3rd URBAN AIR MOBILITY SYMPOSIUM

5 July 2023

DLR Cochstedt, Germany

Agenda

Time	Agenda Item
09:30 – 10:30	Welcome and Opening Speeches
10:30 – 10:45	Coffee Break
10:45 – 12:00	HorizonUAM Project Highlights
12:00 – 12:15	Shuttle to Demonstration Site
12:15 – 13:00	Flight Demonstration
13:00 – 13:15	Shuttle to Hangar
13:15 – 15:00	Lunch Break and Poster Session
15:00 – 15:45	Panel Discussion
15:45 – 16:00	Summary and Farewell

Prof. Dr. Dirk Kügler

Director

Institute of Flight Guidance

German Aerospace Center e.V. (DLR)

-HorizonUAM-

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Cochstedt, Germany

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–HorizonUAM–

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PROJECT OVERVIEW

Dr. Bianca I. Schuchardt

Defining Urban Air Mobility

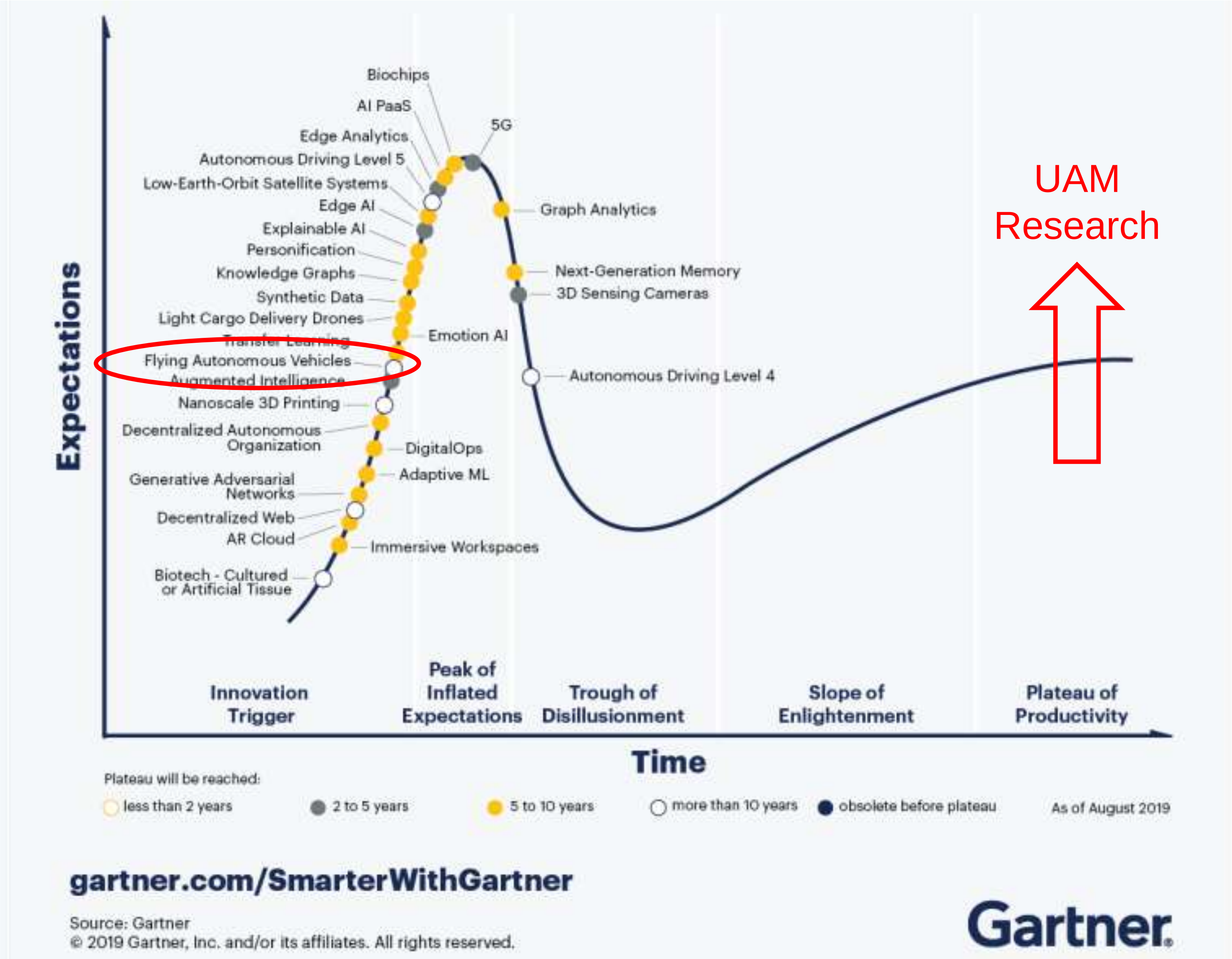
> Mark my word: A combination airplane and motorcar is coming. You may smile, but it will come.
>
> Henry Ford, 1940

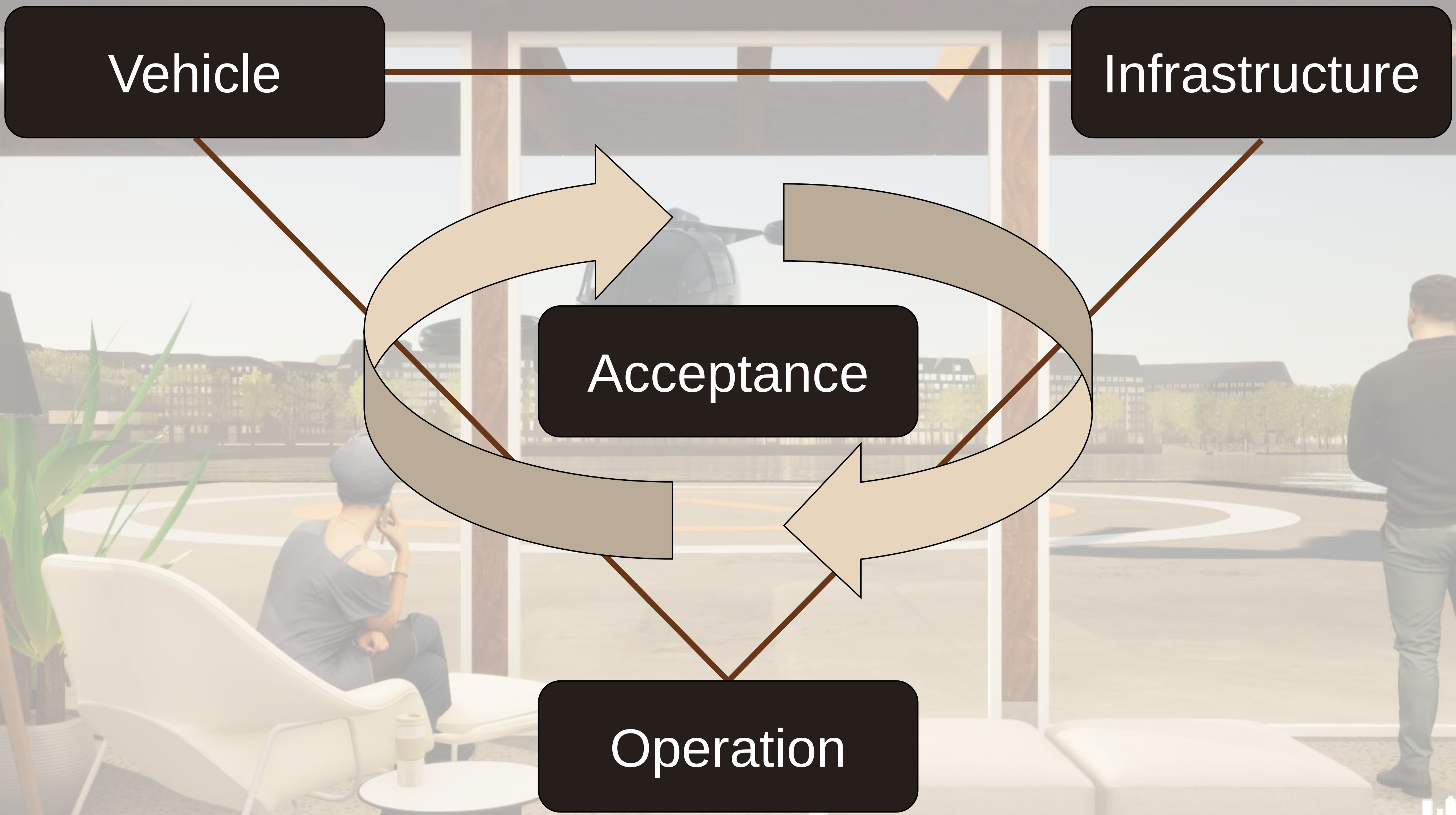
UAM is a new safe, secure and more sustainable air transportation system for passengers and cargo in urban environments, enabled by new technologies and integrated into multimodal transportation systems. The transportation is performed by electric aircraft taking off and landing vertically, remotely piloted or with a pilot on board.

Commercial operations in EU cities are expected to start around 2025 with delivery of goods by drones or transport of passengers by piloted aircraft.

EASA, 2021

Hype Cycle for Emerging Technologies




Vehicle
Infrastructure
Acceptance
Operation

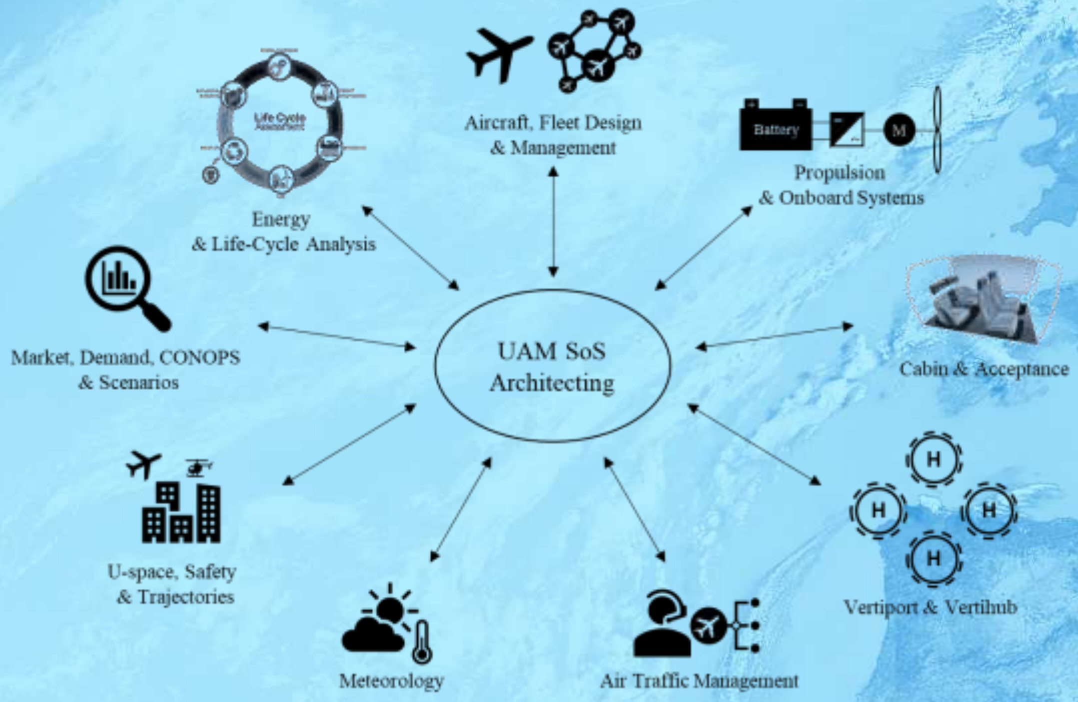
Urban Air Mobility Research at the German Aerospace Center (DLR)

