CHALLENGES AND OPPORTUNITIES OF URBAN AIR MOBILITY

HOW MUCH NOISE IS ACCEPTABLE?

Nabil Hagag, Dr. Bianca I. Schuchardt, Dr. Albert End, Frank Meller, Henry Pak, Karolin Schweiger, Christoph Torens

German Aerospace Center (DLR)

What is Urban Air Mobility?

Nabil Hagag, DLR Institute of Flight Guidance, May 2024

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

Electric air taxis being developed for Paris Olympics in 2024

Aircraft will take off and land vertically, and carry a s passenger between transport hubs, says capital's air

A VoloCity electric aircraft at the Skyports and ADP vertiport ter test site. Senior French aerospace figures see the Olympics as the id planned e-VTOL service. Photograph: Volocopter

Athletes are getting in shape for the Paris Olympic Ga the world's first electric air taxi network.

Japan's first piloted flying taxi test held ahead of 2025 Expo

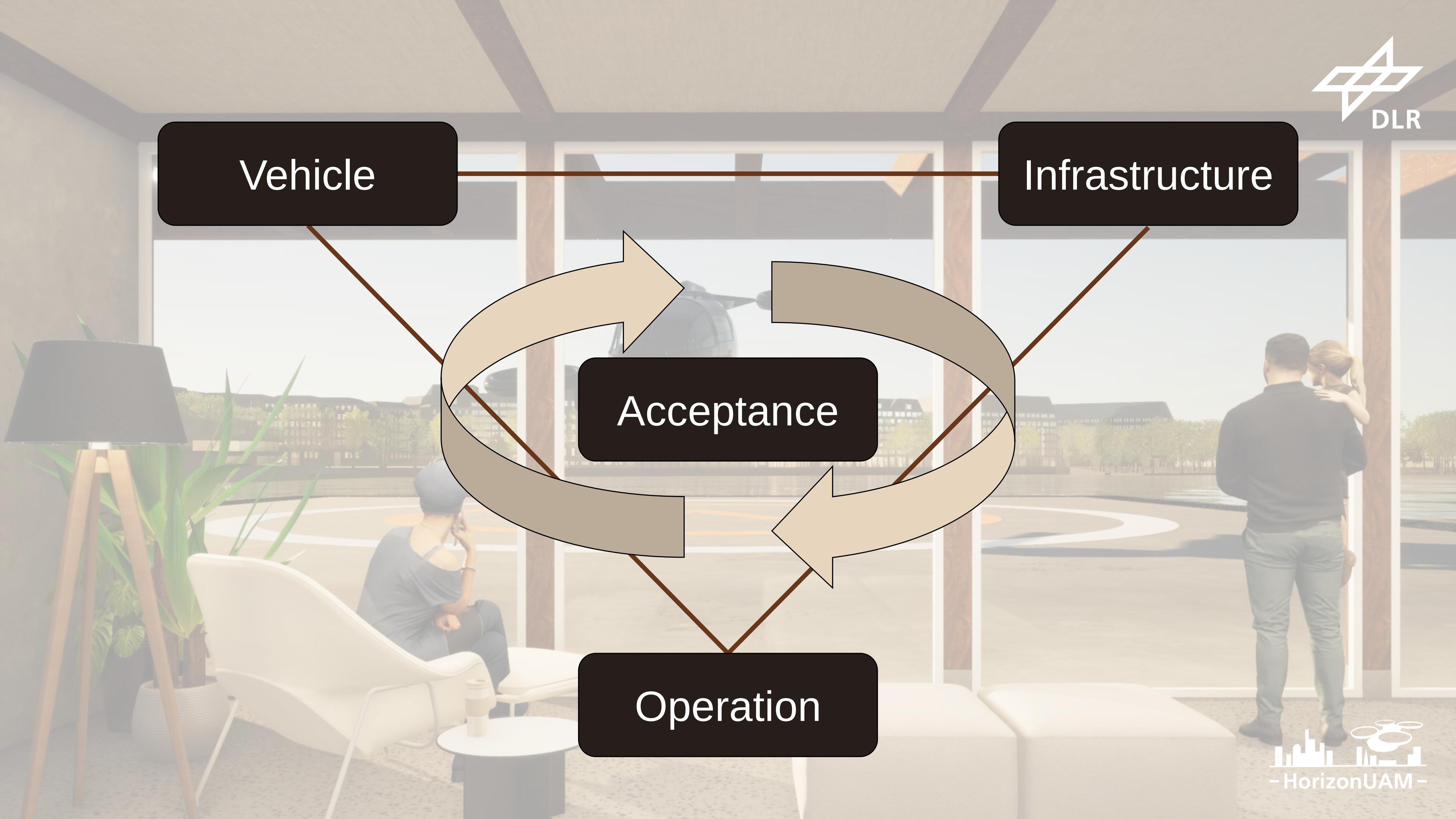
A piloted demonstration flight of a flying taxi in front of Osaka Castle in Osaka on Tuesday. | KYODO

KYODO SHARE Mar 14, 2023

An air taxi service set to feature at the 2025 Osaka Expo was tested in a park in the city on Tuesday, in what the prefectural government says is the first time in the country one of the craft has been piloted from the cockpit.

