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Engineering Cyber-Physical Swarms with Collaborative Modelling

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Overview

- Search and Rescue
  - Terminology
  - Resources
  - Needs
- Collaborative Model-Based Systems Engineering
- Initial Drone Study
- Results and Conclusions
- Future Work

Terminology, Resources and Needs

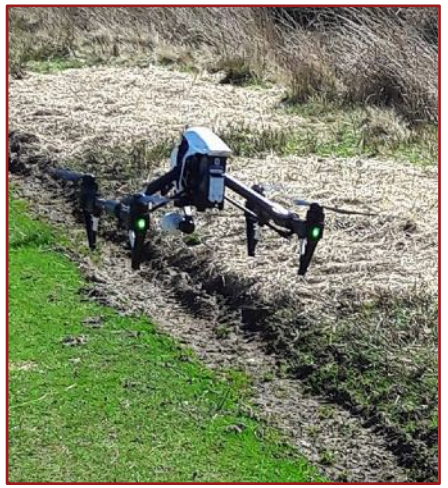
Search and Rescue

Search and Rescue

"The use of available resources to assist persons or property in potential or actual distress."

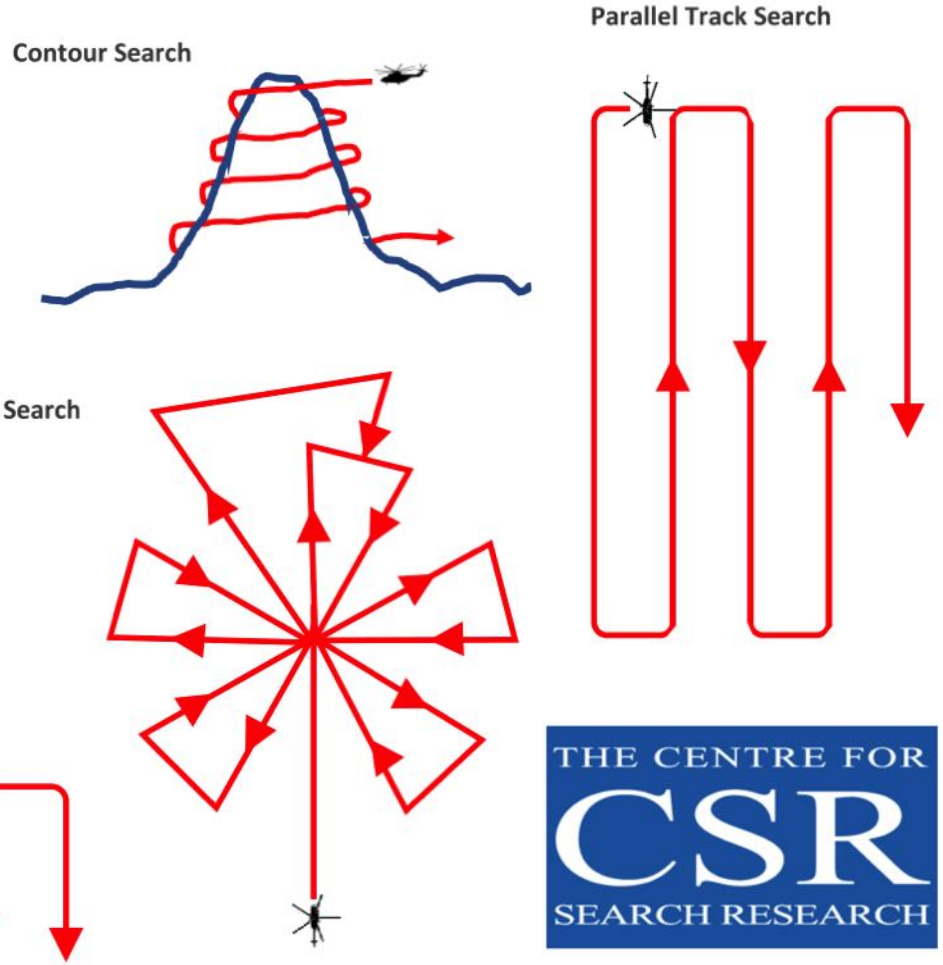
— United States Coast Guard






Search and Rescue Phases

- Initial Response Phase (IRP)
  - Travel aids
  - Locations
- Subsequent Phase
  - Purposeful wandering
  - Grid searching

