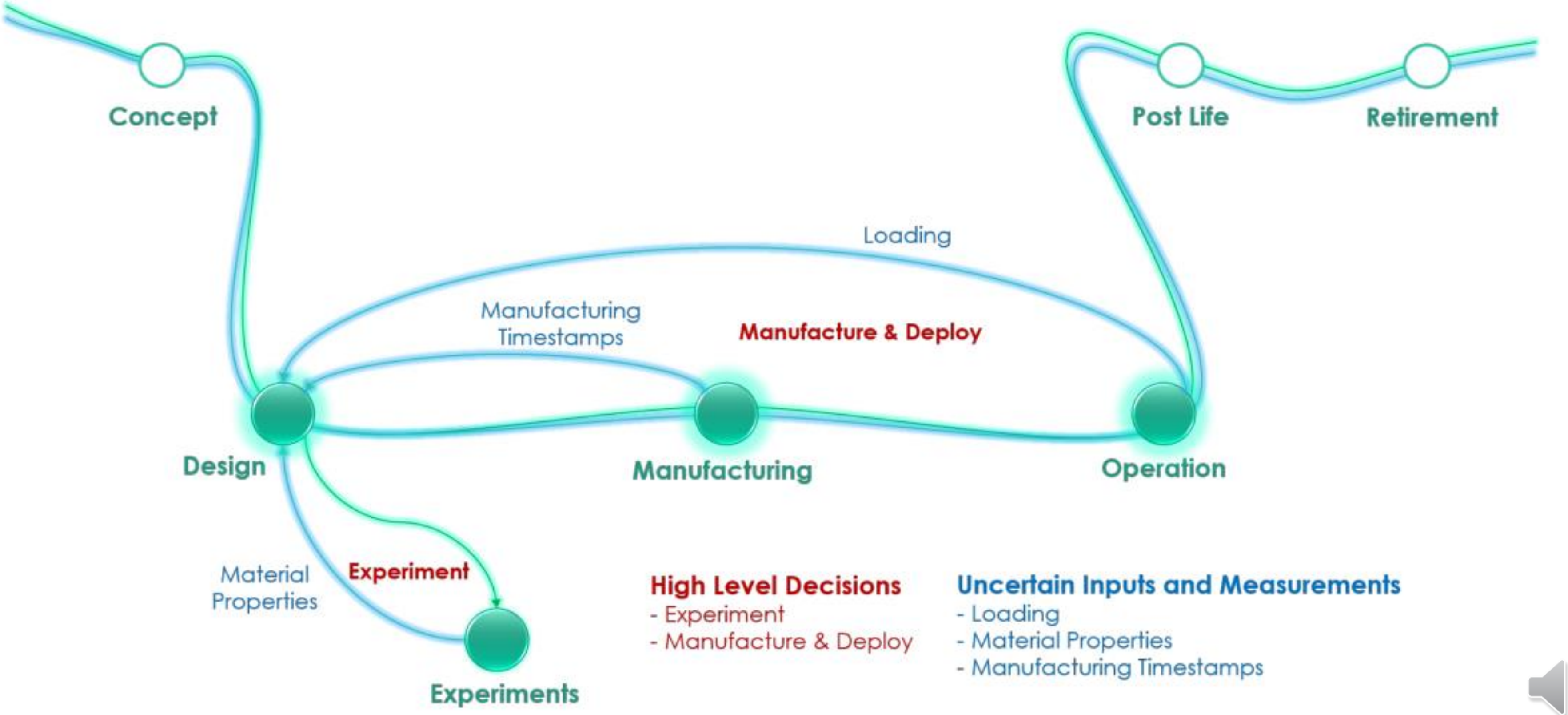
- DT at every level of aircraft lifecycle connected via Digital Thread
  - Electrical, mechanical systems
  - Production lines
  - Certification procedures



https://www.plm.automation.siemens.com/media/global/en/eVTOL%20Executive%20%20ebook_tcm27-102801.pdf