the japan times


KÄLTE KLIMA KÖNIG
IHR KÄLTE UND KLIMA KOMPETENZZENTRUM IN NORDDEUTSCHLAND
NATIONAL EXPERIMENTAL TEST CENTER


Vehicle
Infrastructure
Acceptance
Operation

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

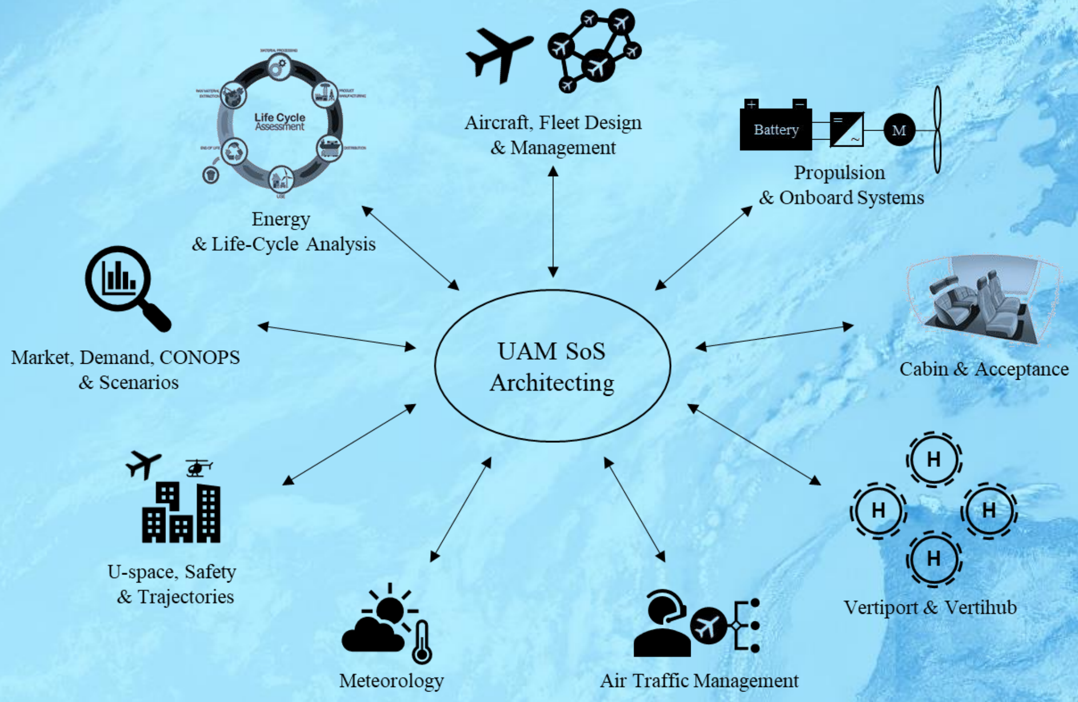
– HorizonUAM –

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

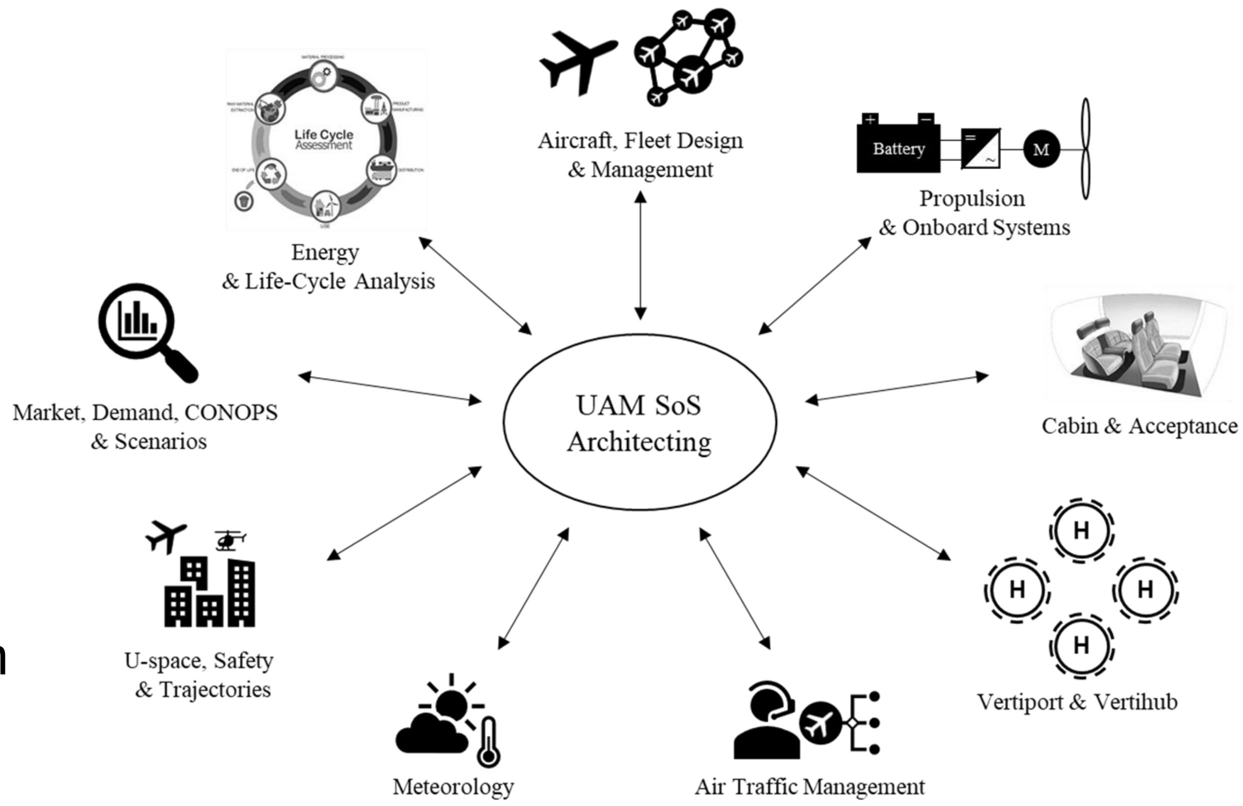
- Duration: 07/2020 – 08/2023
- Scope: 9.1 M€
- Participants: 10 DLR institutes, cooperation partners NASA and Bauhaus Luftfahrt



SYSTEM PERSPECTIVE ON UAM

Urban Air Mobility as System of Systems (SoS)

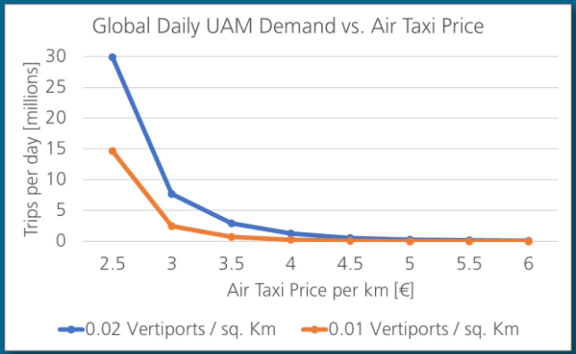
- Complex system of systems
  - System behavior results from the interaction of system components.
  - Changing one component of the system may affect other components and the behavior of the system as a whole.
- Objectives and key questions
  - Understanding of complex interactions between UAM system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

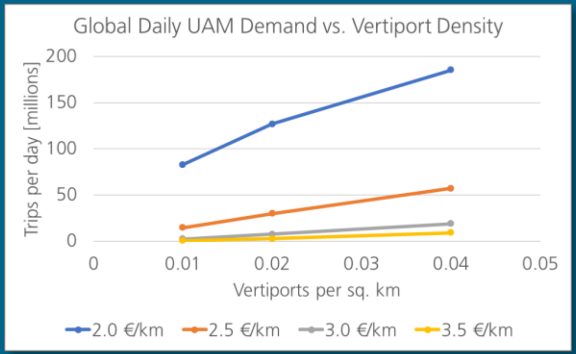


Model-based Forecasting Approach to Estimate Global Demand and Fleet Size

- Schematic urban transport model
  - Applied to 990 urban areas > 500,000 inhabitants
  - Input parameters: population, city area, gross domestic product (GDP)
- Conclusions
  - Low ticket prices and short access and egress to vertidromes are key to driving demand for UAM.
  - There could be market potential for UAM in more than 200 cities worldwide by 2050.

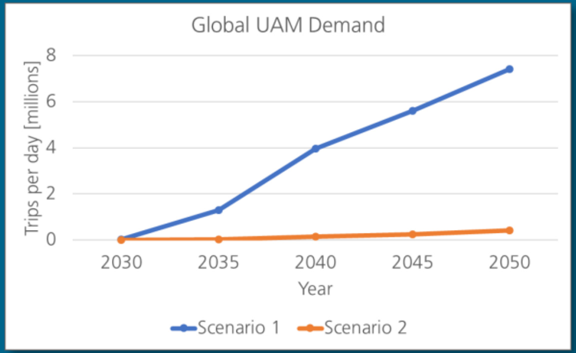
Sensitivity Analyses

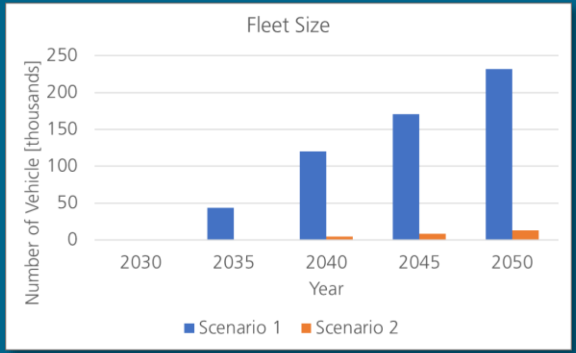




Scenarios of Market Development

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*

VEHICLE

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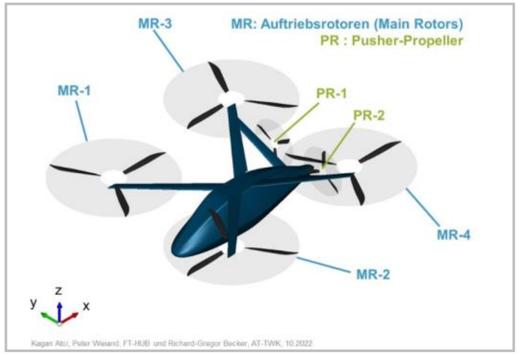
Vehicle Concepts



Preliminary Vehicle Design & Propulsion Analysis

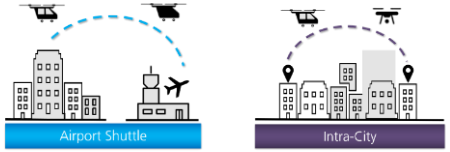
4 Main Rotors / 2 Pusher Prop.