Objective:
Assessment of opportunities and challenges of air taxis and urban air mobility (UAM) concepts

Main content

- Forecast of UAM market share
- Model-based UAM system simulation
- Air taxi vehicle system development
- Flight guidance concepts for vertidromes
- Airport integration of UAM traffic
- Public acceptance
- Scaled flight demonstrations in model city

- Duration: 07/2020 – 08/2023 (38 months)
- Scope: 52.1 person-years (9.1 M€)
- Participants: 10 DLR institutes, cooperation partners NASA and Bauhaus Luftfahrt

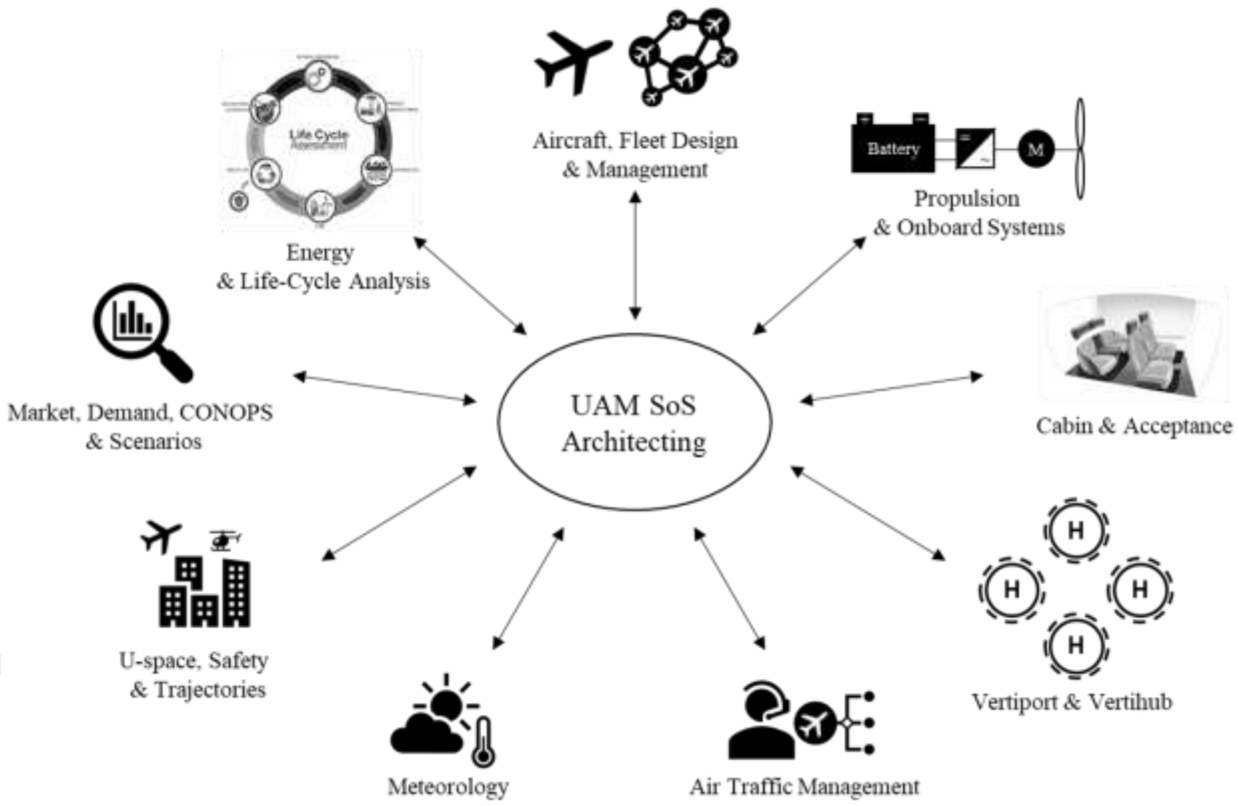


OVERALL SYSTEM SIMULATION

Henry Pak

Urban Air Mobility from a system perspective

- Complex system of systems
  - System behavior results from the interaction of system components.
  - Changing one component of the system may affect other components and the behavior of the system as a whole.
- Objectives and key questions
  - Understanding of complex interactions between UAM system components and impact on system behavior
  - Investigating of the relationship between the UAM system and demand
  - Impact on users, operators, and the environment



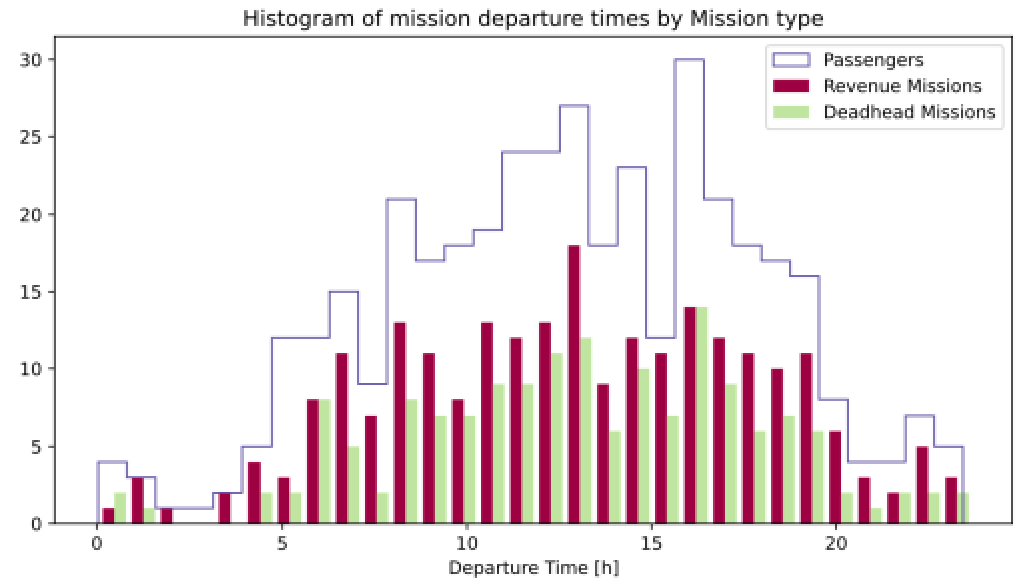
System-of-Systems simulation: Optimizing the UAM system

- System-of-Systems simulation integrates models from different domains.
- Agent-based simulation to capture complex interactions
  - Status and behavior of air taxis, vertidromes, airspace management and passengers are modeled individually.
- Simulation of 24-hour operations with high temporal resolution
- Evaluation of system behavior based on e.g. fulfilled transport requests, deadhead ratio, load factor.
- Applications:
  - Sensitivity analyses
  - Scenario analyses for different technology and demand scenarios

Domain models within System-of-Systems

- Demand
- Mode Choice
- Vertiport Airside Management
- Urban Airspace Management
- Cost and Revenues
- Vehicle Allocation
- Vehicle and Fleet Design

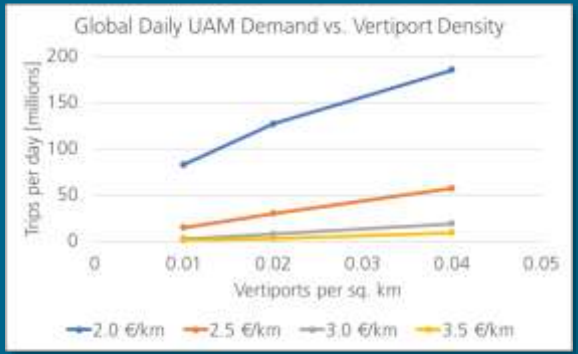
Result



Model-based forecasting approach to estimate global demand and fleet size

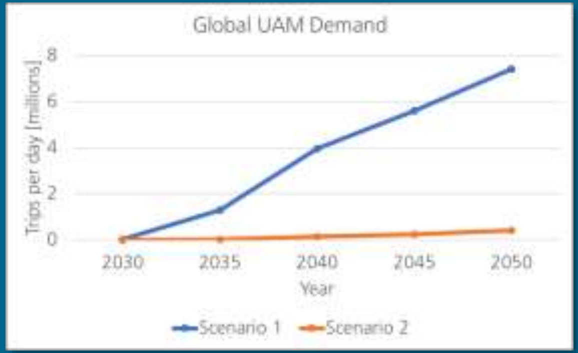
- Schematic urban transport model
  - Applied to 990 urban areas > 500,000 inhabitants
  - Input parameters: population, city area, gross domestic product (GDP)
- Modelling approach to estimate UAM demand
  - Cities are represented as circles
  - Total transport demand is specified by using a trip rate and a distribution of trips by distance
  - Two options: air taxi and car
- Scenario variables:
  - Air taxi price and speed
  - Vertiport density

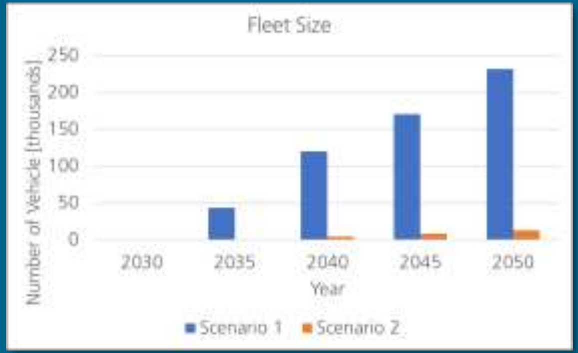
Sensitivity Analyses



Scenarios of Market Development

Scenario 1: *Up to 2 vertiports per 100*1 sq. km and ticket price of 3.00 € per km*
Scenario 2: *Up to 1 vertiport per 100*2 sq. km and ticket price of 3.75 € per km*





*1 *Equivalent to a density of 0.02 vertiports per sq. km*
*2 *Equivalent to a density of 0.01 vertiports per sq. km*

