CFD-Related Perspective in Industry

3rd AIAA Workshop on Multifidelity Methods for Design and Uncertainty

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Agenda

- The Motivating Challenge
- CFD in Today’s Design Cycle
- Multi-Fidelity Modeling Paradigms
- Some Industry Needs/Opportunities
- Some Future Trends

The Motivating Challenge

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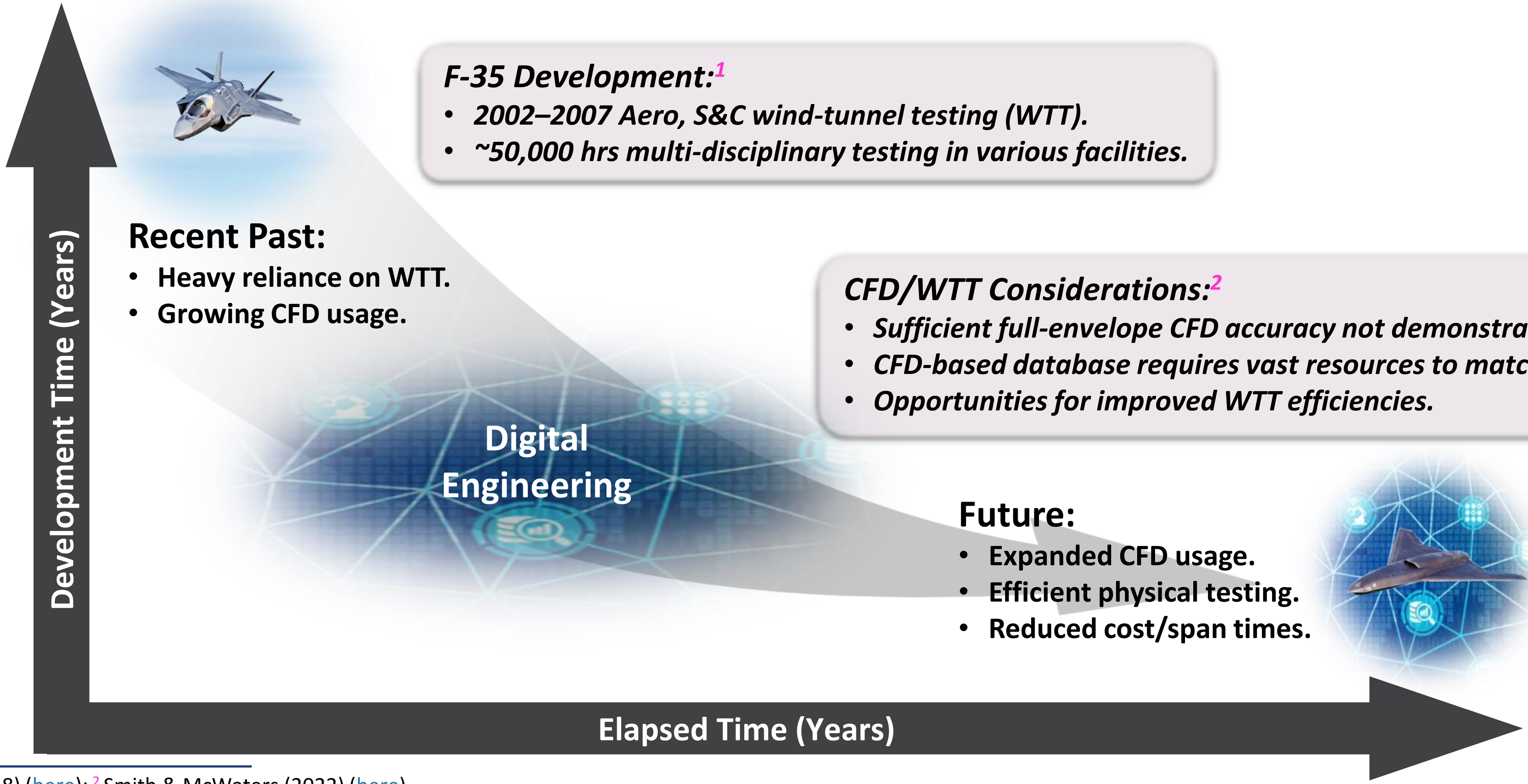