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

Quadrotor (Battery-electric)

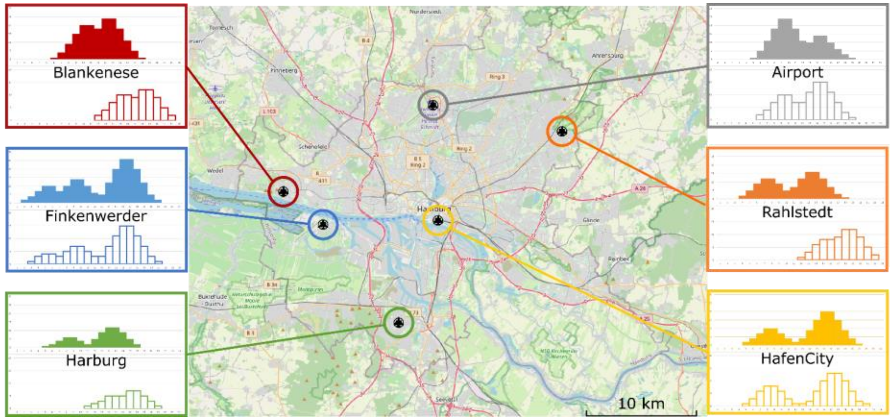
Intra-city / Airport shuttle:

50 km; 120 km/h; 2 Stops



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

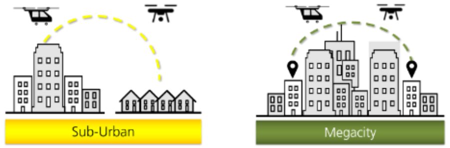
Conceptual Vehicle Design



Tiltrotor (Battery-electric)

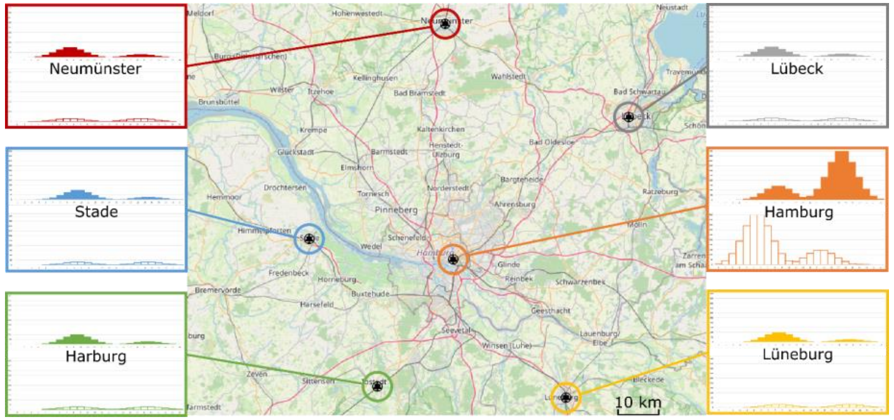
Sub-urban / Megacity:

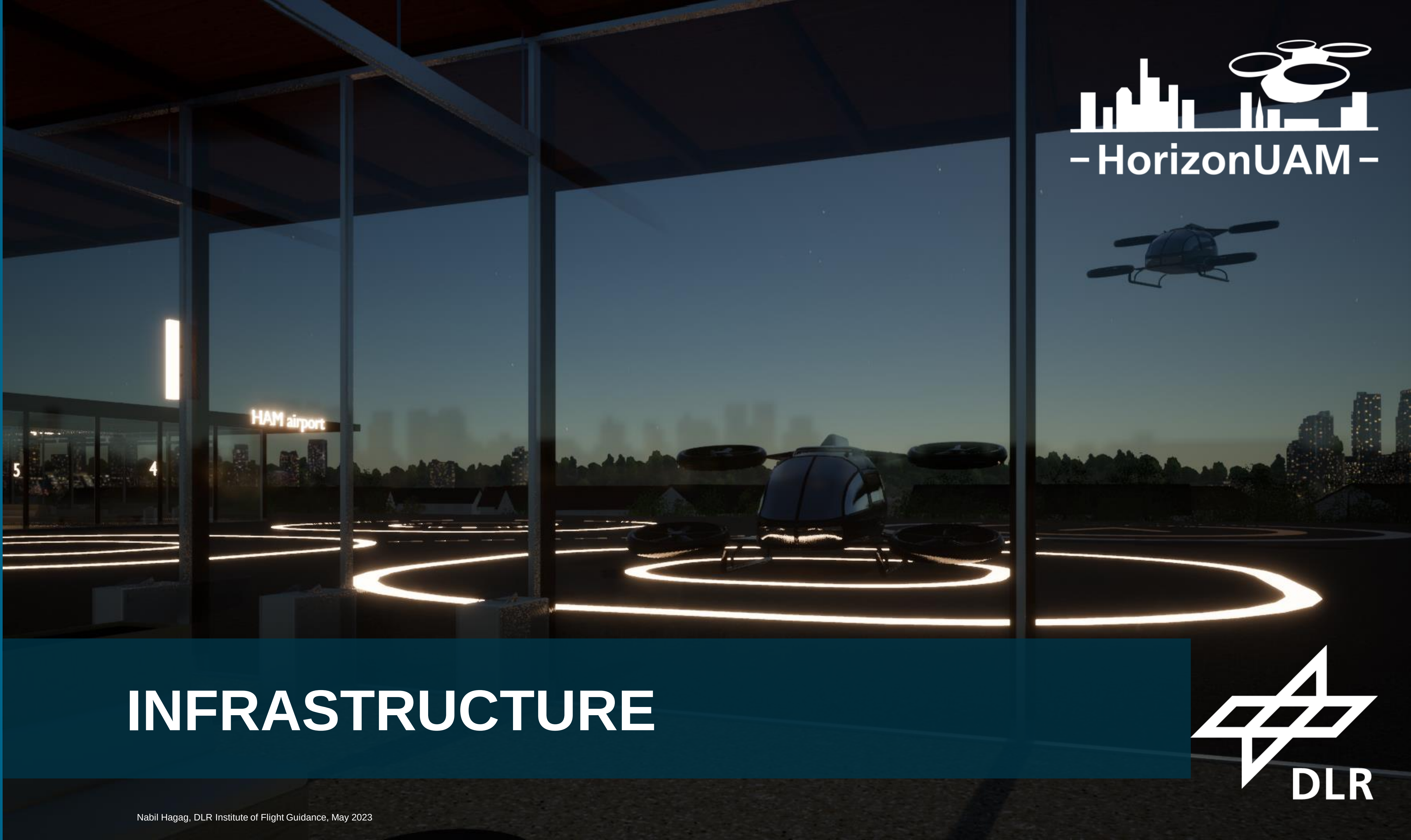
100 km; 200 km/h; 1 Stop



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

Conceptual Vehicle Design





INFRASTRUCTURE

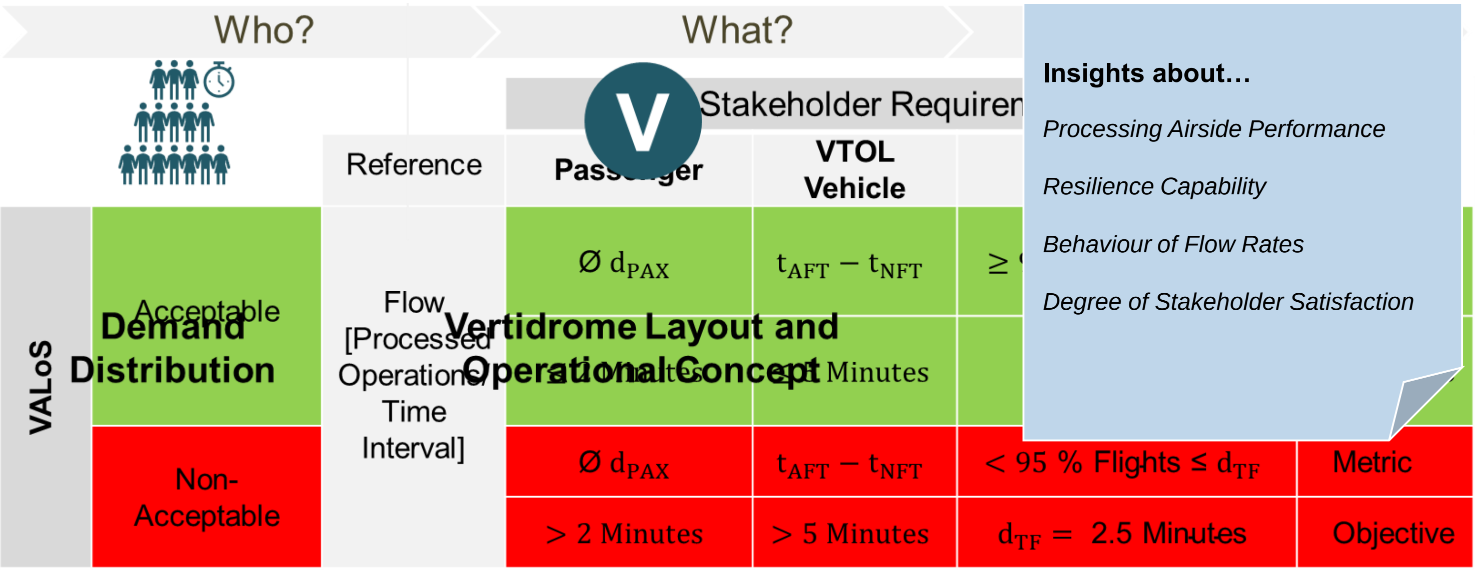
Vertidrome Airside Level of Service

Uber, Gannett Fleming

Fraport

How do we decide if a vertidrome satisfies our requirements from an operational perspective?

Vertidrome Level of Service (VALoS) Concept

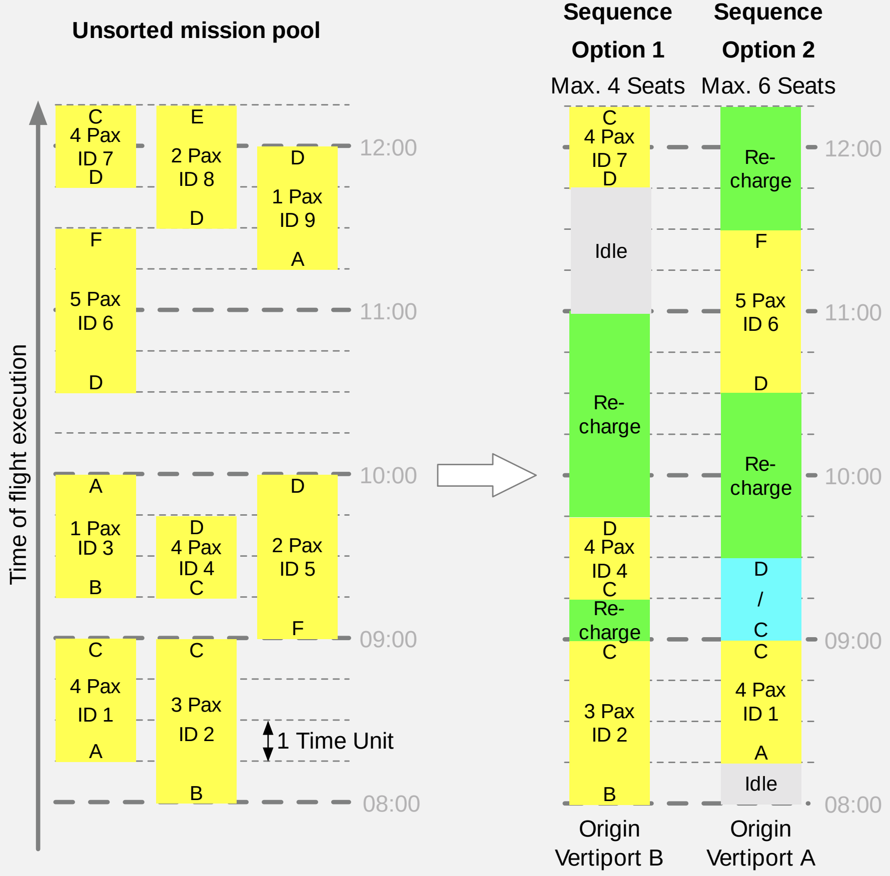


Nomenclature

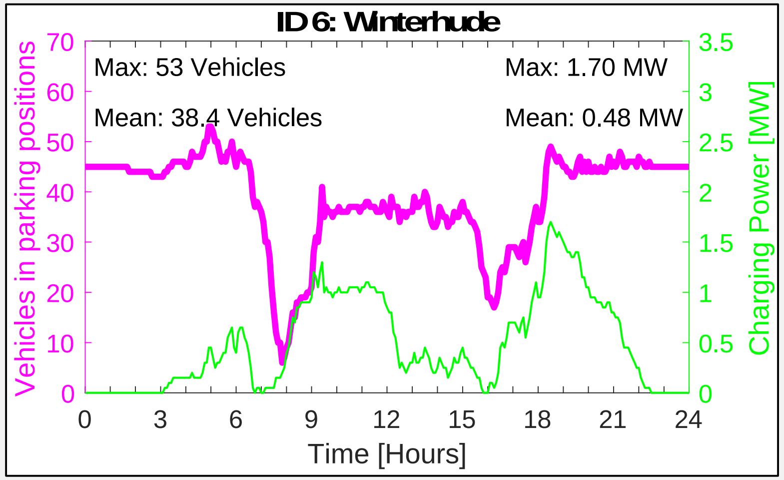
d=delay
t = time (duration)
AFT = actual flight time
NFT = nominal flight time
TF = total flight
PAX= passenger

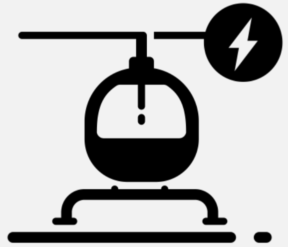
A UAM Network Management Perspective

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.

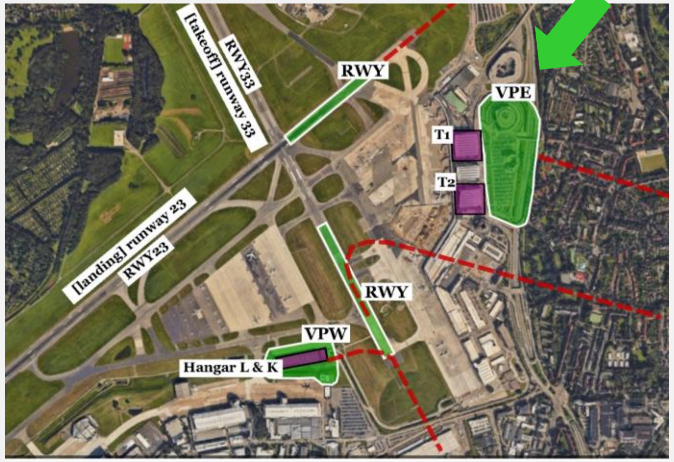
A reduction of **battery charging time** can reduce the fleet size by 18%, causing a spatial footprint reduction of 24% regarding parking stands.