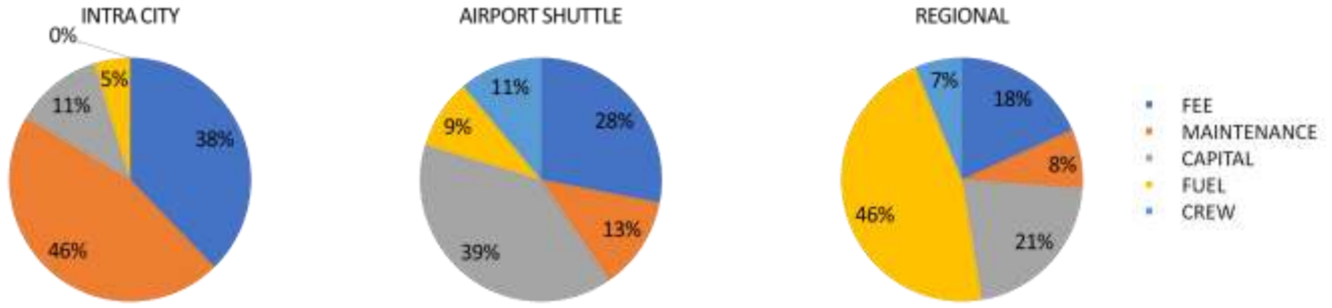
Towards economic viability of UAM: Estimation of operating cost and ticket fares

- Model of Direct Operation Cost (DOC)
  - Landing, terminal, air traffic service charges
  - Maintenance and overhaul
  - Capital cost and depreciation
  - Energy
  - Crew
  - Flight Cycles (FC)
- Parameters for DOC estimation based on
  - Literature
  - Existing prices of general aviation
  - Conclusions by analogy
- Determination of ticket fares by prescribing
  - Share of Indirect Operating Cost (IOC)
  - Profit margin
- Three representative applications
  - Intra city
  - Airport shuttle
  - Regional

Overview of cost and revenue estimation

Use Case	Intra City	Airport Shuttle	Regional
Vehicle name	Ehang 216	Archer Midnight	Lilium Jet
Vehicle seats (pax+pilot)[-]	2 (2+0)	6 (5+1)	8 (7+1)
Flight Distance [km]	12.13	15.11	186.35
DOC per FC [€]	62.07	231.30	700.83
Fare optimistic [€/km]	4.1	6.1	1.0
Fare conservative [€/km]	5.7	8.5	1.4

DOC distribution for each use case



Conclusions

- Low ticket prices and short access and egress to vertidromes are key to driving demand for UAM.
- Infrastructure, ATM, maintenance, and aircraft price account for a large proportion of operating costs and should be further investigated for their potential to reduce costs.
- Agent-based system-of-systems simulation has proven valuable in optimizing UAM systems.
- There could be market potential for UAM in more than 200 cities worldwide by 2050.

VEHICLE

Frank Meller

Overall Objectives

- Conceptual definition of **vehicles** for passenger transport in urban airspace
- Selection of certifiable **system** & **powertrain** architectures
- Development of safe, comfortable and acceptable **cabin** concepts
- First steps into **maintenance** & its planning of air taxis



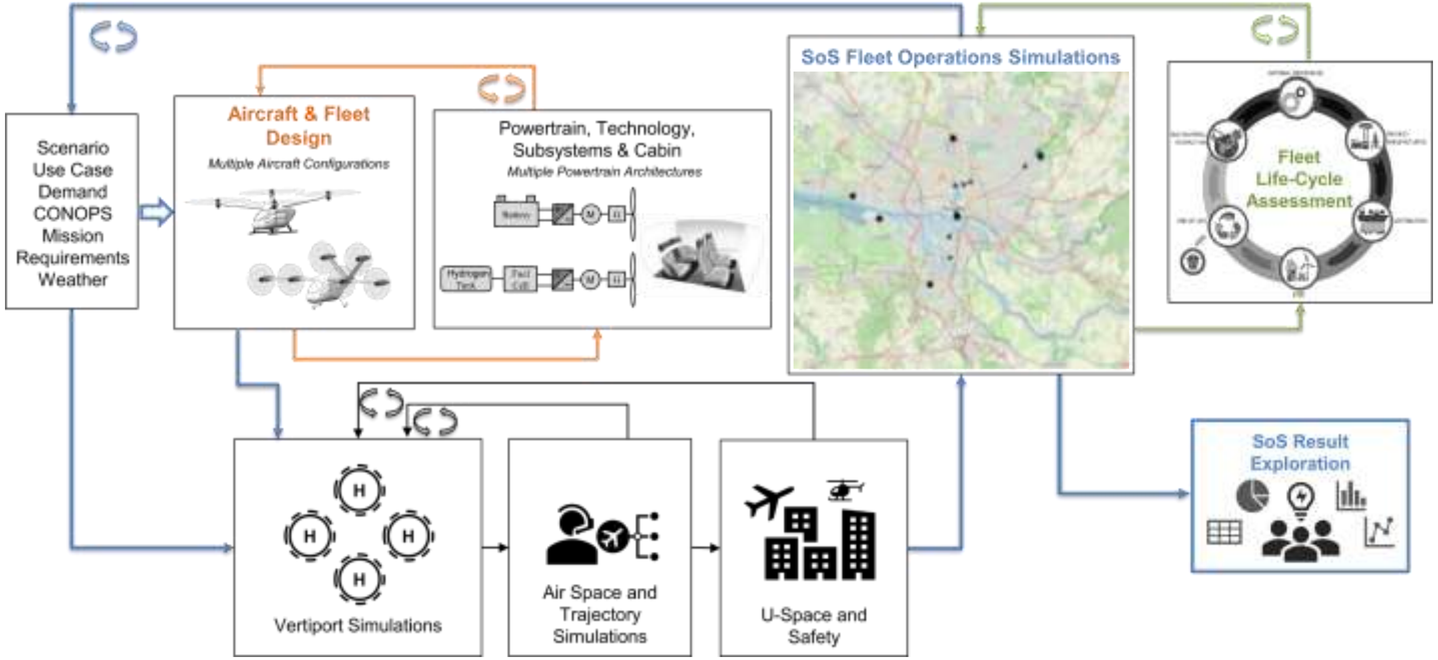




System-of-Systems (SoS) Simulation of Urban Air Mobility

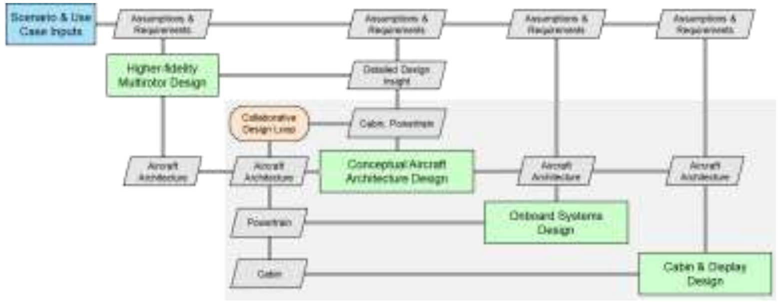
System-of-Systems Framework

Agent-based simulation developed for on-demand fleet impact assessment



Vehicle Design Workflow

Collaborative vehicle design workflow established & demonstrated



Results

Vehicle Design Space / Family Concepts

- Diverse Missions / Top Level Aircraft Requirements
- Entry-Into-Service Scenarios
- Technology Portfolios

Vehicle design concepts driven by fleet operations in an SoS context

Vehicle Concepts

Preliminary Vehicle Design & Propulsion Analysis

4 Main Rotors / 2 Pusher Prop.

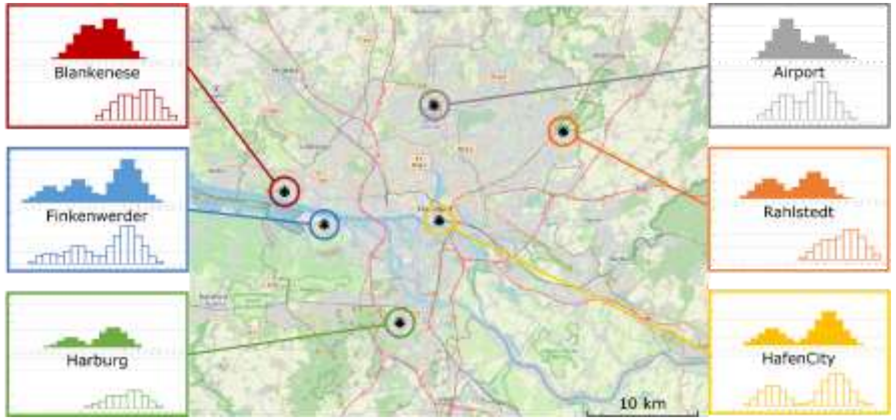
- flight-mechanical modeling
- aero-mech. rotor analysis & optimization using blade elements
- investigation of initial design limits

Quadrotor (Battery-electric)

Intra-city / Airport shuttle:
50 km; 120 km/h; 2 Stops

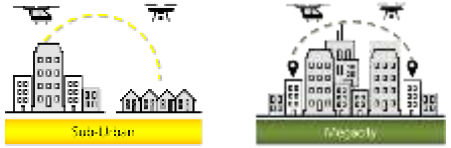
- Entry-Into-Service: 2030/2035
- MTOM: 1,543 kg
- Payload: 440 kg / 4 PAX

Conceptual Vehicle Design



Tiltrotor (Battery-electric)