F-35 Development:[1]

- *2002–2007 Aero, S&C wind-tunnel testing (WTT).*
- *~50,000 hrs multi-disciplinary testing in various facilities.*

Recent Past:

- **Heavy reliance on WTT.**
- **Growing CFD usage.**

CFD/WTT Considerations:[2]

- *Sufficient full-envelope CFD accuracy not demonstrated.*
- *CFD-based database requires vast resources to match WTT.*
- *Opportunities for improved WTT efficiencies.*

Future:

- **Expanded CFD usage.**
- **Efficient physical testing.**
- **Reduced cost/span times.**

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[1] Parsons *et al*. (2018) (here); [2] Smith & McWaters (2022) (here).

Digital engineering aims to compress schedule/reduced cost; must balance with CFD/WTT realities.

CFD in Today’s Design Cycle

CFD in Today's Design Cycle

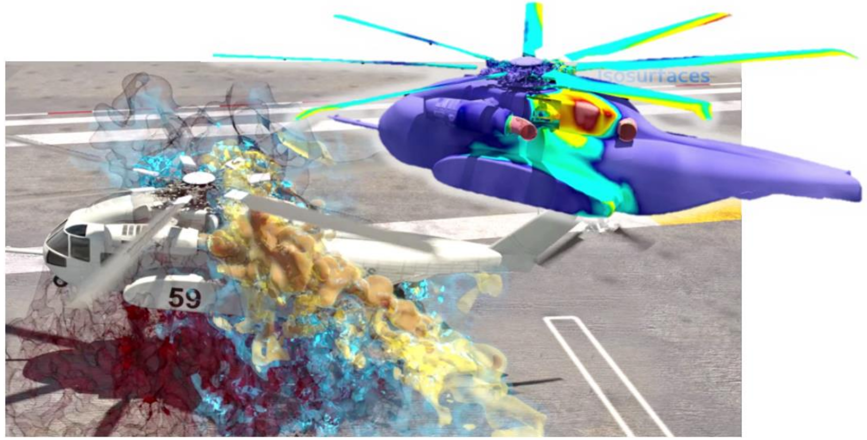
CH-53K King Stallion:

- **Background:** 2018-19 Initial Operational Testing revealed Engine Exhaust-Gas Reingestion (EGR).[1,2]
- **Response:** Joint Navy (NAVAIR), Sikorsky, and Army (DEVCOM AvMC) "Tiger Team" formed.
- **Goal:** Use CFD to identify and mitigate EGR quickly.
- **Approach:** 135+ configurations RANS → 15+ in DES/LES.
- **Outcome:** 2020 flight tests showed EGR mitigation.[3]

Lockheed Martin Vectis®:

- Digital Engineering for next-gen aircraft development.
- Drives affordability and speed.

CH-53K High-Fidelity Simulation [3]



Lockheed Martin Vectis® [4]

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[1] Neerarambam *et al.* (2021) (here); [2] Duque *et al.* (2023) (here); [3] NAVAIR News (2019) (here); [4] Lockheed Martin (2025) (here).

Potential of multi-fidelity CFD to impact key design changes more quickly than fly-fix-fly paradigm.

Key Considerations

Computational Resources:

- Design and databasing typically demand many data points.
- Scale-resolved CFD can take week(s)+, produces enormous amount of data.

Workflow Productionization:

- Pre-processing, simulation data management, visualization.
- Access/interpretation by non-CFD specialists.

Toolset Diversity:

- Several different codes often used (RANS, DES, LES).
- Tools may vary across sub-discipline (e.g., external aerodynamics, inlet modeling).