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

OPERATION

Airport Integration

Fast-time Simulation



Vertiport East (VPE): lowest average delay and energy consumption.

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

Real-time Hardware-in-the-loop Simulation

Hamburg Case Study: 44 conventional aircraft, 15 air taxis per hour and 10 air traffic controllers.

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

From Simulation to Scaled Urban Scenario Testing

At the National Experimental Test Center for UAS, Cochstedt, Germany

Modular model city concept at scale 1:4

Urban Air Mobility Flight Demonstration

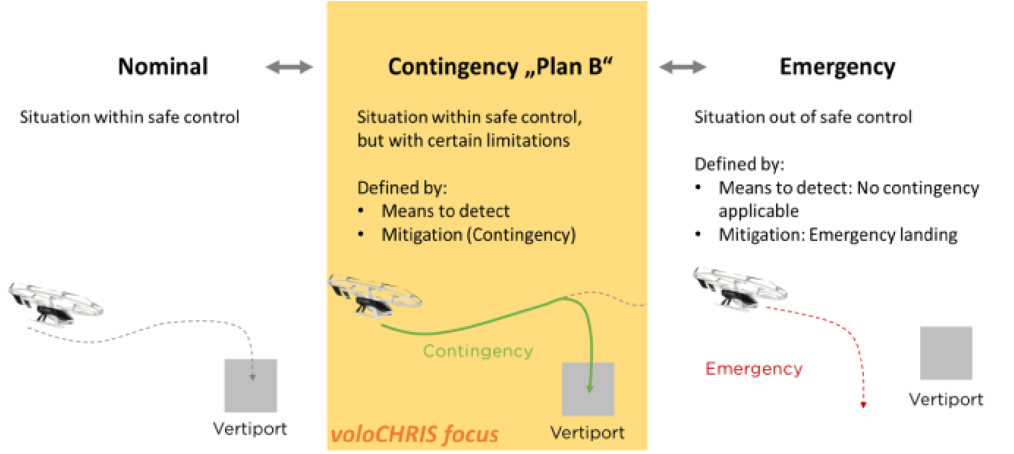
- Air taxi flight from vertidrome “Hamburg Airport” to “Hamburg Binnenalster”
- Scaled demonstration: multicopters representing passenger carrying air taxis
- Focus of demonstration:
  - Airspace integration through U-space
  - Vertidrome management
  - Artificial intelligence for automatic detection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

1. Mission-based Flight Guidance
UAM envisions a future by air taxis / eVTOLs

How can UAM ensure safe and reliable flight operations?

Contingency procedures

- **“Plan B"** incorporates:
  - Emergency situations
  - Holding procedures
  - Alternative routes / diversion
  - Alternative landing sites
- Backbone: Powertrain system of eVTOLs



(2)

Aim of this research:

1. What is the **realistic energy demand** for an **eVTOL** in **dynamic urban scenarios**?

2. What should be the minimum **energy reserve** for an urban mission **considering non-nominal scenarios**?

(3)

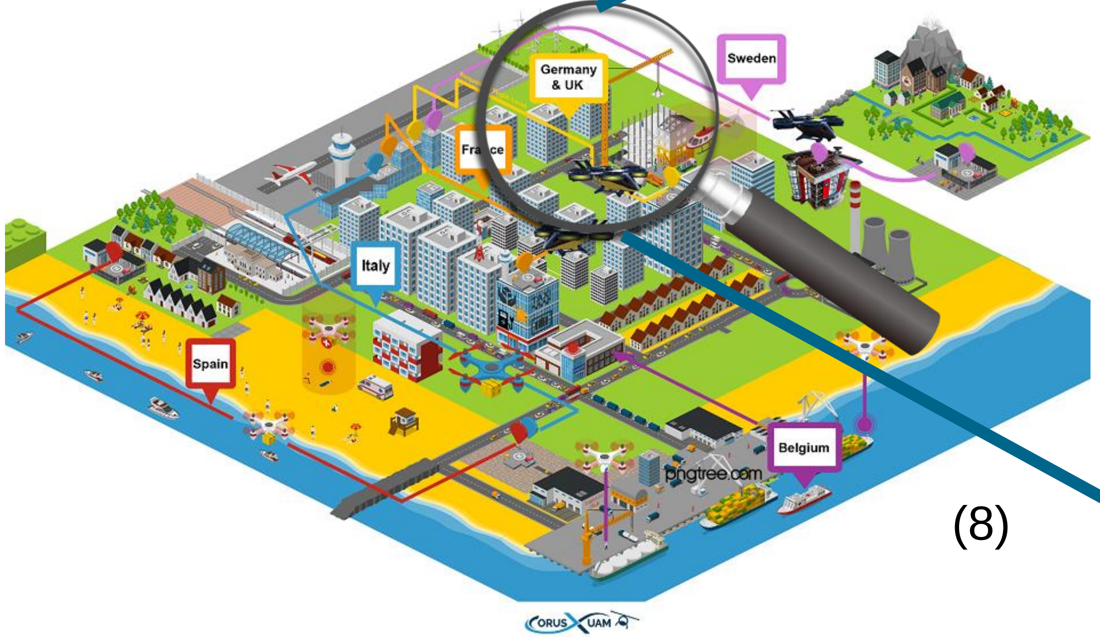
2. State-of-the-Art:
UAM Concept of Operation