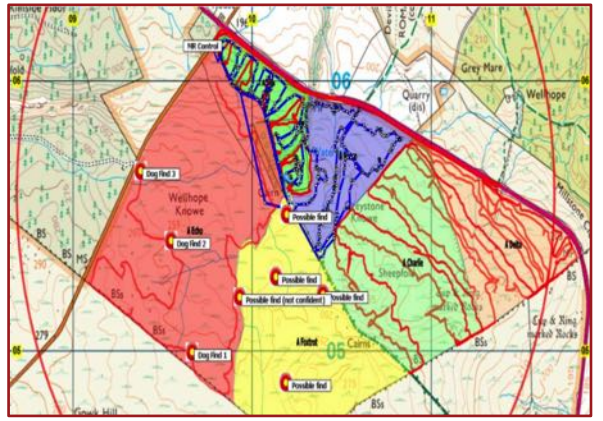


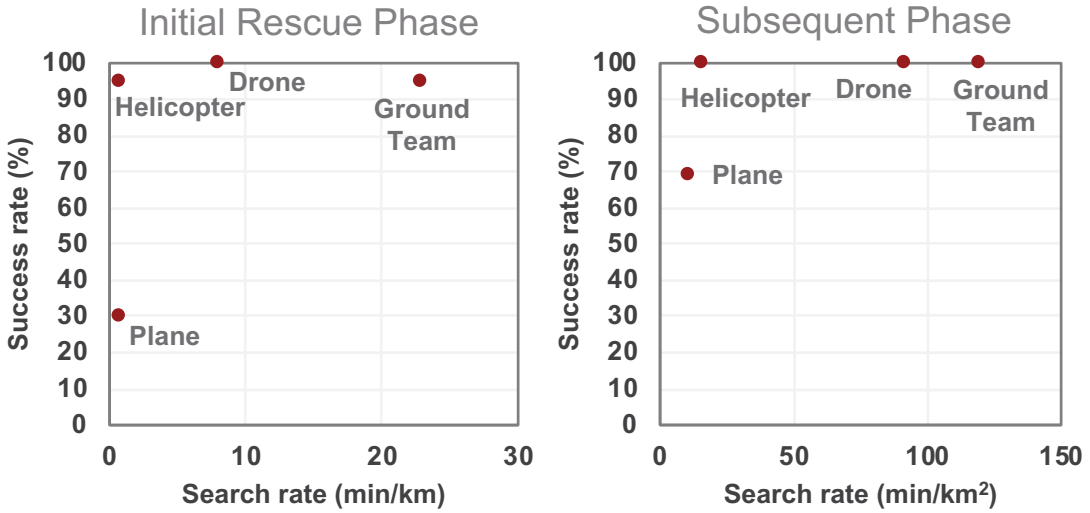
Hamilton et al., 2017.

Search and Rescue Resources

- Helicopters
- Airplanes
- Ground Search Team
  - Humans
  - Dogs
- Drones

Hamilton et al., 2017.





Current State of Civilian Search & Rescue

- **Collaboration** between multiple agencies
- Experienced teams of both employees and volunteers
- Increasing use of COTS drones in an **ad hoc** manner
  - Need for evidence, guidelines, and solutions
- Rare use of **expensive** field trials
  - UK 1987, 2008, 2017

Recommendations for Drone Research

- “Further field trials [required] to evaluate the utility of [drones] in a range of topographies & search **scenarios**”
- “Further work needed to [optimise] operational integration during a **multi-agency search** setting”
- “**Integrating** [drones] into search management thinking and planning needs further investigation.”
- “Investigate what effect [search patterns] have on search **effectiveness**”

Hamilton et al., 2017.

Working Assumptions

- Application of **collaborative model-based systems engineering** (MBSE) has demonstrated a reduction in the need for physical prototypes in cyber-physical systems design.
- Future search and rescue operations will be increasingly **cyber-physical** in nature, mixing humans, drones.
- Application of collaborative model-based systems engineering can therefore produce a viable and cost-effective **platform for virtual field trials** for civilian search and rescue.

Engineering Cyber-Physical Swarms

Collaborative Model-Based Systems Engineering

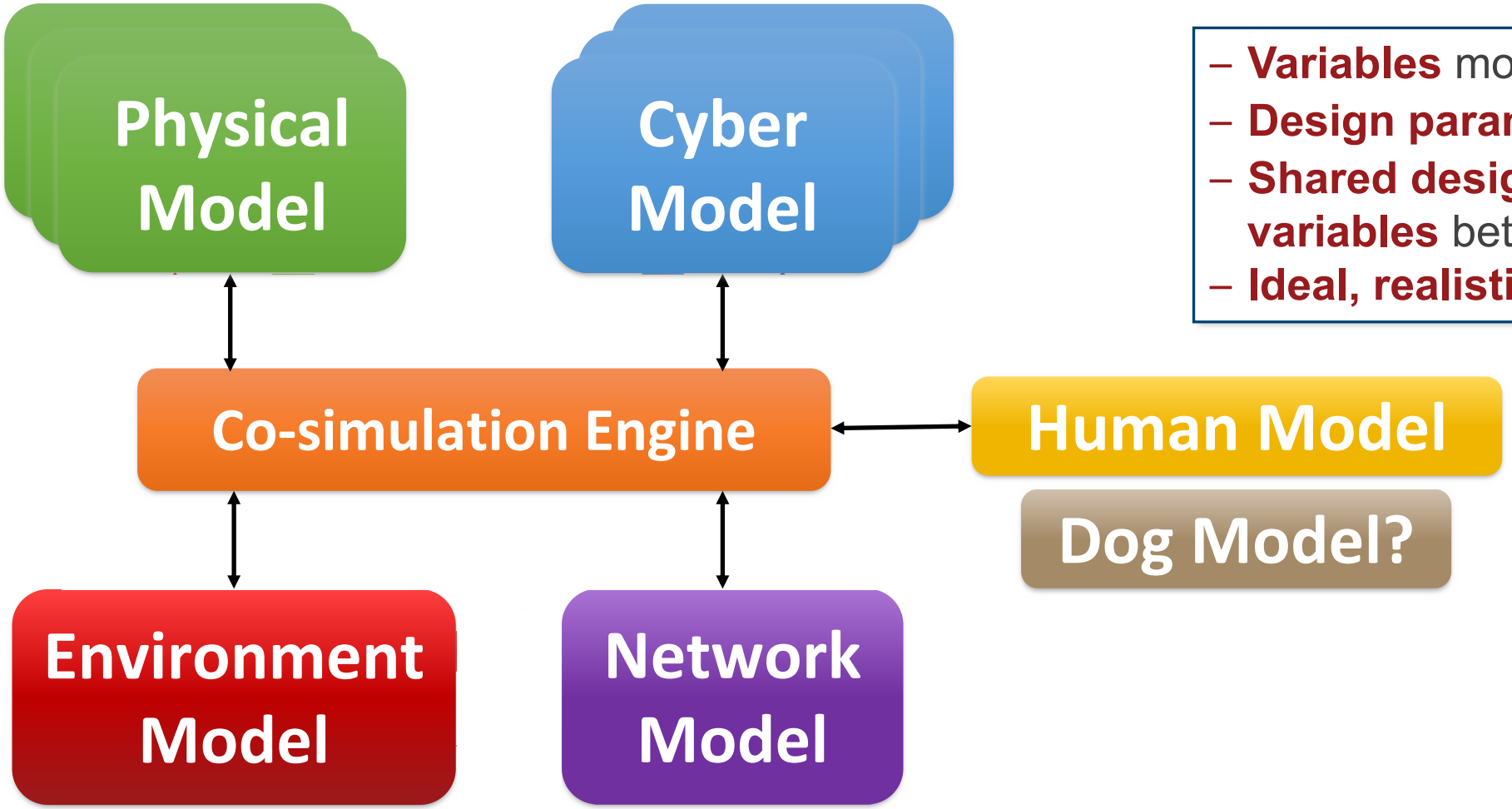
What is a Cyber-Physical System?