Sub-urban / Megacity:
100 km; 200 km/h; 1 Stop

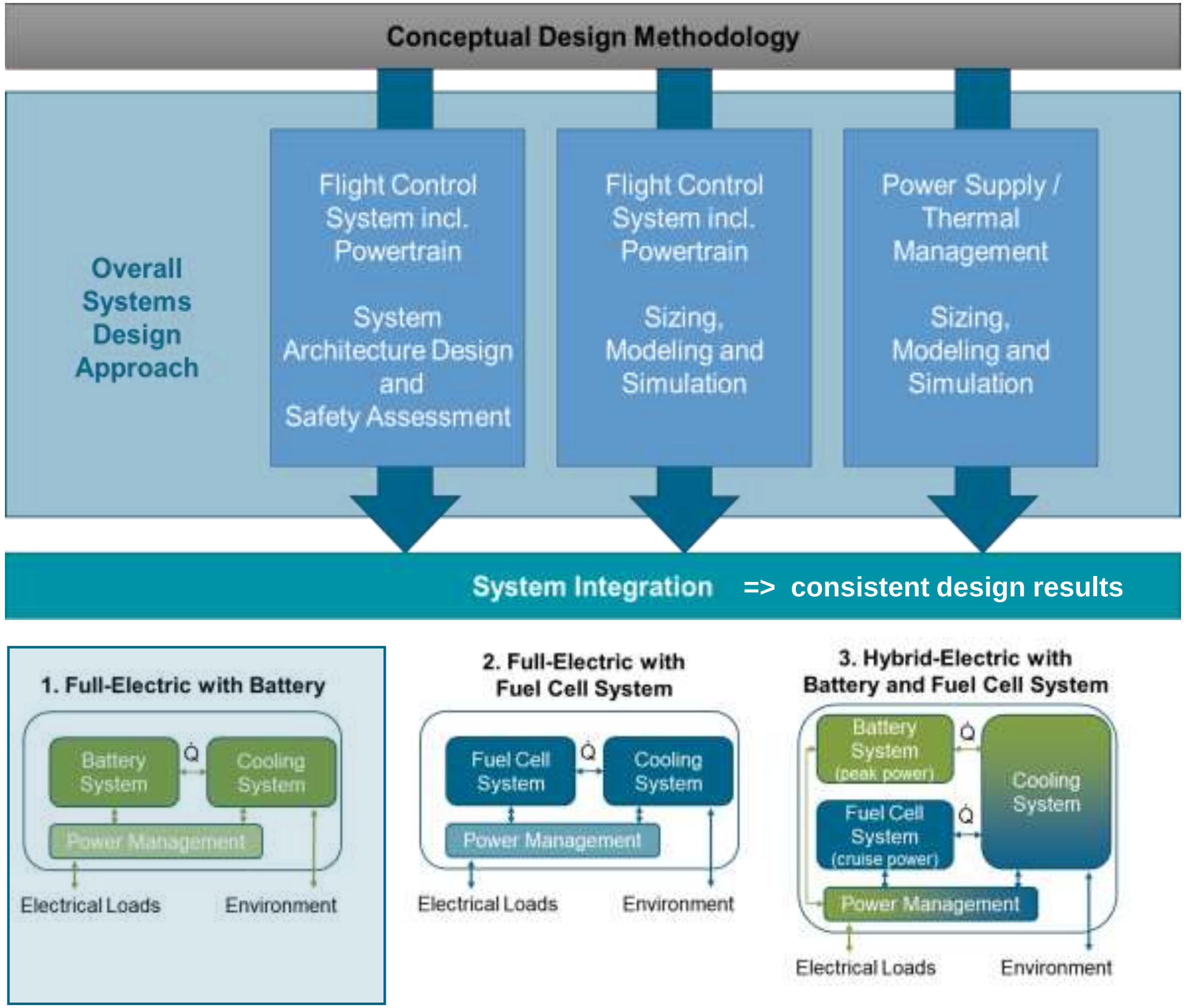


- Entry-Into-Service: 2030/2035
- MTOM: 2,065 kg
- Payload: 360 kg / 4 PAX

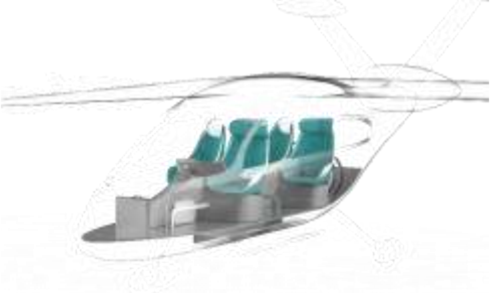
Conceptual Vehicle Design

Onboard Systems

- **Model Based Systems Engineering:**
  - **Conceptual Design Tool** developed for sizing, modeling and simulation of multirotor eVTOL **propulsion system, energy system & thermal management system**
- **Key Results**:
  - Conceptual design of a **safe, battery-electric propulsion system architecture**
  - **EASA safety & reliability goals** met & safety measures implemented
  - **Design requirements** derived for air taxi multirotor concept, e.g.:
    - **Dual** redundant electric **motors** per rotor with passivation capabilities
    - Additional **pusher propeller** to counteract any main rotor loss
    - Each drive train must be able to provide **200 % of normal power** in case of system malfunction
    - Five battery packs, at least three FCCs,…
    - **Cooling system** required for the electric motor, motor controller and battery packs
- **Maintenance Key Findings:**
  - **Component Degradation**
    - **Electric Motor:** Ageing and degradation of vehicles analyzed
    - **Batteries:** Li-Ion battery expected lifetime between 1000 – 8000 missions (2-6 years)
  - **Maintenance Scheduling**
    - Integration into aircraft assignment for on-demand operation

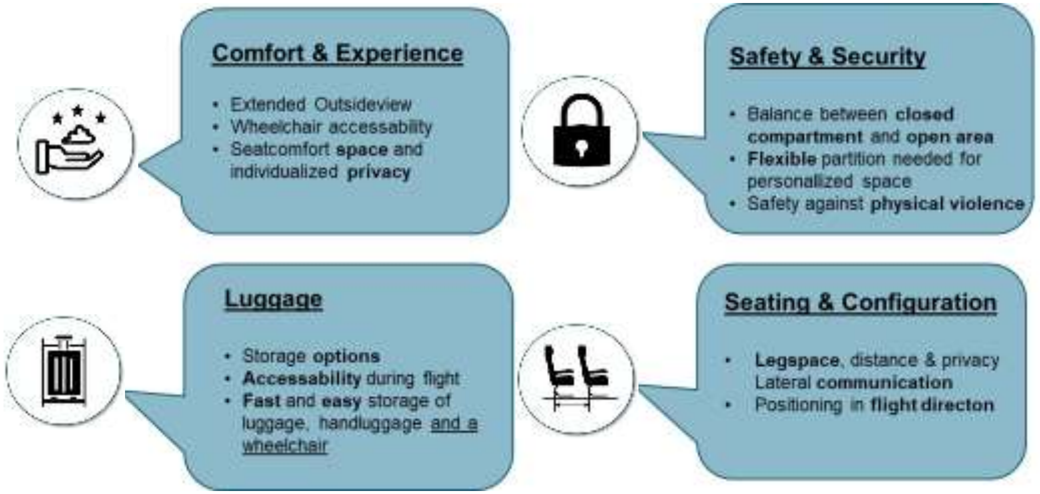


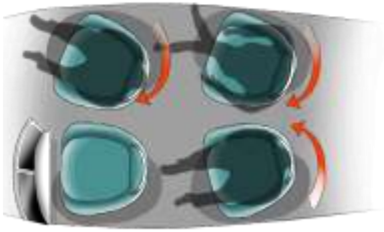
Cabin Design



- User-centric **Cabin Concept**
  - Based on feedback from user acceptance tests supported by Institute of Air- and Space Psychology
  - Cabin design and evaluation approach in cooperation with various DLR experts
  - Early involvement of user = enabler to raise the acceptance level
- **Air Taxi Cabin Simulator**
  - Cabin mock-up with virtual / mixed reality capability allows realistic passengers in-flight experience
  - Used for acceptance studies

- **Key Results**
  - Combination of **airport shuttle and intra-city** use case
  - **Comfort, safety and privacy** prioritized during focus group studies:
    16 participants, 4 sessions plus online survey with 202 user



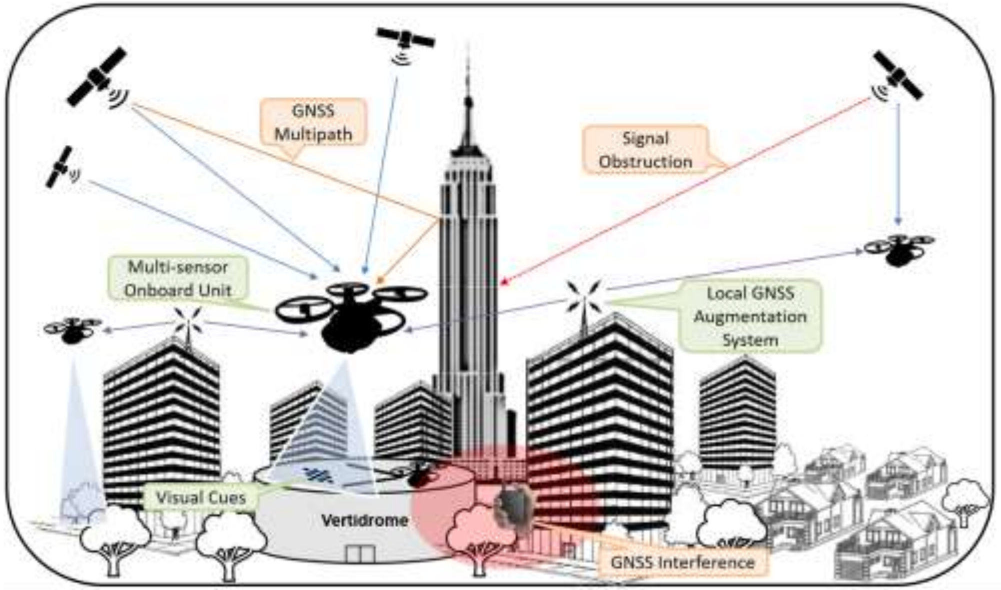


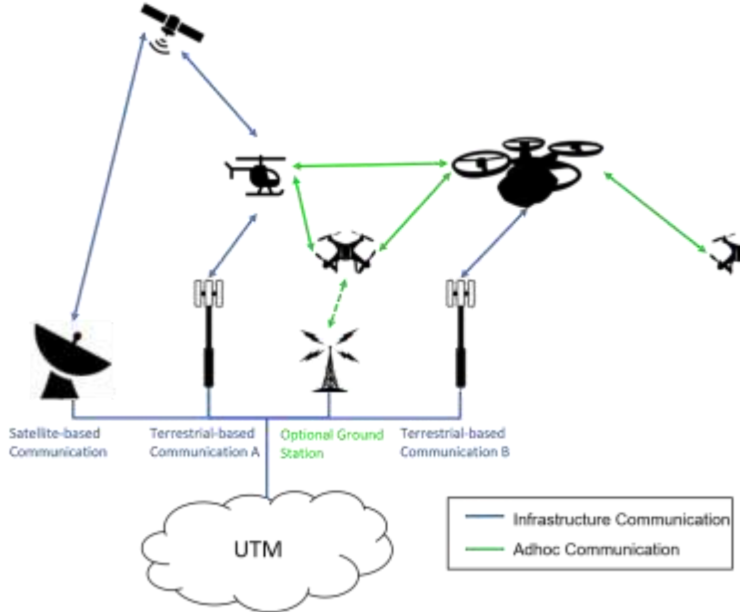
SAFETY AND SECURITY

Christoph Torens

Assess and Support the Safety and Security of UAM

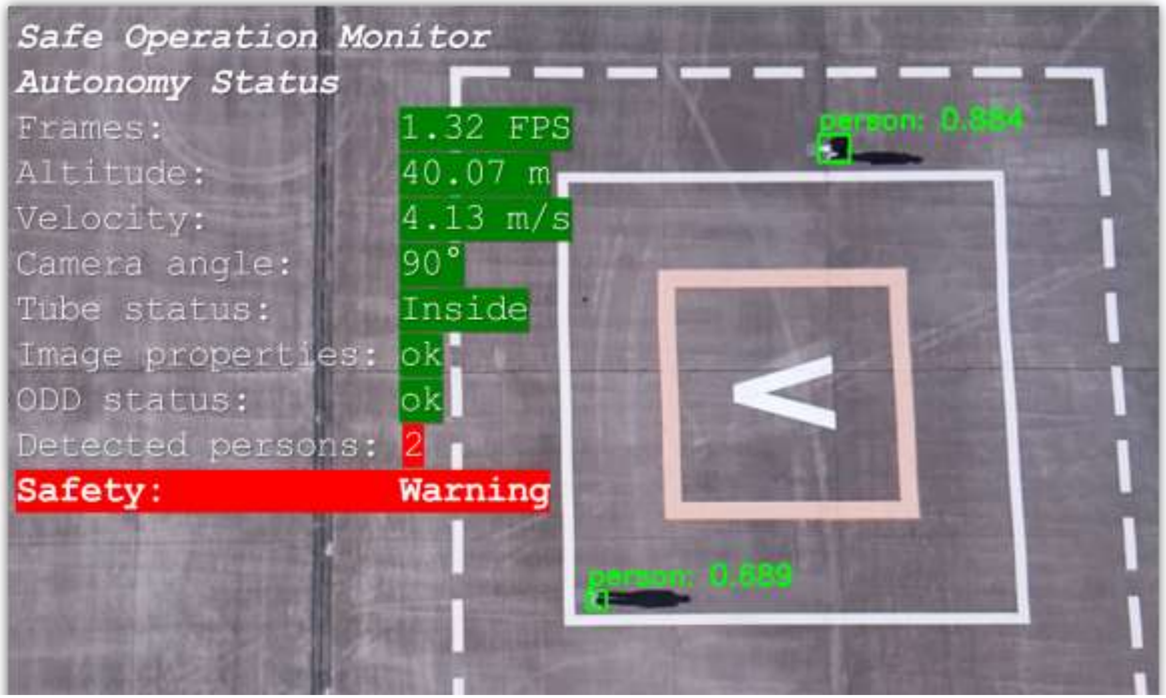
- **Save autonomy**
  - Huge demand for machine learning (ML) technology
  - Data driven approaches require new verification concepts
  - Standardization and certification gaps for ML
- **Reliable multi-sensor navigation**
  - High accuracy & high integrity demands
  - GNSS multipath / interference in urban areas
  - Standardization and certification gaps for multisensor navigation
- **Robust and efficient communication**
  - Design and development of drone-to-drone communication system
  - Enable multi-datalink approach
  - Enable collision avoidance in urban environments
- **U-space interface**
  - Completely new layer of services required for safe integration
- **Cyberphysical safety and security**
  - High threat potential for strongly connected and automated flights