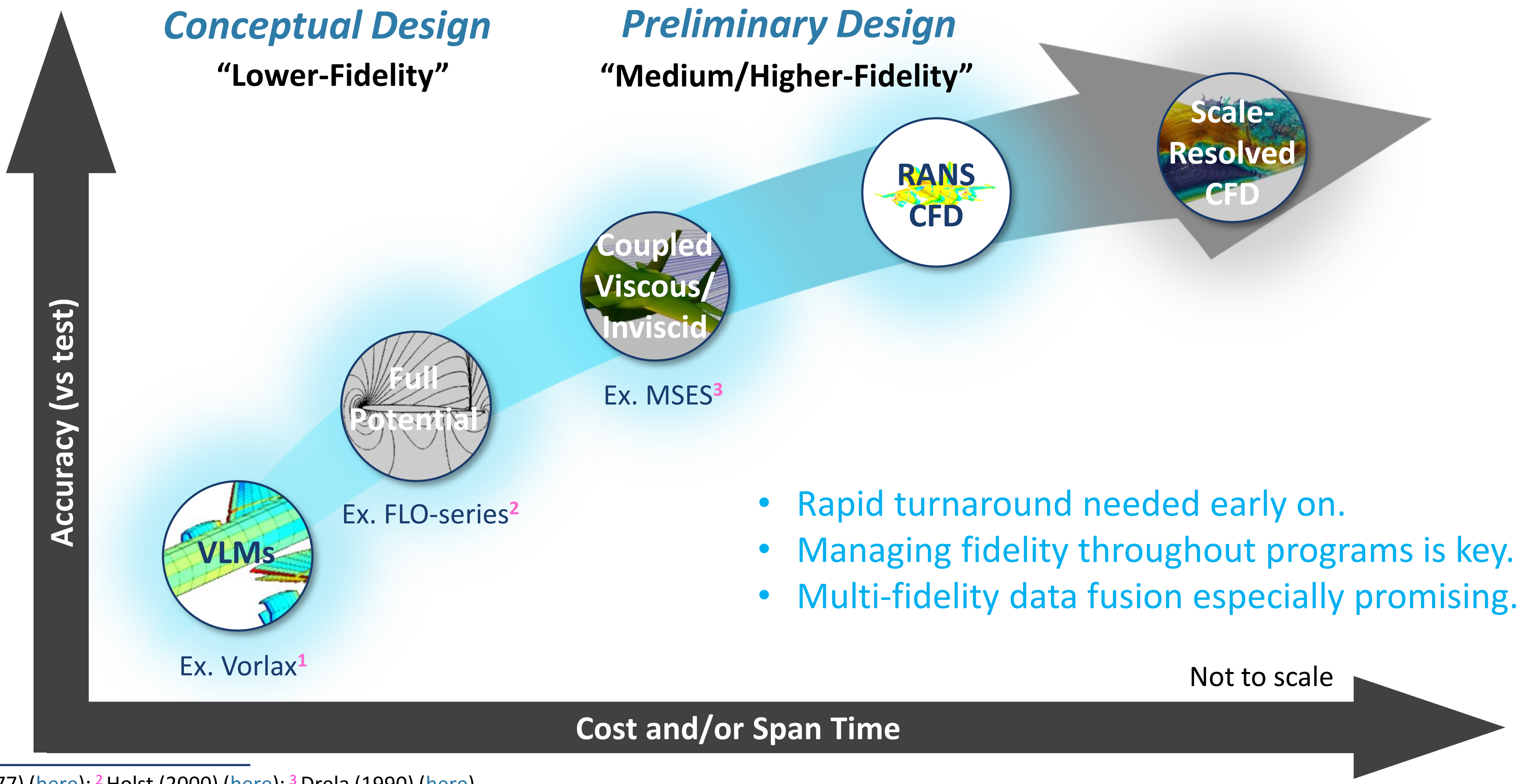
Confidence Levels:

- Becoming increasingly important as a digital-first approach is embraced.