- Systems of interacting systems
  - Computing elements
  - Physical elements
  - Human interactions
- Complex, networked character
- Distributed control
- Error detection and recovery

Collaborative MBSE

- Model-based engineering established in key disciplines
- Disciplines are often **siloed**
- Systems engineering **requires collaboration** across disciplines and concurrent engineering
- Enable **collaborative MBSE** by connecting domain models into holistic **multi-models**
- Analysis through **co-simulation** and other techniques

Cyber-Physical Multi-Models



- **Variables** modified during run
- **Design parameters** fixed per run
- **Shared design parameters** and **variables** between models
- **Ideal, realistic, faulty** behaviours

Functional Mock-up Interface (FMI)

- Tool independent standard for co-simulation
- Models packaged as **Functional Mock-up Units** (FMUs)
- FMUs can be black boxes to protect IP
- XML describes an FMU interface
  - Called a **model description**

FUNCTIONAL MOCK-UP INTERFACE

http://fmi-standard.org/

INTO-CPS and the Maestro Engine

- Integrated Tool Chain for Model-based Design of CPS
- Maestro – fully FMI 2.0 compliant co-simulation engine
- Tool chain supports
  - SysML architecture modelling
  - Design space / trade space exploration
  - Test automation and model checking
  - Hardware-in-the-loop (HiL) simulation
- INTO-CPS Association