Safe Autonomy
Safe Machine Learning (ML) for UAM

- Development of example ML use case: human detection
  - Securing of (emergency) landing sites
  - Reduce risk during flight
  - Delivery of relief supplies



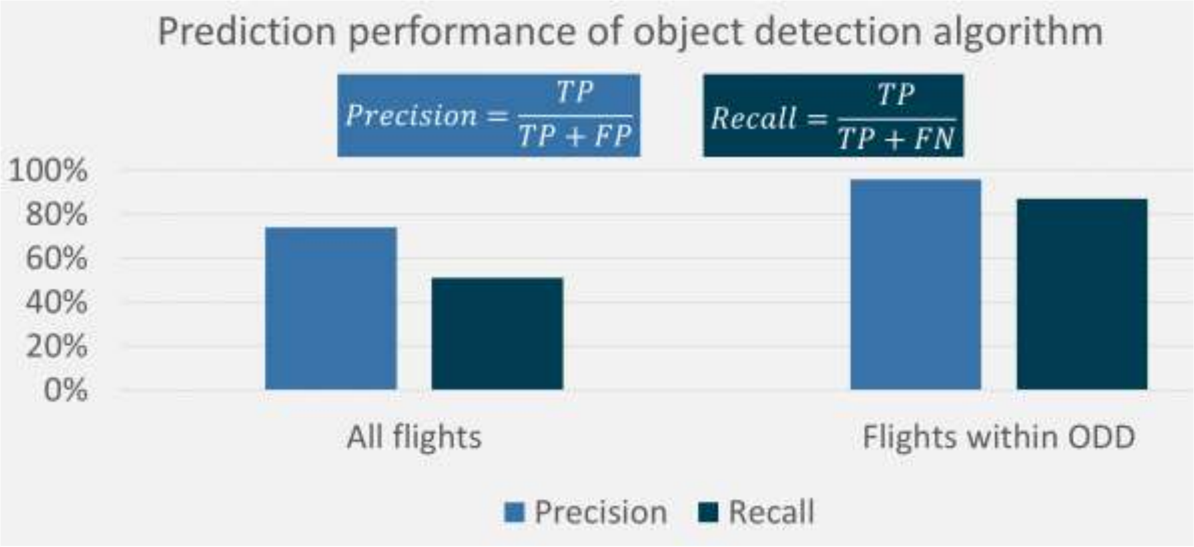
- Research on safety and certification aspects of ML
  - Define limitations on operating conditions
  - Supervision of operational design domain (ODD)
  - Impact on ML performance

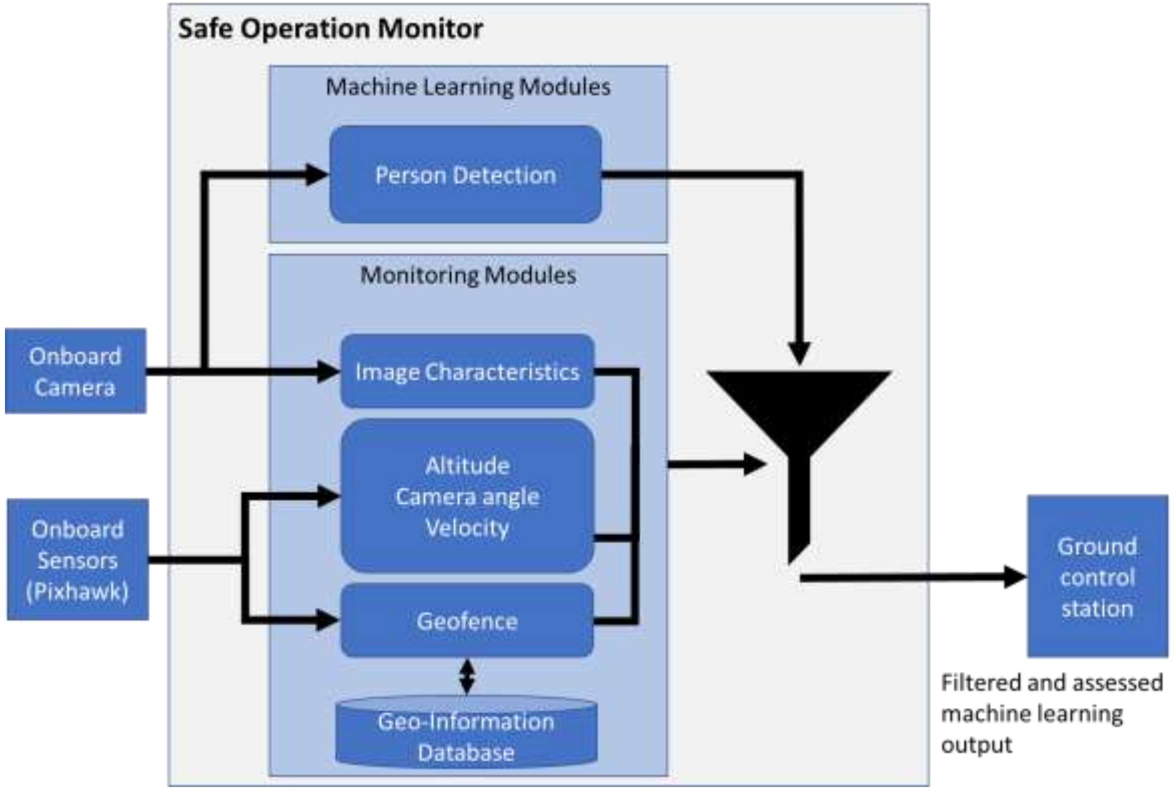
- Assess autonomy status
  - Integrate system and ODD status
  - Assess operational safety

Safe Autonomy
Certification Aspects of Machine Learning

- Development of Safe Operation Monitor
  - Improve reliability by monitoring system and operation
  - Focus on ODD aspects and new standards and guidance material from EASA

- The Safe Operation Monitor improves the
  - Robustness of the ML component
  - Safety of the overall system

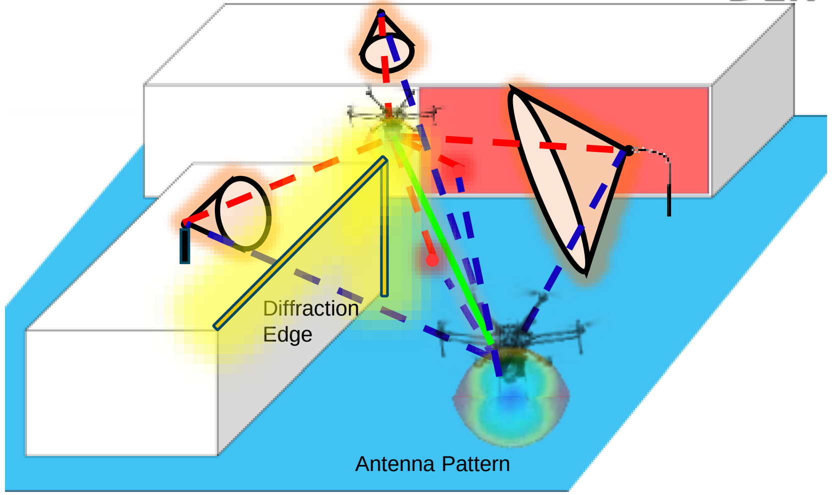


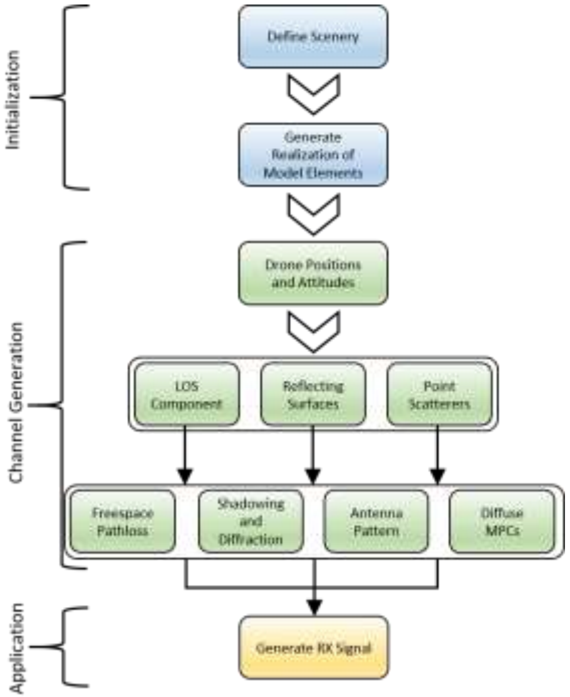


Robust and Efficient Communications
Development of DroneCAST

- Development of **DroneCAST** (Drone Communications and Surveillance Technology)
  - A drone-to-drone communications system for collision avoidance in urban airspace
  - Used as a last course of action, similar to ADS-B in civil airspace
  - Part of multi-datalink approach that considers dense urban and worst case critical scenarios with further applications