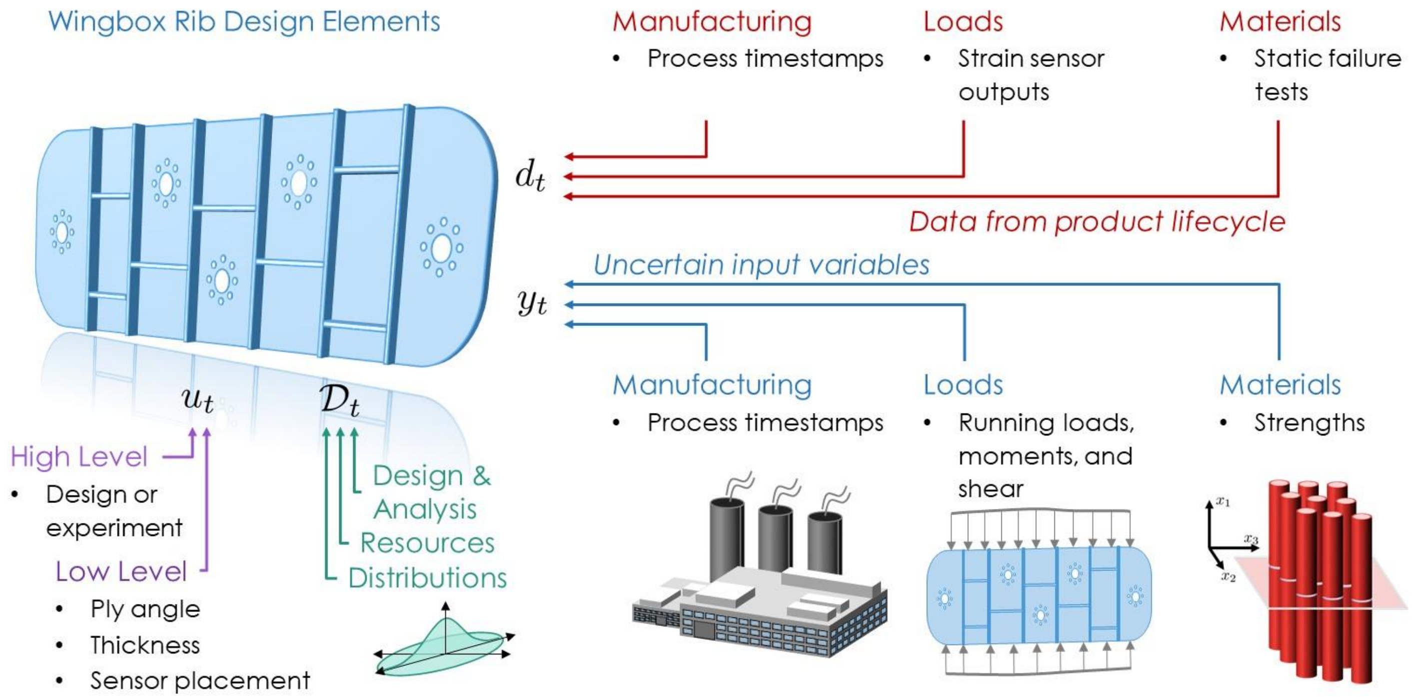
Aircraft Structural Component Design

- Full featured digital twin with real-time data supply is usually not needed at stages of design, however design optimization supported by a real data is critically important for a safe design



Singh, Victor, and K. E. Willcox. "Engineering Design with Digital Thread." *AIAA Journal* 56, no. 11 (November 2018): 4515–28. https://doi.org/10.2514/1.J057255.

Aircraft Structural Component Design



- The uncertain input variables (what we would like to learn)
- The measurement data (what we learn from)
- The Digital Thread itself (how to represent what we know)
- The decision variables (the decisions and design choices we can make)

Singh, Victor, and K. E. Willcox. "Engineering Design with Digital Thread." *AIAA Journal* 56, no. 11 (November 2018): 4515–28. https://doi.org/10.2514/1.J057255.

Challenges and Future of Digital Twins

- Digital twins are being used for design and operations of critical systems (transportation, infrastructure, etc.)
- Data security and cyber threats are among the critical issues
- Large scale simulations, machine learning and data analytics require high performance computing
- Integration Across Lifecycle & Stakeholders
- Future AI/ML/LLM enable more autonomous and adaptive DT instances

Impact on Aviation and AAM

- Facilitate air traffic management and infrastructure planning with digital twin technology.
- Support simulation-based risk assessments for autonomous urban flights.
- Enhance certification processes through virtual testing of new aircraft, reducing regulatory approval time and costs.
- Leverage fleet-wide digital twins to improve maintenance, fuel efficiency, and safety.

Image source: https://www.aviationfile.com

Conclusions

- Digital twins are transforming aerospace: real-time monitoring, predictive maintenance, optimization of operations
- Core technologies: IoT, AI, simulation, and cloud computing
- NASA, Boeing, Airbus, and emerging AAM companies demonstrate the real-world impact of digital twin technology
- The future of digital twins in AAM looks promising, with potential for fully autonomous air mobility, improved safety, and streamlined certification processes.
- Collaboration between industry, academia, and regulators will be key to unlocking the full potential of digital twins in aerospace.

Thank You!

for your attention

Contact me if you have any questions

m.tyan@newuu.uz

maximtyan.github.io

Maxim Tyan

Associate Professor

Department of Mechanical Engineering

New Uzbekistan University