INTO-CPS

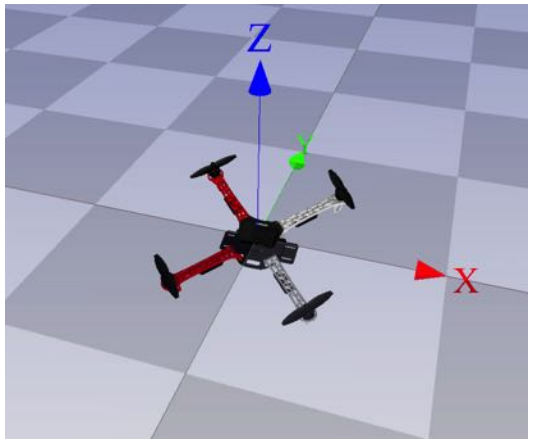
http://into-cps.org/

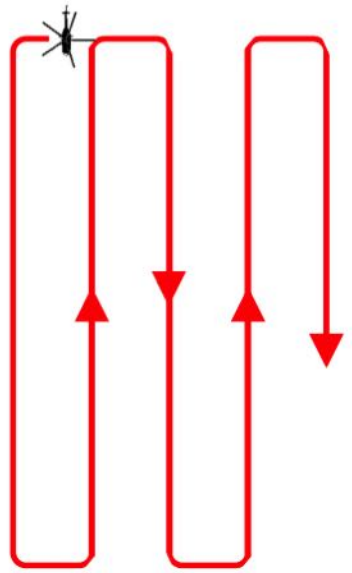
Drone Swarm Scenario for Grid Search

The Multi-Model

Scenario

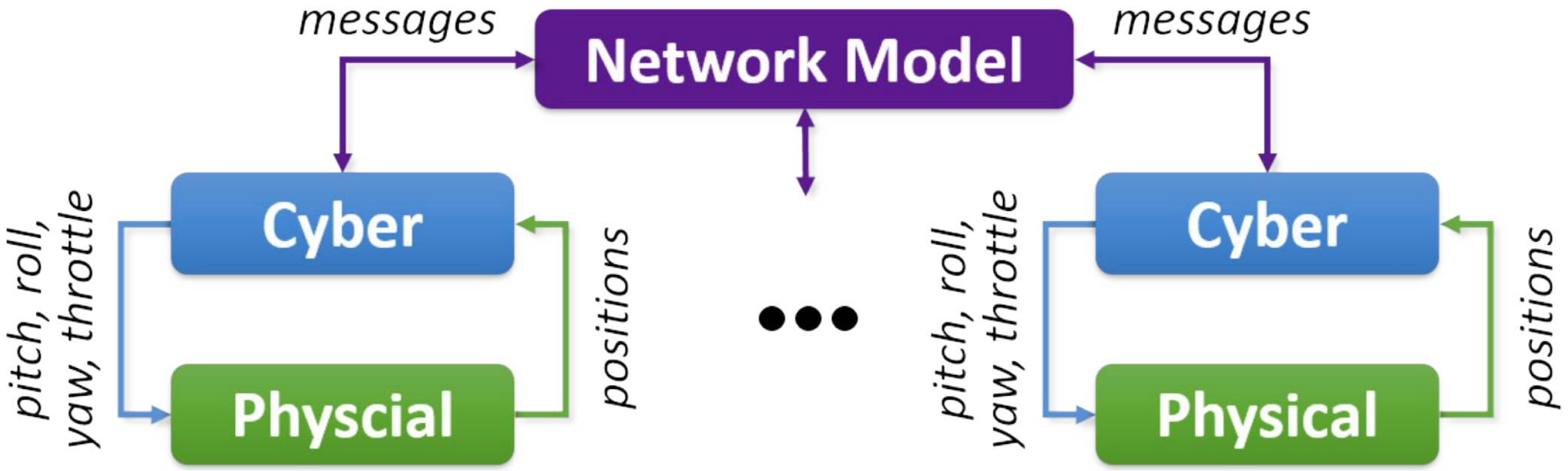
- Initial virtual field trial
  - Grid search using Parallel Track Search
  - Multiple drones
  - Coordinated searching
  - Return-to-base for refuelling
  - Resilience to failed drones
- Drone
  - Quadcopter
  - Dual camera (infrared and visual)





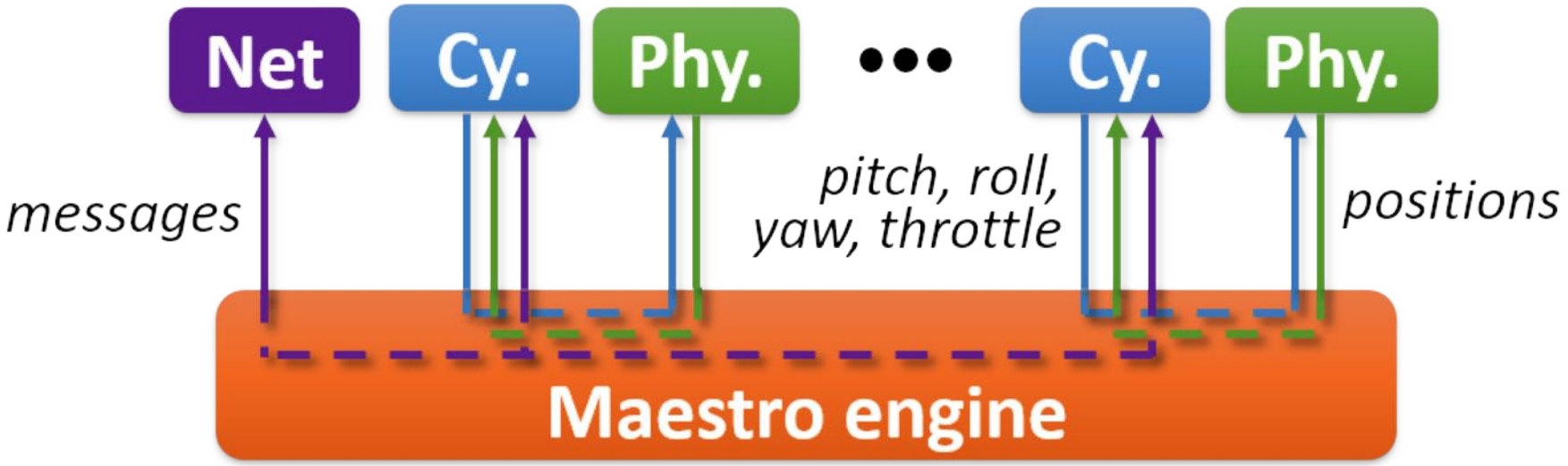
Multi-model (Logical View)

- Cyber-physical pairs representing each drone
- Cyber models connect via network model