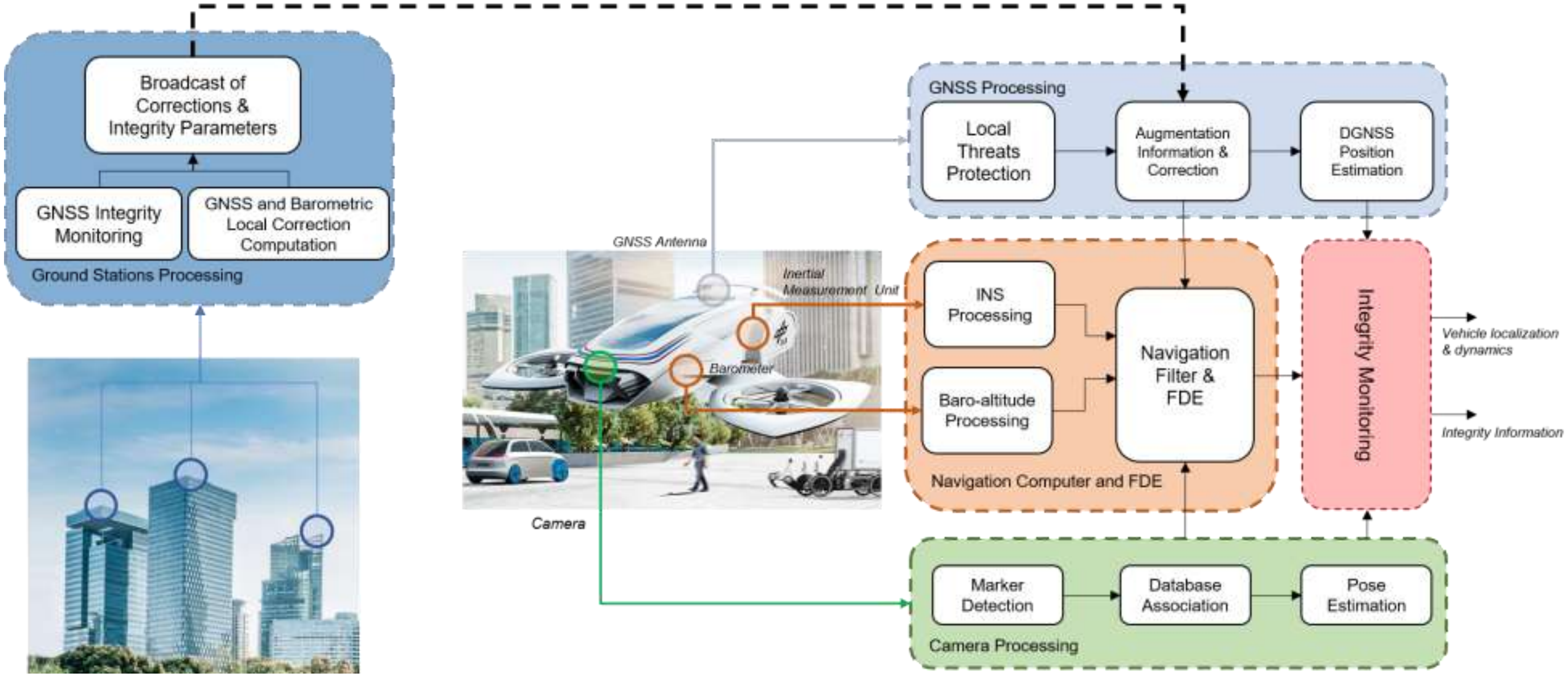
- Milestone: A **D2D channel model** for urban environments
  - Based on measurements in an urban environment at DLR campus Oberpfaffenhofen
  - Increases robustness of datalink by considering the underlying signal propagation effects
  - Helps to validate several research questions and different communication concepts
  - Communication channel for different urban scenarios can be simulated





Reliable Multi-sensor Navigation for UAM

- **Design of a reliable multi-sensor navigation system**
  - Airborne equipment (multi-sensor onboard unit)
  - Ground infrastructure (U-GBAS augmentation, visual cues, meteo-stations)
  - Innovative multi-sensor solution leading to integrity-monitoring architecture
  - Research on innovative integrity concepts for different sensors



VERTIDROME

Karolin Schweiger

VERTIPORT DESIGN

UAM NETWORK MANAGEMENT

MODELCITY

VERTIPORT INTEGRATION AT AIRPORTS

VERTIPORT DESIGN

VERTIPORT FOUNDATION

VERTIPORT SIMULATION

UAM NETWORK MANAGEMENT

MODELCITY

VERTIPORT INTEGRATION AT AIRPORTS

DLR

VERTIPORT DESIGN

UAM NETWORK MANAGEMENT

- AIRSPACE ROUTE STRUCTURE
- OPTIMIZATION OF UAM NETWORK RESSOURCES

MODELCITY

VERTIPORT INTEGRATION AT AIRPORTS


VERTIPORT DESIGN
UAM NETWORK MANAGEMENT
MODELCITY
VERTIPORT INTEGRATION AT AIRPORTS
VERTIPORT LOCATION
ATCO SUPPORT SYSTEM
HAM airport
DLR

VERTIPORT DESIGN

UAM NETWORK MANAGEMENT

MODELCITY

CONCEPTUAL DEVELOPMENT

FLIGHT DEMON-STRATION

VERTIPORT INTEGRATION AT AIRPORTS

A Vertiport Design Perspective

Literature

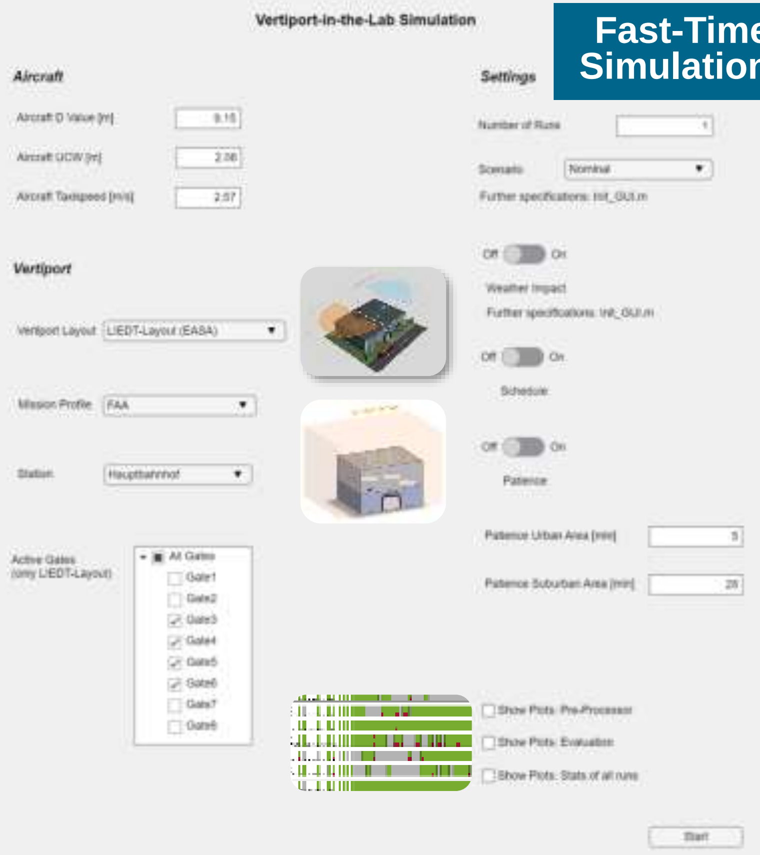
Airside Level of Service

VALoS		Reference	Passenger	VTOL Vehicle	Vertidrome	
	Acceptable	Flow [Processed Operations/ Time Interval]	$\varnothing\ d_{PAX}$	$t_{APT} - t_{NPT}$	$\geq 95\ \%$ Flights $\leq d_{TF}$	Metric
			≤ 2 Minutes	≤ 5 Minutes	$d_{TF} = 2.5$ Minutes	Objective
	Non-Acceptable		$\varnothing\ d_{PAX}$	$t_{APT} - t_{NPT}$	$< 95\ \%$ Flights $\leq d_{TF}$	Metric
			> 2 Minutes	> 5 Minutes	$d_{TF} = 2.5$ Minutes	Objective

Wind-dependent Vertiport ConOps

Wind Operational | Wind Advisory | Wind Warning | Wind Shutdown

Fast-Time Simulation



Security, Noise and **Weather** are significantly under-represented in UAM research.

The **Level of Service** framework is suitable to rate vertiport airside operations unifying multidisciplinary stakeholders.

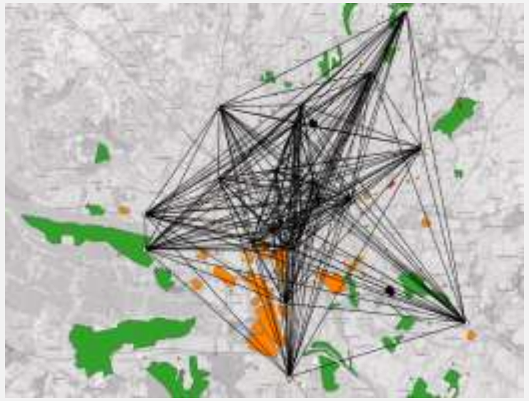
Hamburg & Munich Case Study: Exceeding Wind Operational conditions especially during midday and early afternoon hours.
>50% of the cancellations in the first quarter of the year (2019/2012).

A UAM Networkmanagement Perspective I

ATM-X 2020-2025

Slot based Approach (SBA)

Trajectory based Approach (TBA)



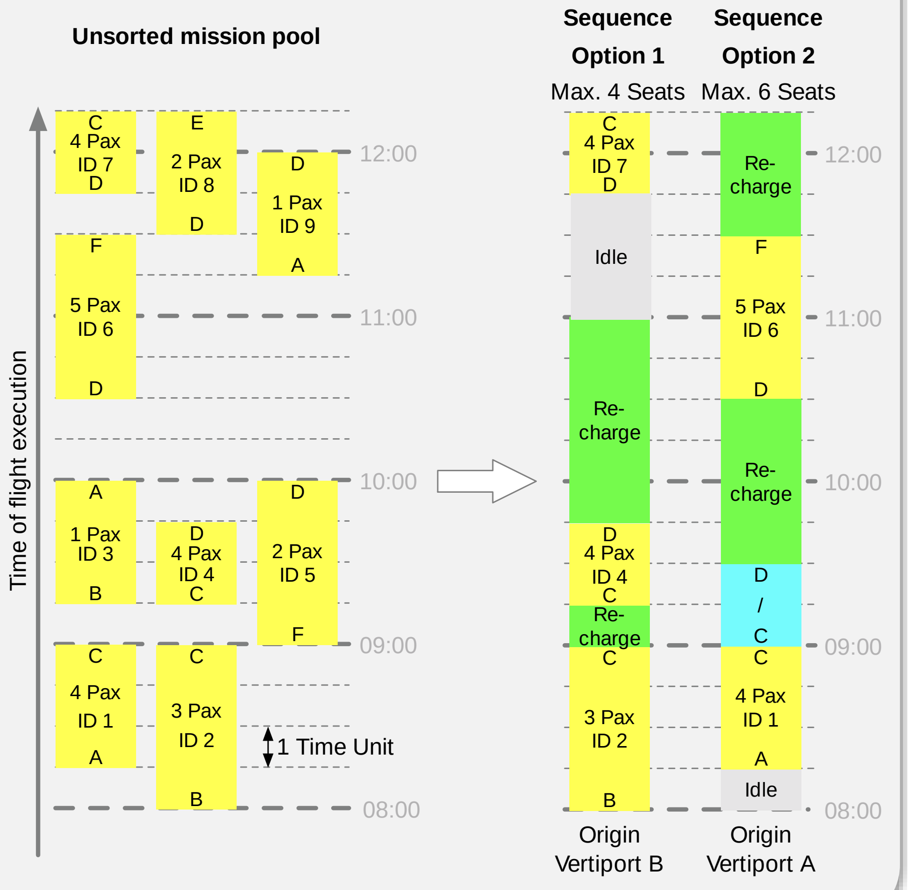
SBA shows a **longer flight time** compared to **TBA** (16.54 min vs. 10.86 min) and a **higher throughput** compared to **TBA** (15 aircraft/min vs. 10 aircraft/min).