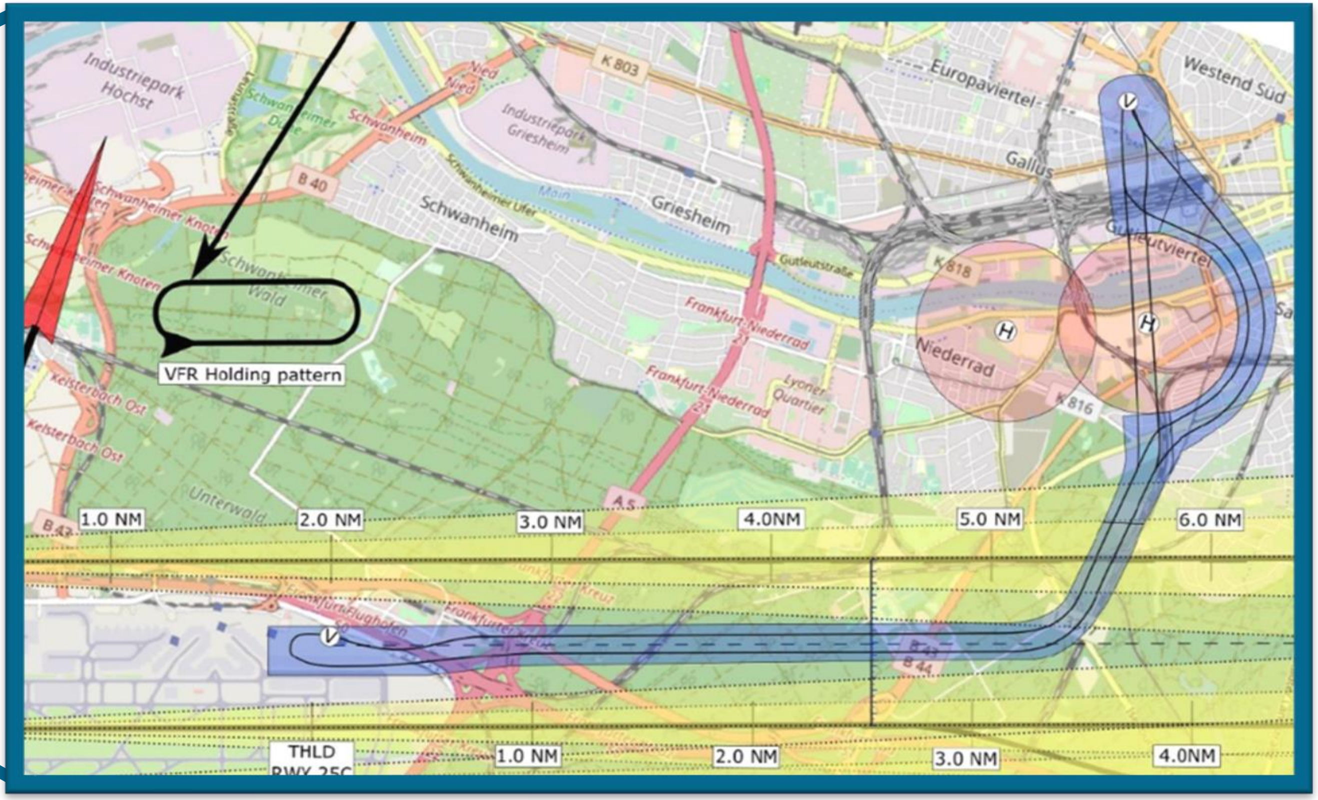
SESAR-project:
CORUS-XUAM

▦ Duration: 01/2021 – 04/2023

Aim of this project

➢ Demonstration of U-space services and solutions could support UAM flight operations





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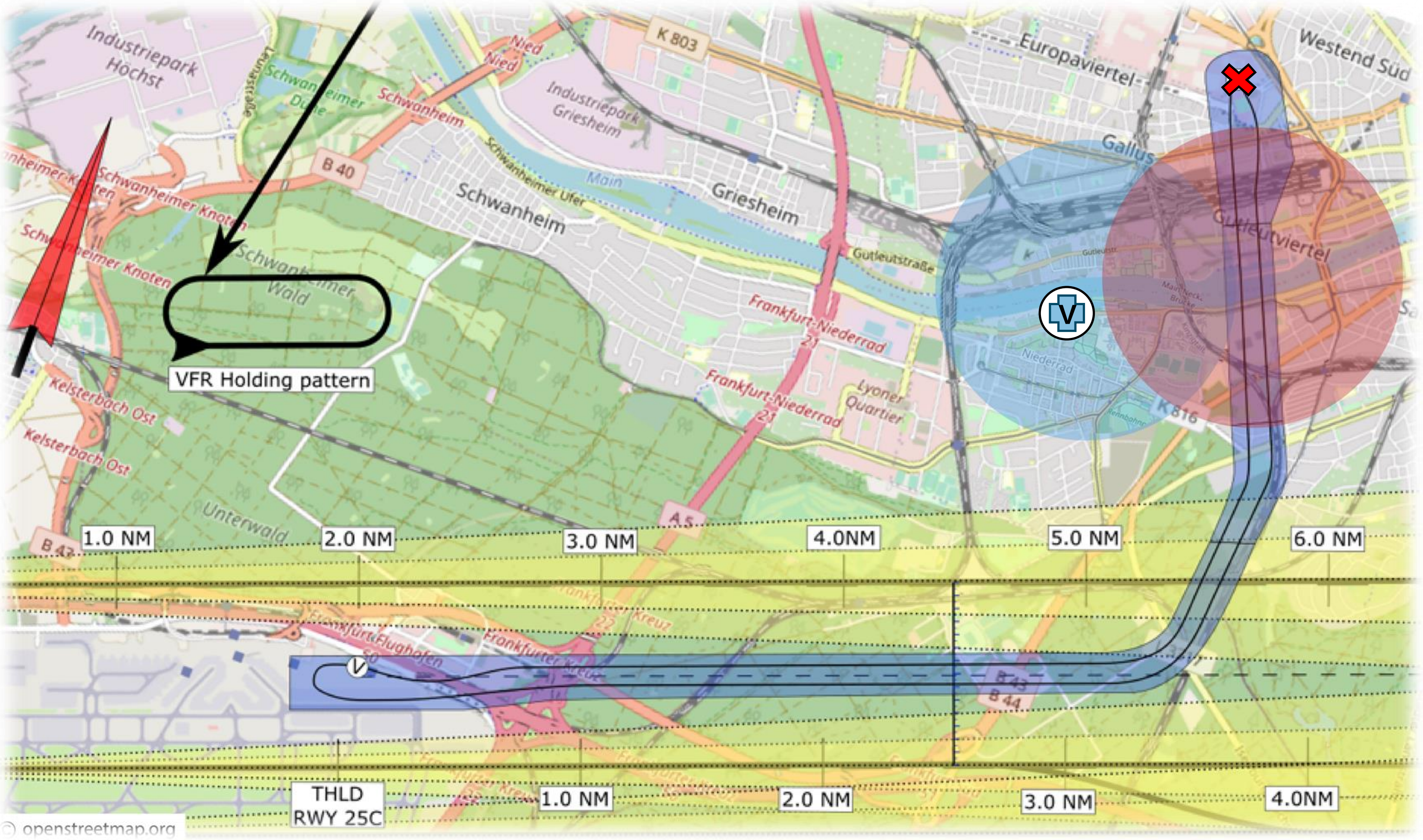
This project has received funding from the SESAR Joint Undertaking under the European Union's Horizon 2020 research and innovation programme under grant agreement No 101017682.

3. Methodology: Selected Scenarios



Nominal flight route (REF)

No-Fly Zone (Hospital)

Moving Obstacle (Helicopter)

Target vertiport

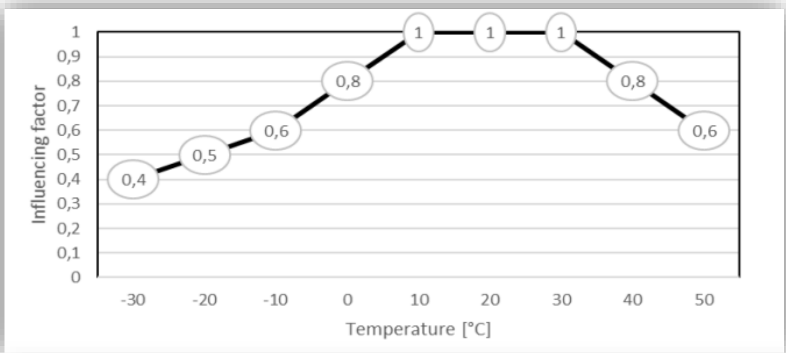
Blocked target vertiport

Alternative vertiport

SID / STAR for conventional aircraft

5. Discussion
Limitations

- Linear models for Energy demand analysis
- **Environmental factors** are not considered like:
  - wind
  - air temperature



Air Temperature	10,4 °C	-9,1 °C	39,4 °C	
Headwind speed	0 m/s	4,9 m/s	10,1 m/s	20 m/s