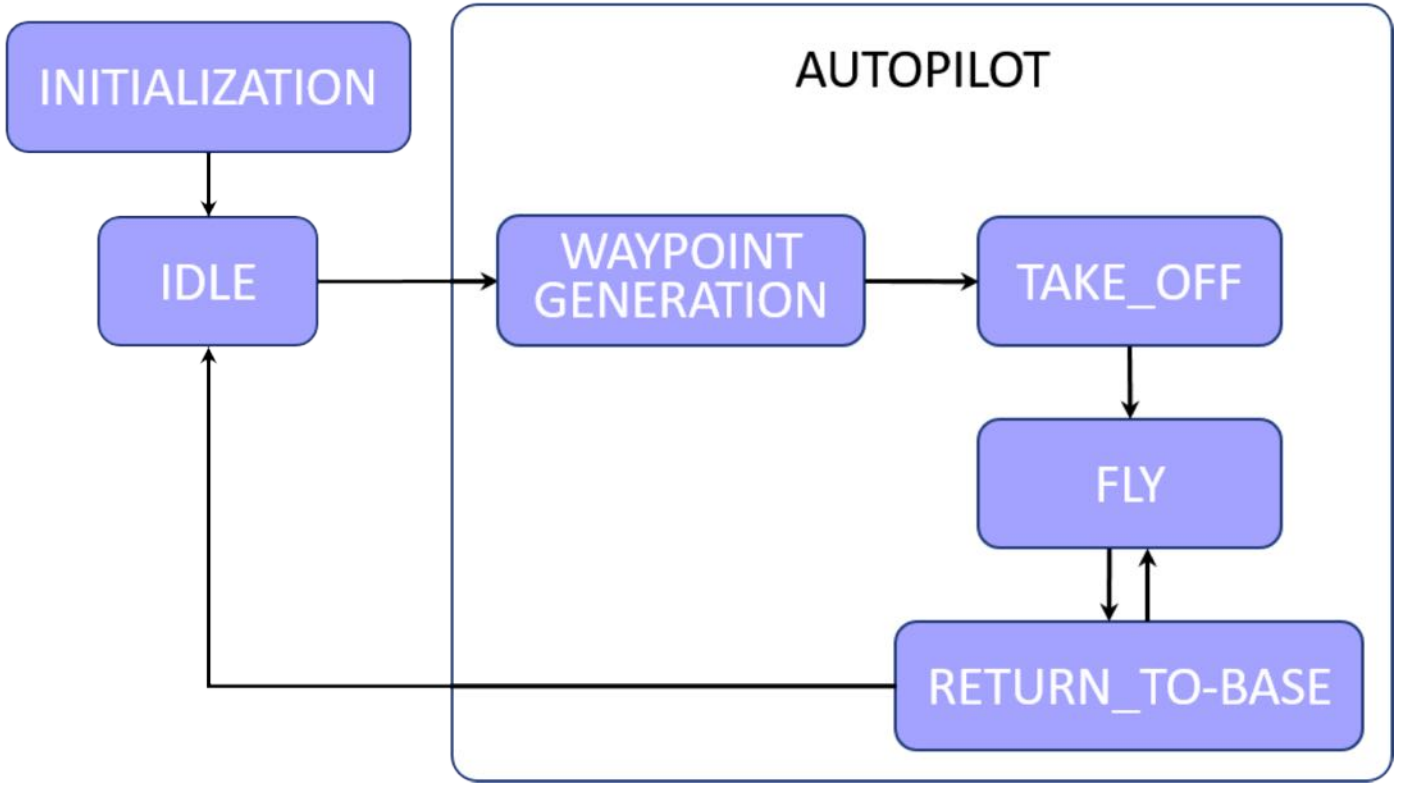
Multi-model (FMI View)

- Cyber, physical and network FMUs
- Connected through Maestro engine



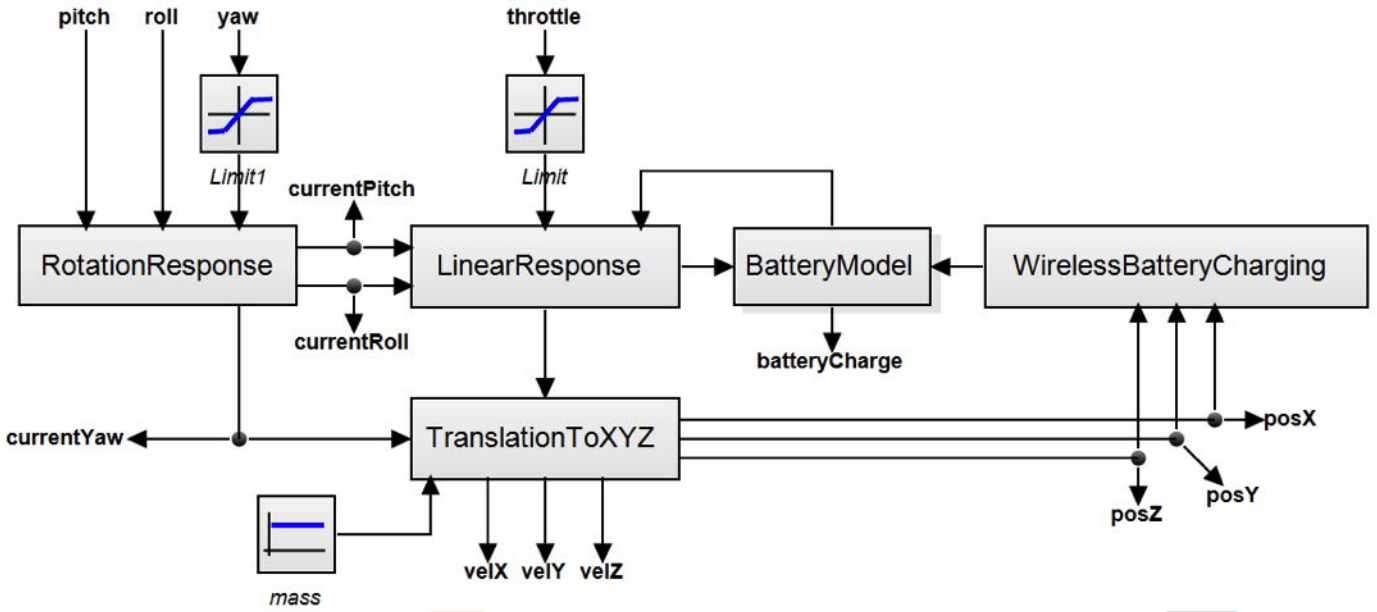
Controller Model

- Modal control
- Flight control
  - Pitch
  - Roll
  - Yaw
  - Throttle
- Messaging
  - Send / receive position
  - Leader election