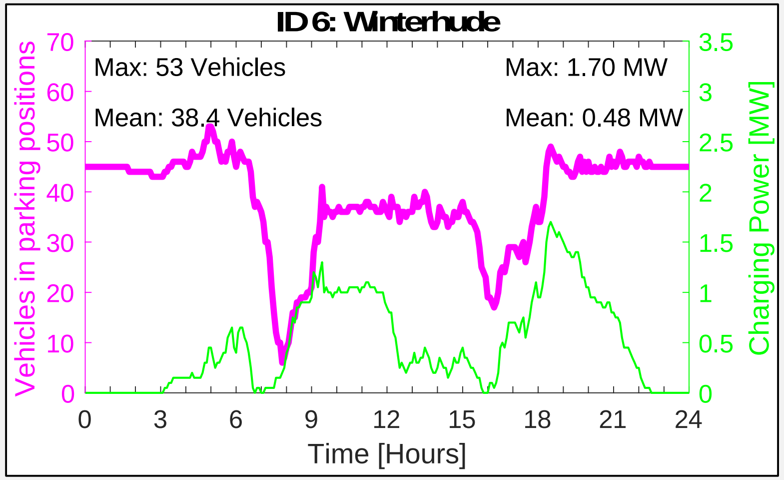
When **compared to ground traffic**, **SBA** shows **time savings** of up to **34.23%**, whereas **TBA** shows a range of up to **39.56%** with a median of **31.72%.**

Average **flight delay**: 2.17 min

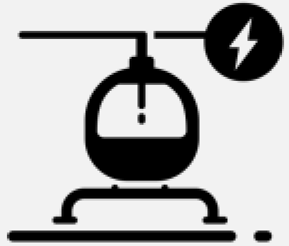
A UAM Networkmanagement Perspective II

Ride Matching Algorithm





Vertiport Capacity Allocation



Hamburg Case Study: A network of 20 vertiports requires 422 parking positions, a maximum cumulated charging power of 11.05 MW and 275 vehicles to service 2800 missions per day.

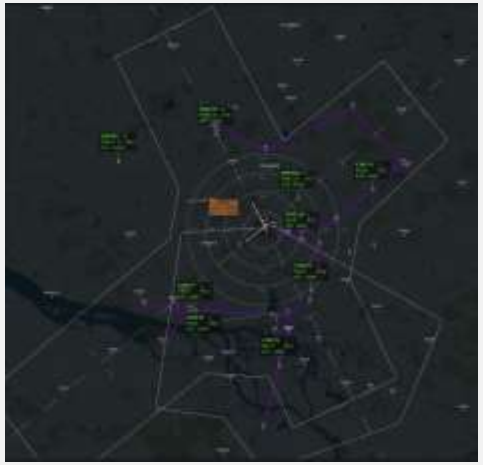
A reduction of **battery charging time** can reduce the fleet size by 18%, causing a spatial footprint reduction of 24% regarding parking stands.

Fleet analysis shows that **average load factors** of 45% are feasible at fleet sizes with varying occupancy rates of up to 80%.

A Vertiport Integration Perspective

Fast-Time Simulation

Real-time HITL Simulation



VPE: the lowest average delay and energy consumption.

Integration into conventional runway systems is only recommended for low-traffic hours.

Hamburg Case Study: 44 conventional A/C, 15 AirTaxis/hour and 10 ATCOs.

Situation awareness and **workload** within reasonable boundaries in all scenarios. **Exclusive air taxi working position** in case of more traffic is suggested.

A MODELCITY PERSPECTIVE
→ NEXT PRESENTATION


ENTRANCE
Vertidrome
Poster
Session
8

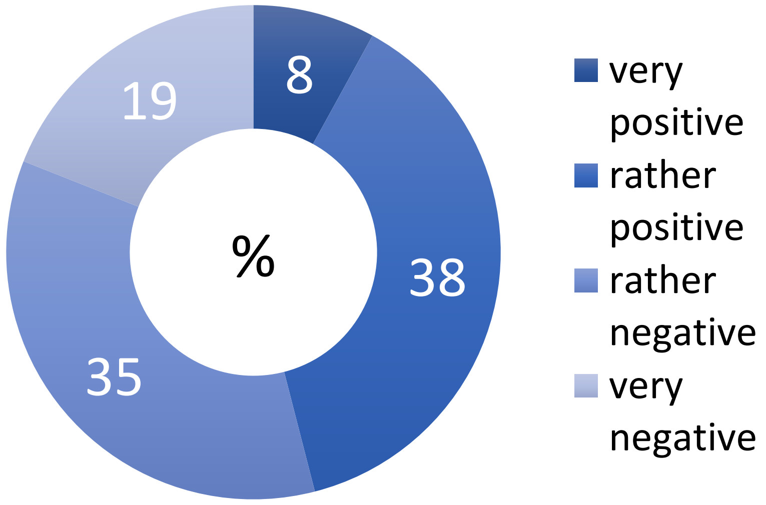
PUBLIC ACCEPTANCE

Dr. Albert End

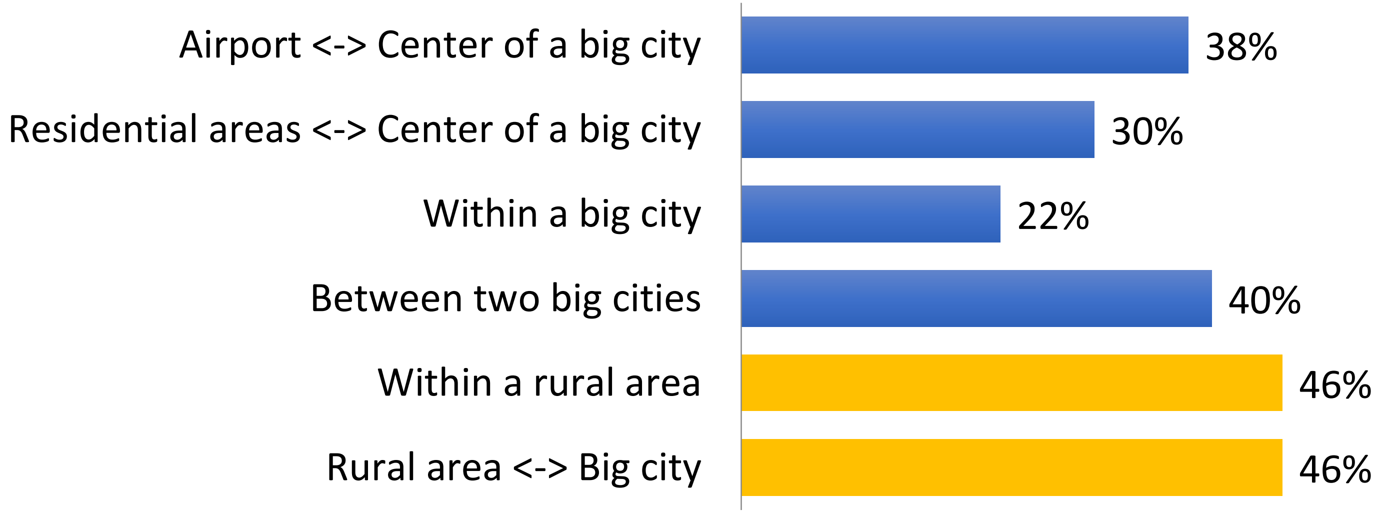
A Large-Scale Telephone Survey in the German Population

- *N* = 1001 computer-assisted telephone interviews in 2022 (Ø 21 min.)
- Acceptance of civilian drones in general and air taxis in particular

Attitude towards air taxis



Willingness to use an air taxi



DroNoise – A Smartphone App for Assessing Drone Noise

- Development of a smartphone app to measure drone noise and assess subjective annoyance
  (Eißfeldt, 2020, Sustainability)
- Tested during live drone flight demonstrations in Cochstedt 2023

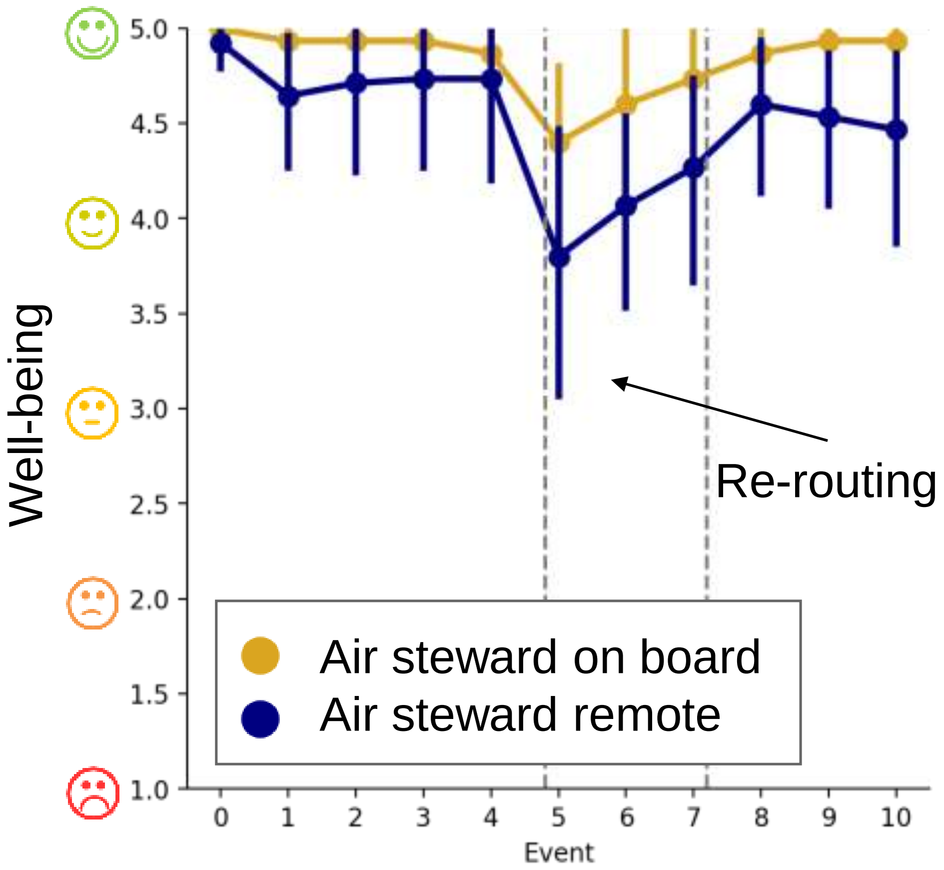
→ Basis for creating noise pollution maps

→ Opportunity for adapting flight routes/profiles such that drone noise could be distributed as equally as possible among residents

→ Considering the public's health and acceptance

Virtual Reality Study on the Well-being of Air Taxi Passengers

- *N* = 30 participants experienced a virtual airport shuttle flight in the city of Hamburg in a mixed reality air taxi simulator



- Well-being was significantly reduced at the start of re-routing (p = .001)
- Well-being tended to be higher when an air steward was on board during flights with re-routing (p = .086)

Virtual Reality Study on the Well-being of Passers-by

- *N* = 47 participants experienced civil drones flying above Braunschweig as well as an air taxi landing from the perspective of passers-by

8 items, for example:

I felt comfortable in the scenario.
I felt safe in the scenario.
I felt observed in the scenario.
I felt nervous in the scenario.