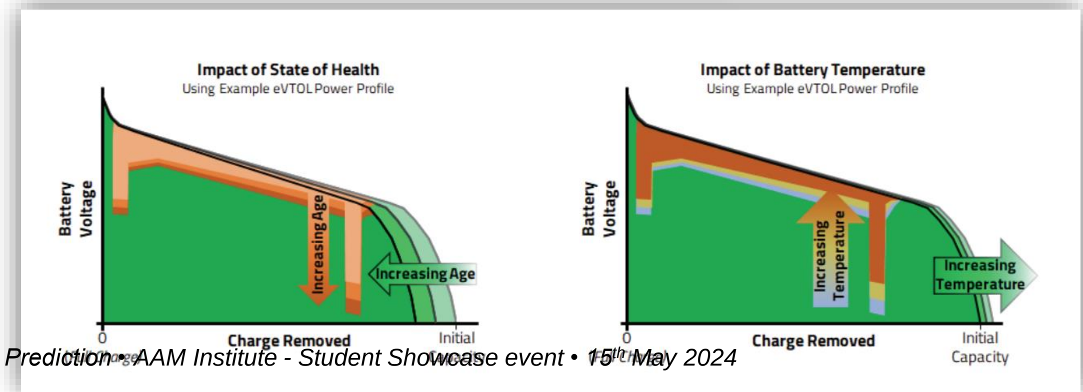
- Vehicle parameters are approximated,

lacking **empirical validation** such as:
  - weight
  - inertia tensor
  - propeller performance

Technical characteristics	Value	Unit
Maximum take-off mass	1954	kg
Payload	360	kg
Rotor radius	2.64	m
Vehicle diameter	13.76	m
Moment of inertia about the roll axis	8700	$kg\,m^2$
Moment of inertia about the pitch axis	9495	$kg\,m^2$
Moment of inertia about the yaw axis	11 490	$kg\,m^2$
Forward flight drag coefficient	75.27	$N\,s\,m^{-1}$
Efficient cruise speed	27.77	$m\,s^{-1}$
Maximum cruise efficiency	0.9	-
Spec. energy density of the energy system	147	$Wh\,kg^{-1}$

- **Battery model's validity** is affected by factors

impacting energy demand model results like:
  - ambient temperature
  - cell aging



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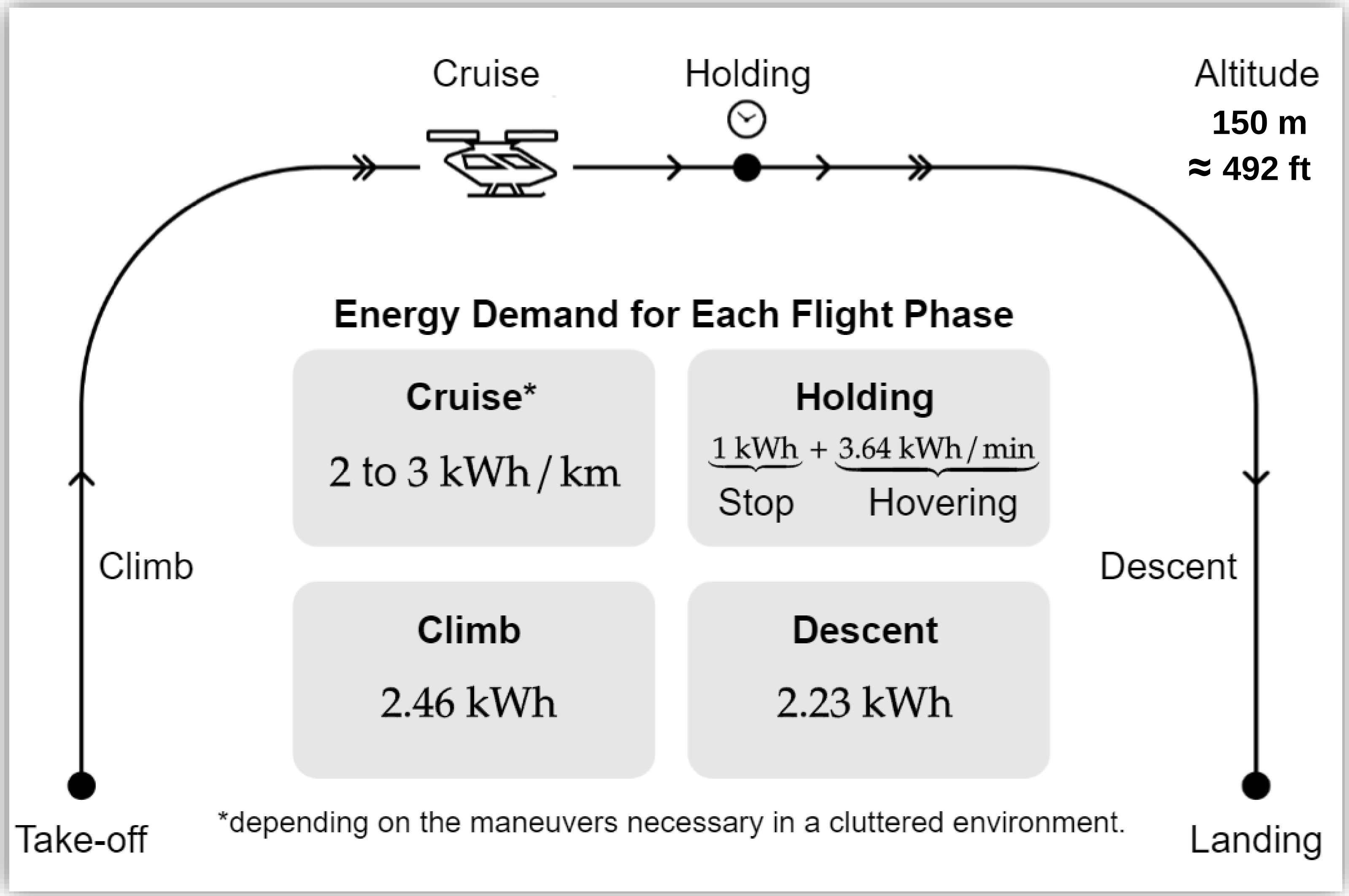
4. Key Results:
Energy Demand Analysis



5. Conclusion & Outlook

Key Findings

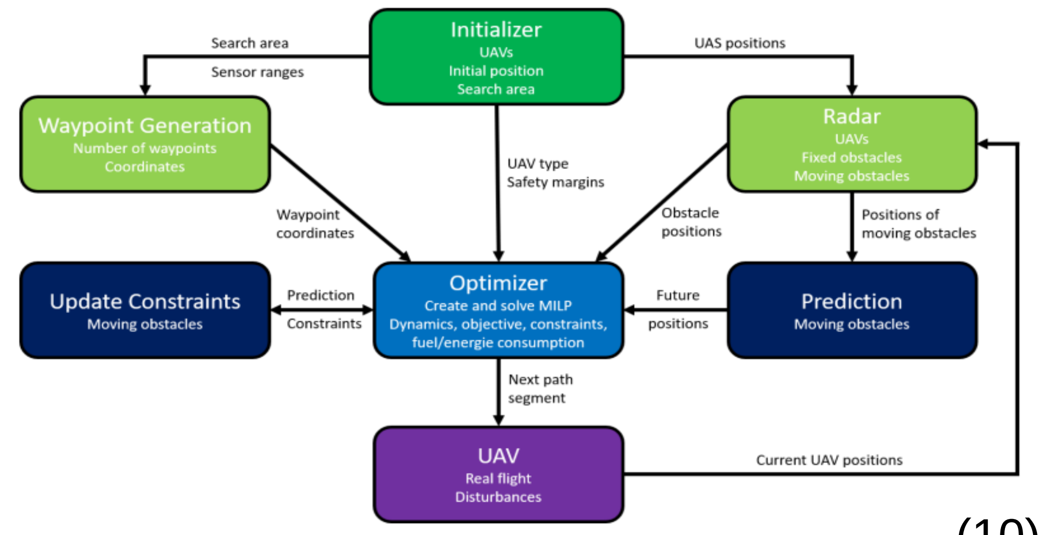
- **Brief stopover procedure consume ~ 1 kWh**
- **Hovering phase demand more energy ~ 3.64 kWh/min**
- **Climb phase was observed to require ~ 10 % more energy than decent phase**