Recent successes have exposed considerations that would enable more widespread use.

Multi-Fidelity Modeling Paradigms

The Multi-Fidelity Modeling Landscape



Conceptual Design

"Lower-Fidelity"

Preliminary Design

"Medium/Higher-Fidelity"

- Rapid turnaround needed early on.
- Managing fidelity throughout programs is key.
- Multi-fidelity data fusion especially promising.

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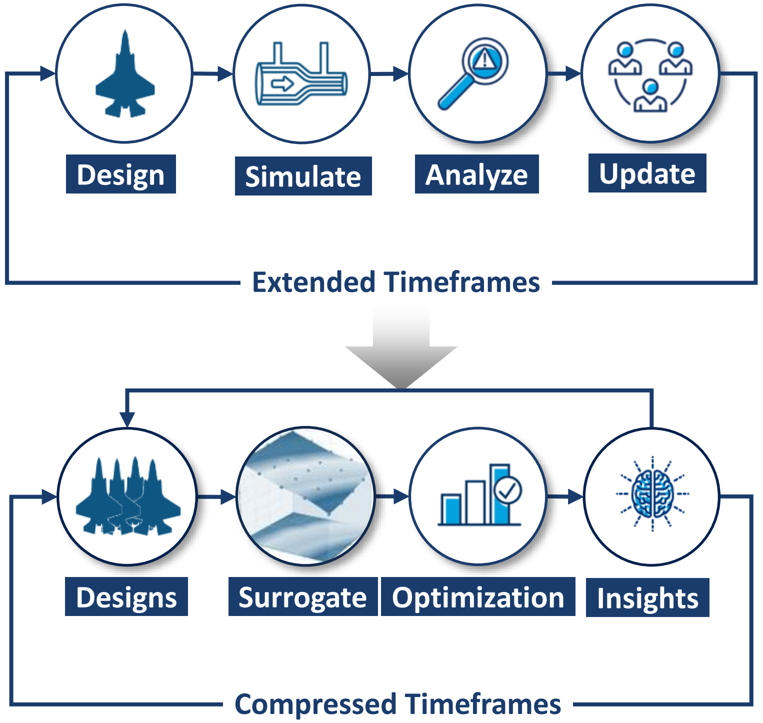
[1] Miranda *et al*. (1977) (here); [2] Holst (2000) (here); [3] Drela (1990) (here).

Fluid dynamics offers a range of fidelity levels, making it ideal for multi-fidelity strategies.

Paradigm #1: Design Cycle Acceleration

Overview:

- Surrogates embedded in design loops; from serial[1] to parametric studies with real-world constraints.



Design
Simulate
Analyze
Update
Extended Timeframes

Designs
Surrogate
Optimization
Insights
Compressed Timeframes

Legacy:

- Highly serialized, human capital-intensive workflows.
- Design configuration updates incremental, in isolated steps.
- Data handoffs to adjacent disciplines.

Today:

- Multi-fidelity surrogate models embedded in design workflows.
- Uncertainty-aware, with real-world constraints.
- Combined within a multi-disciplinary optimization framework.