Physical Model

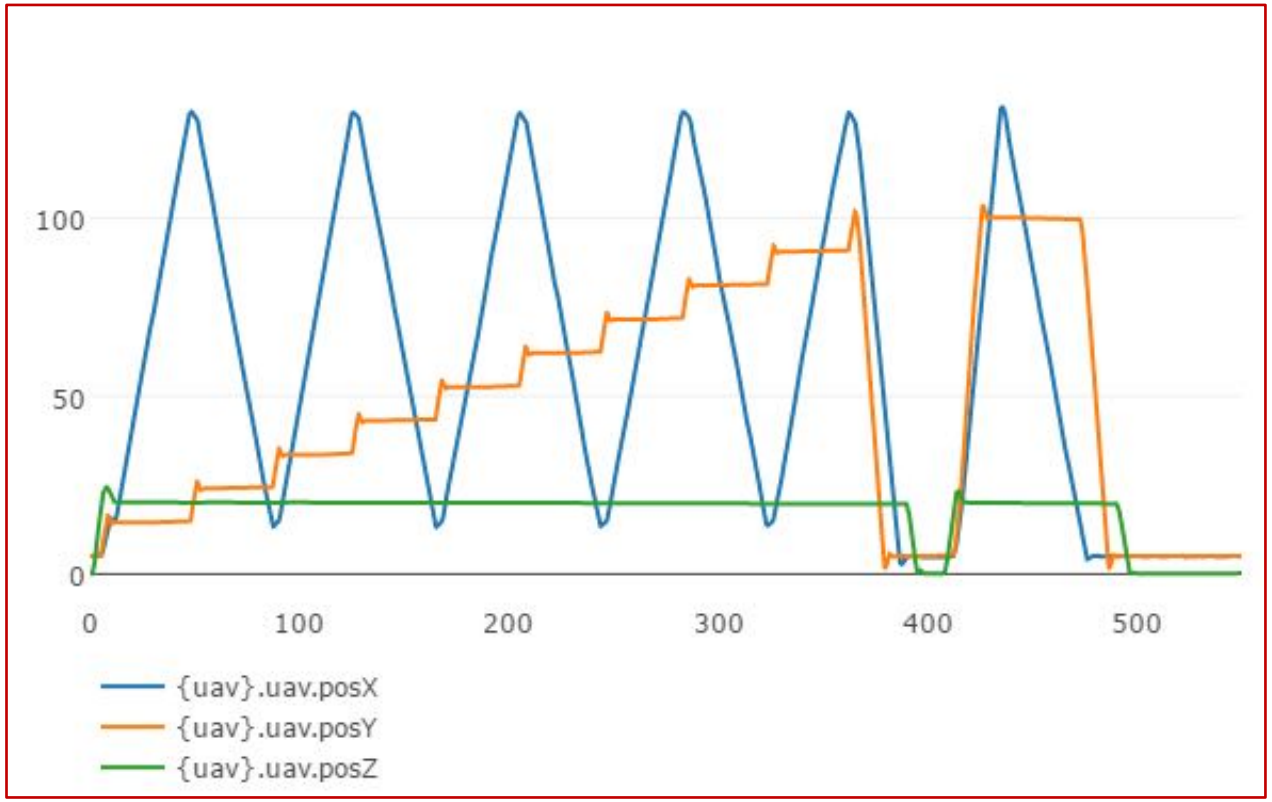
- High-fidelity physics model using differential equations
- Position and flight dynamics
- Energy use and battery level



Results and Future Work

Co-simulation Outputs

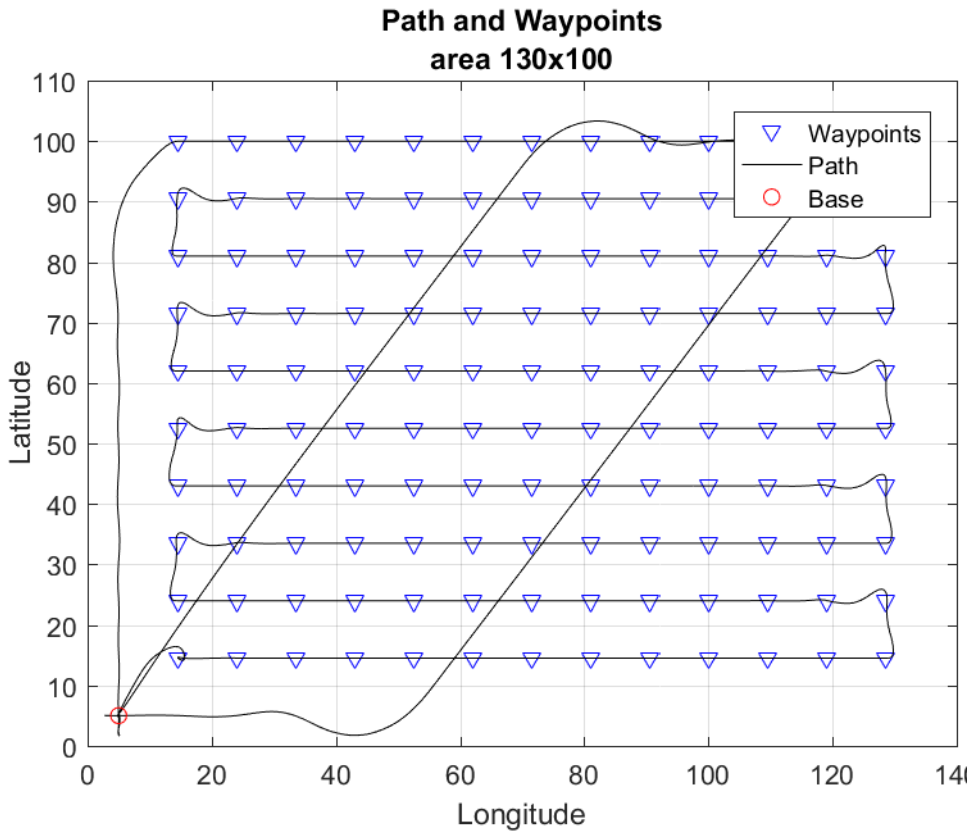
- Numerical data from Maestro engine
  - Live plotting
  - Post-processing from CSV