(7-point scale)

- Well-being was better when fewer drones were visible and when they were flying at higher altitudes (sign. effects in 8/8 and 3/8 items, $p < .05$)
- Well-being was (slightly) reduced when drones or an air taxi were visible as compared to conventional traffic only (sign. effects in 6/8, 8/8, 8/8 items, $p < .05$)

Conclusions

- Attitude towards air taxis was found to vary from positive to negative in a relatively evenly distributed way within the German population. Willingness to use an air taxi was revealed to be most pronounced for use cases including rural areas.
- Smartphone app *DroNoise* was developed to provide an opportunity for considering drone noise and corresponding annoyance when designing urban air mobility.
- Mixed reality air taxi simulator study indicated that the presence of an air steward on board may improve passenger’s well-being especially in non-nominal flight situations.
- Virtual reality study showed that the well-being of passers-by will probably be influenced by the presence of drones and air taxis in urban airspace.

DEMONSTRATION

Dr. Bianca I. Schuchardt

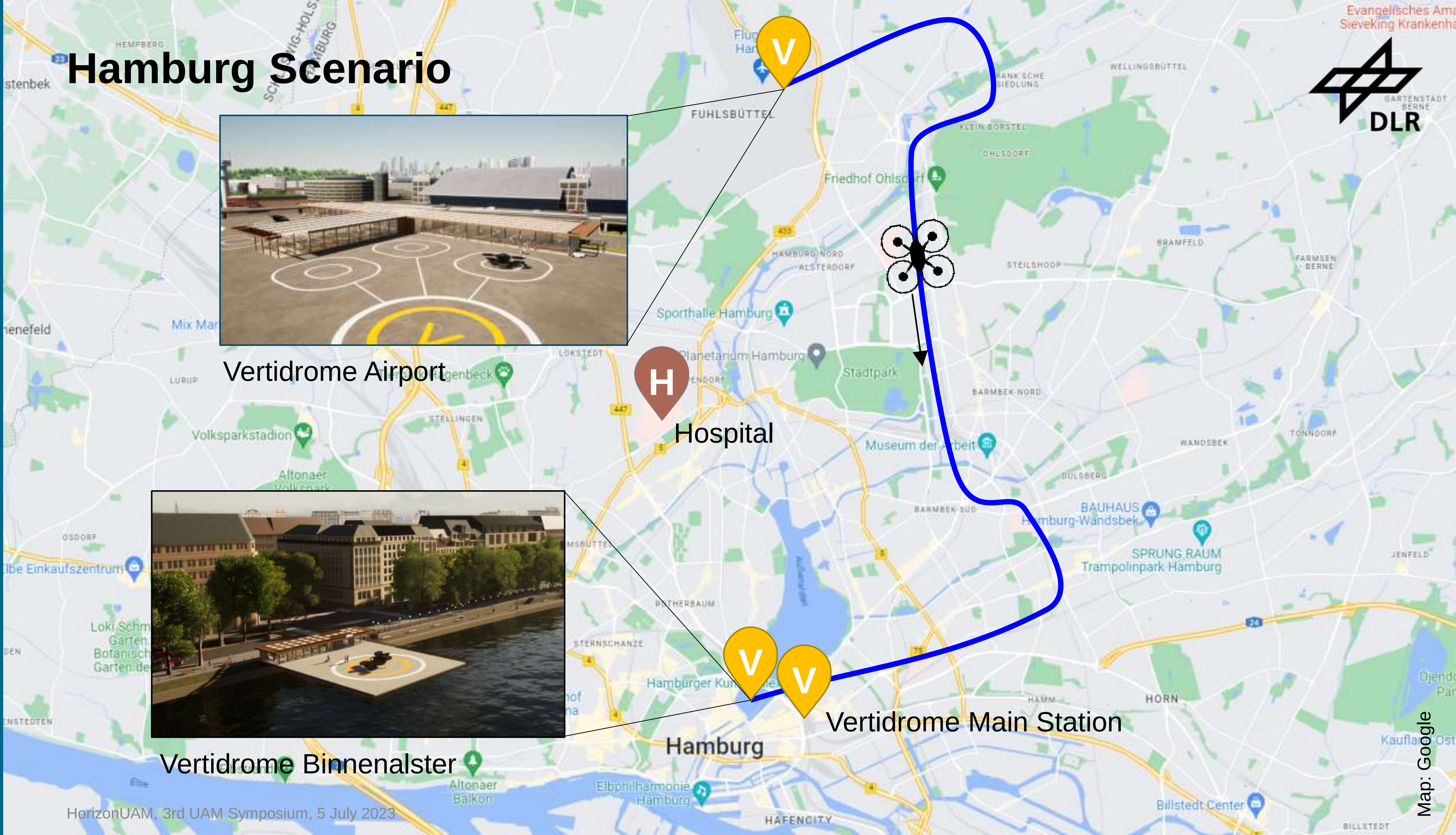
From Simulation to Scaled Urban Scenario Testing

Modular model city concept at scale 1:4

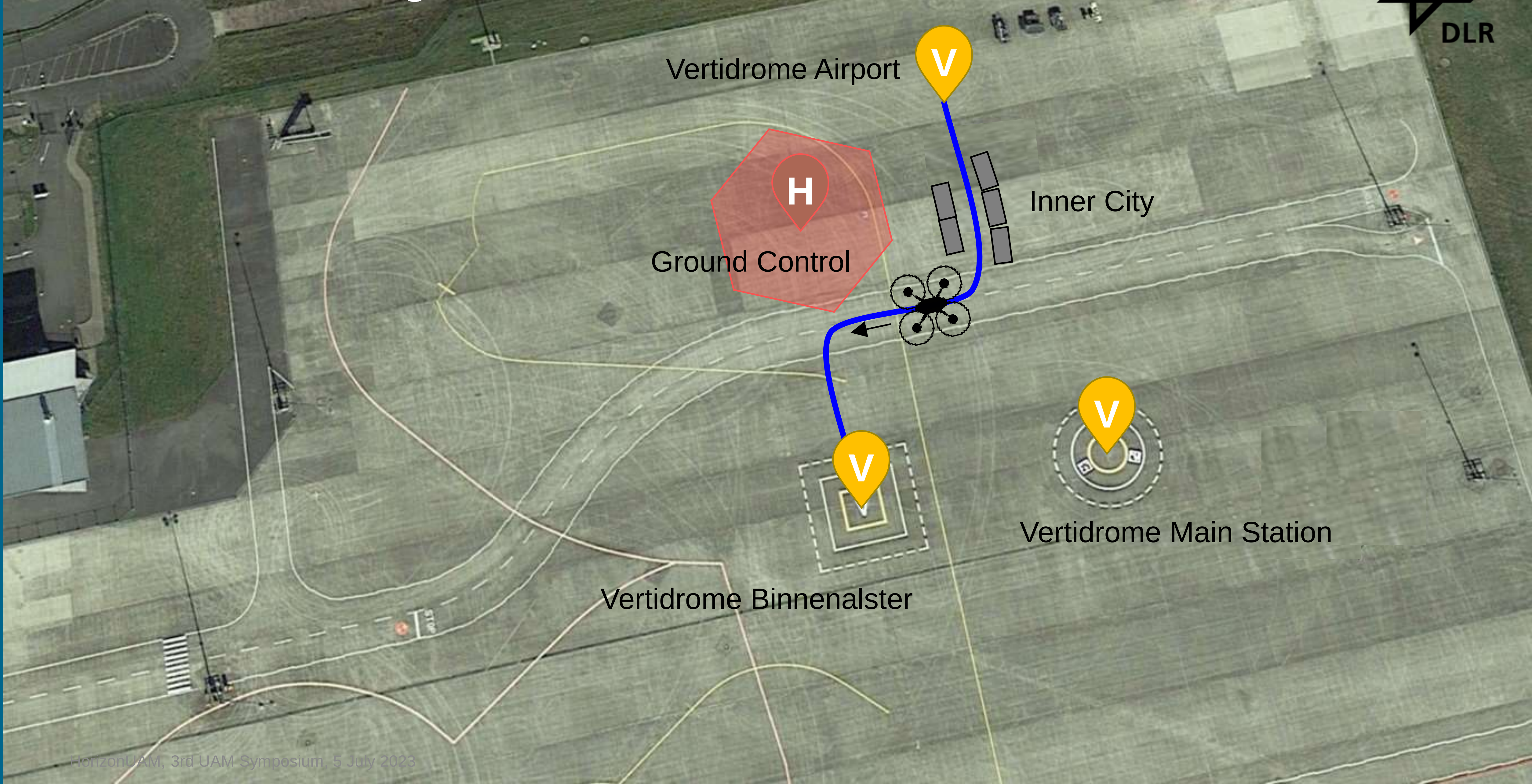
Urban Air Mobility Flight Demonstration

- Air taxi flight from vertidrome "Hamburg Airport" to "Hamburg Binnenalster"
- Scaled demonstration: multicopters representing passenger carrying air taxis
- Focus of demonstration:
  - Airspace integration through U-space
  - Vertidrome management
  - Artificial intelligence (AI) for automatic detection of persons
  - Urban communication and navigation

Hamburg Scenario



Scaled Hamburg Scenario



Conclusion

- HorizonUAM has revealed the complexity of Urban Air Mobility and the interdependency of the system's elements.
- Key results:
  - **System-of-system simulation** established for UAM scenario testing and sensitivity analyses
  - **High market potential** shown for more than 200 cities worldwide
  - Viable **vehicle** concepts for intra-city and sub-urban use cases designed
  - DroneCAST (Drone **Communications and Surveillance** Technology) developed
  - Safe Operation Monitor methodology for improving the reliability and trustworthiness of **artificial intelligence** functions evaluated
  - Method for the **Vertidrome Airside Level of Service** evaluation established
  - Tools developed for **vertidrome network and fleet management** optimization and feasibility of **airport integration** assessed with air traffic controllers
  - **Public acceptance:** Passengers' and pedestrians' perspective on UAM evaluated, and attitude of the German population assessed
  - Modular model city erected as scaled environment for **demonstration** of airspace integration, vertidrome management, artificial intelligence functions, and urban communication and navigation

HorizonUAM

THANK YOU
FOR YOUR ATTENTION

Imprint

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