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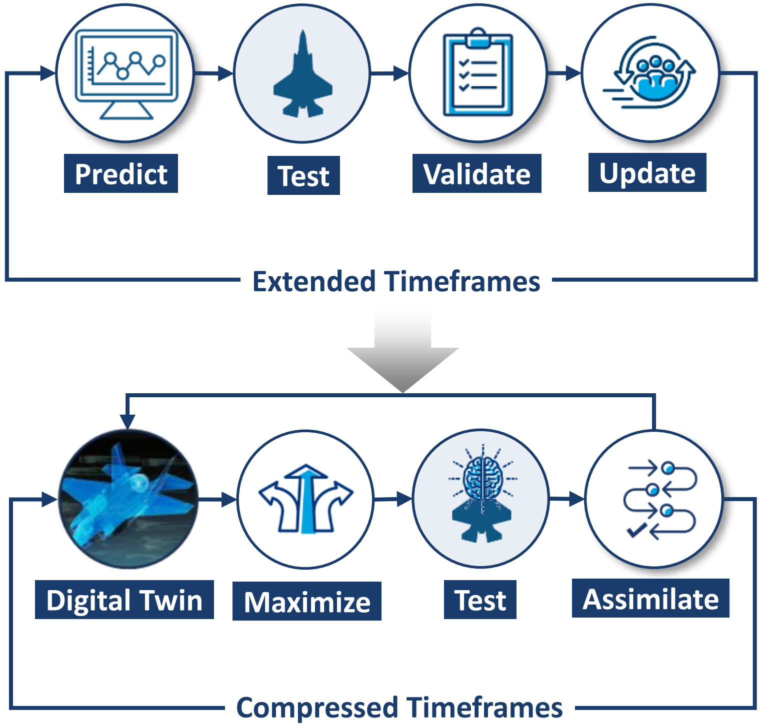
[1] Wooden & Azevedo (2006) (here).

Accelerated design cycles via multi-fidelity, multi-physics surrogate model frameworks.

Paradigm #2: Test & Evaluation

Overview:

- Decouple test duration from system complexity via multi-physics models + AI enablers.[1]



Legacy:

- Heuristically-driven high-fidelity model validation.
- Incremental, often years long test campaigns.
- Time-frame typically grows with system complexity.

Today:

- Multi-physics, data assimilating models (digital twins).
- Models inferred to help guide the test campaign.
- Assimilate test data back into the physics model.

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[1] Examples include DARPA CyPhER Forge (here).

Accelerated test of physical systems via digital twins and AI enablers.

Some Industry Needs/Opportunities

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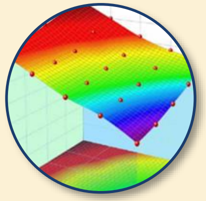
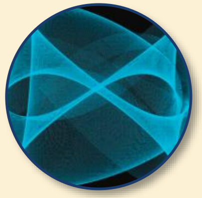


Computation/Data:

- Large number of runs typically required for training; and off-design accuracy can be poor.
- Adaptive sampling and inductive biases (physics-constraints) to improve performance.



Architecture/Maturity:

- Rapidly-evolving methods (GNNs, FNOs, transformer); performance not always clear.
- More systematic approach(es) to select models based on characteristics/requirements.

Tool Shift:

- Workflows often demand expertise; need for capabilities non-specialists can operate.
- End-to-end platforms promising that automate data exchange, unify tools, scale workflows.

Cultural:

- Challenges moving from deterministic to probabilistic thinking; variability valuable.
- Risk-informed decision-making that embraces uncertainty and the discomfort it brings.

Some Future Trends

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Traditional workflow:
Serial, human-intensive and defined by distinct steps.

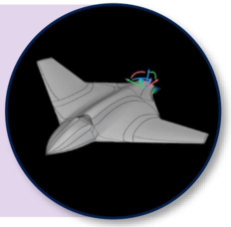
Pre-processing

Post-processing

Foundation-Scale Models:[1]
- Large-parameter surrogates trained on massive datasets.
- Diverse sampled geometries and conditions.

Agentic AI for Engineering Workflows:
- Integrated APIs orchestrating cleanup, meshing, runs.
- Auto case-management, visualization, and result archiving.

Computational Design Advancements:
- “Unbreakable” parametric models with high-dimensionality.
- Manufacturing constraints, requirements, and analyses built-in.



New workflow:
Interconnected, AI-driven enablers accelerating workflow.

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[1] Ashton *et al*. (2025) (here).

Multi-fidelity methods integrated with AI-driven enablers offer exciting opportunities.

Questions?