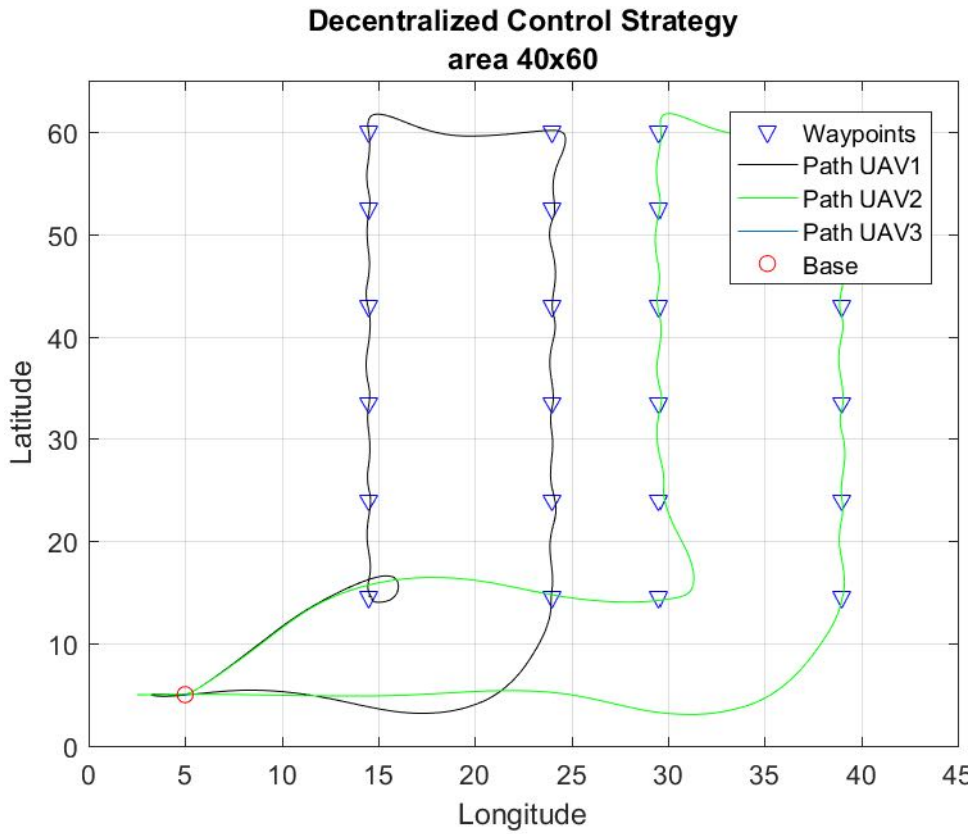


Co-simulation Outputs

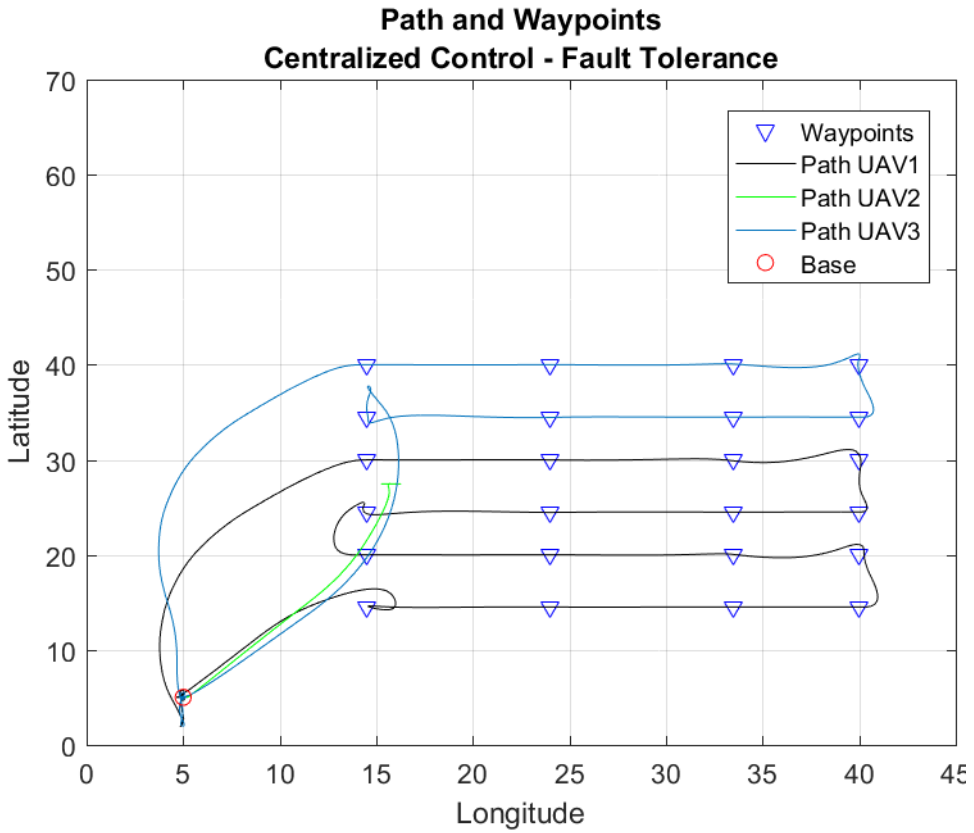
- Live visualisation through 3D engine

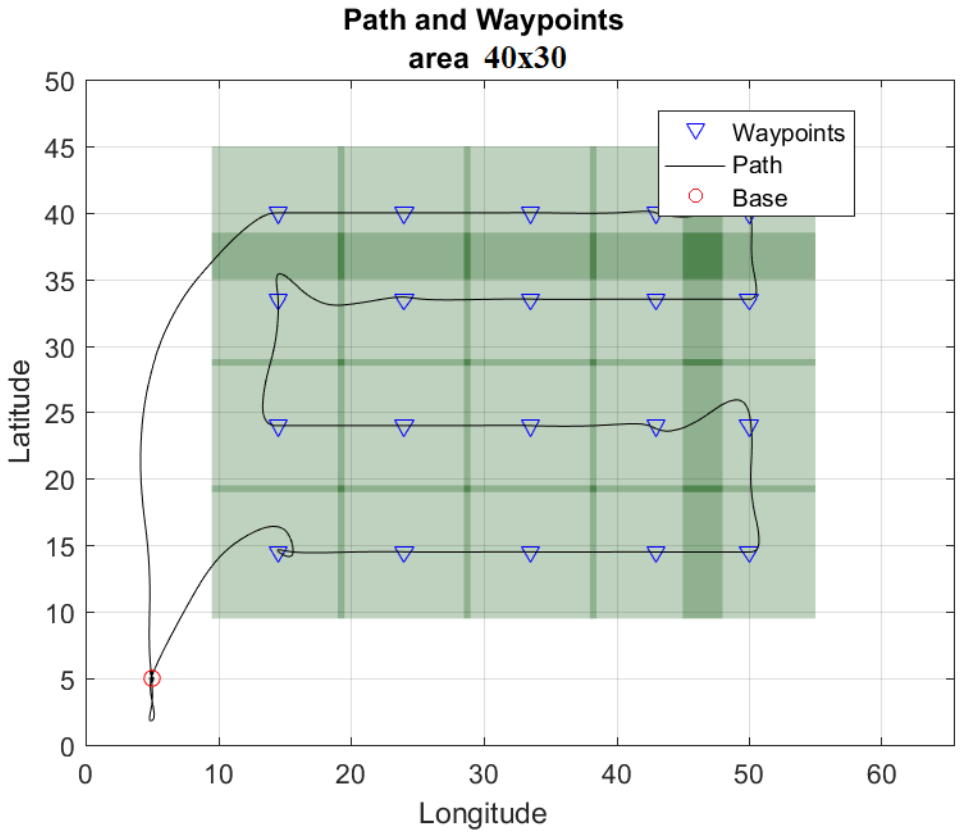
Visualisation of Search (1)





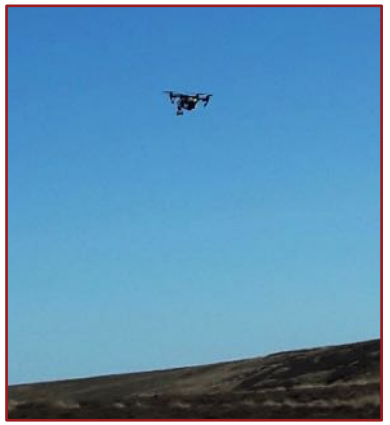
Visualisation of Search (2)





Summary

- Applied collaborative MBSE to design initial virtual field trial of multi-drone swarm search
- Developed concurrently by four different engineers
- Positive feedback from Centre for Search Research


Conclusions

- Application of collaborative MBSE produced a viable platform for **virtual field trial** in a limited study.
- Simulations aid **communication** with non-experts.
- Multi-modelling permits **concurrent engineering** by domain experts and flexibility, extensibility.

Future Work

- Improved models
  - Add environment / terrain models
  - Add human / dog team models
  - Improve network model
- Trade-space analysis / design space exploration
  - Search patterns, make-up of search teams, etc.
- Further scenarios, guidelines
- Multi-agency search, SoS aspects

References

- Carl Hamilton, Dave Perkins, Pete Roberts, and Steve Hughes, *Exercise Northumberland Research Report*, Centre for Search Research, 2017.

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