Specific energy density, energy demand, and powertrain efficiency are crucial factors for path planning for eVTOLs

Outlook

- **Environmental factors**
- **Impact of State of Health**
- **Impact on Battery Temperature**

- **New battery technologies**
- **Energy-effienct path planning algorithm**
- **Calculation of other vehicle configurations**
  - **other powertrain systems**
  - **other performance models**
- **Different flight mission profiles**



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PUBLIC ACCEPTANCE

Background: Drone Noise Assessment

- Study on „Noise Impact of Drone Operations on the Environment“, commissioned by German Environment Agency (Umwelt Bundesamt)
- Noise assessment for drones < 25 kg
  - Topics: Drone market, noise emission, noise impact, regulations, impact on society and nature, need for action

➢ Very little valid noise assessments available, mainly for multicopters

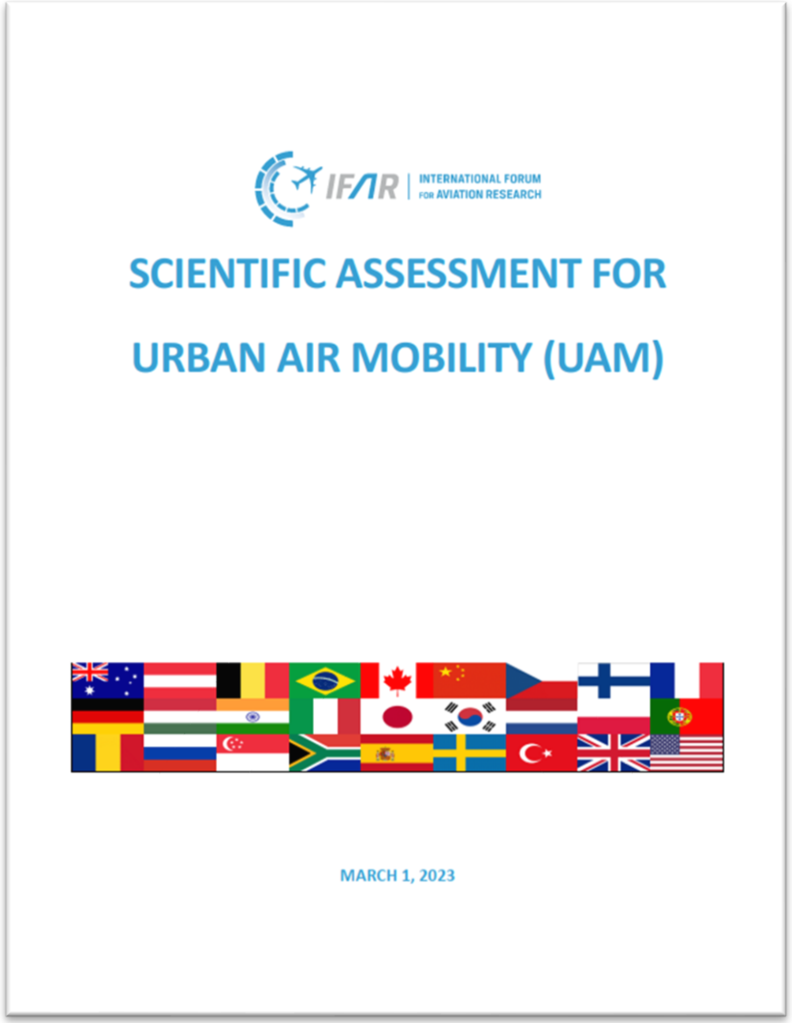
➢ Psychological investigations only under lab conditions

➢ Pronounced tonality, easily distinguishable from other environmental/urban sounds, tonality should be decreased by design

ISSN 236-829X

Background: IFAR Scientific Assessment for UAM

- International Forum for Aviation Research
- 80+ UAM experts
- Key takeaways on UAM noise research:
  - “UAM vehicles have very different noise sources from traditional transport aircraft or helicopters, and little is known about the response to the new noise profiles. Studies are needed that will assess the impact of noise with topics that include child learning, community impact, sleep disturbance, and cardiovascular health effects.”
  - ”There are numerous gaps ranging from characterizing the noise source mechanism, to propagation, and human response.”


IFAR | INTERNATIONAL FORUM FOR AVIATION RESEARCH

SCIENTIFIC ASSESSMENT FOR URBAN AIR MOBILITY (UAM)

MARCH 1, 2023

www.ifar.aero

Telephone Survey on the Acceptance of Civil Drones and Air Taxis in Germany (2022)

- Survey method: Computer-assisted telephone interviews (CATI)
- Implementation: BIK - ASCHPURWIS + BEHRENS GmbH (Hamburg, Germany)
- Number of cases: *N* = 1001
- Duration per interview: *Mdn* = 21 minutes
- Sample drawn from phone selection basis of ADM Arbeitskreis Deutscher Markt- und Sozialforschungsinstitute e.V. 2022

  Dual frame approach with landline and mobile phones

  Representative for the German population with respect to key characteristics by weighting

End et al. (2023) Upcoming Preprint

Initial Briefings for Participants

Civil Drones

- Unmanned aerial vehicles
- Mostly look like small helicopters with several rotors
- Mostly fly with electrical propulsion
- Can serve different purposes (for example photography, measurements, transport of goods)
- Can be controlled remotely from ground or in part even fly autonomously to specified destinations
- This study only aims at civil use cases, not at military usage

Air Taxis

- Aircraft, typically with space for two to five persons
- Several concepts exist, at different stages of development and licensing
- Either look like smaller helicopters or like a type of smaller plane
- Supposed to mostly fly with electrical propulsion
- Short-term: For reasons of safety and licensing, will probably be controlled by pilot on board; mid-/long-term: Planned to be controlled remotely from ground and more or less autonomously

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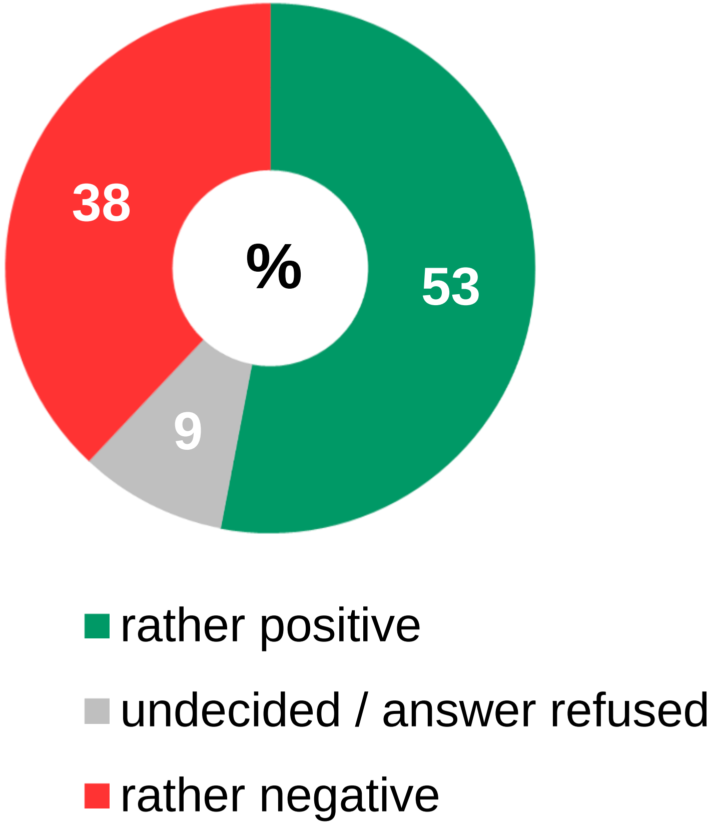
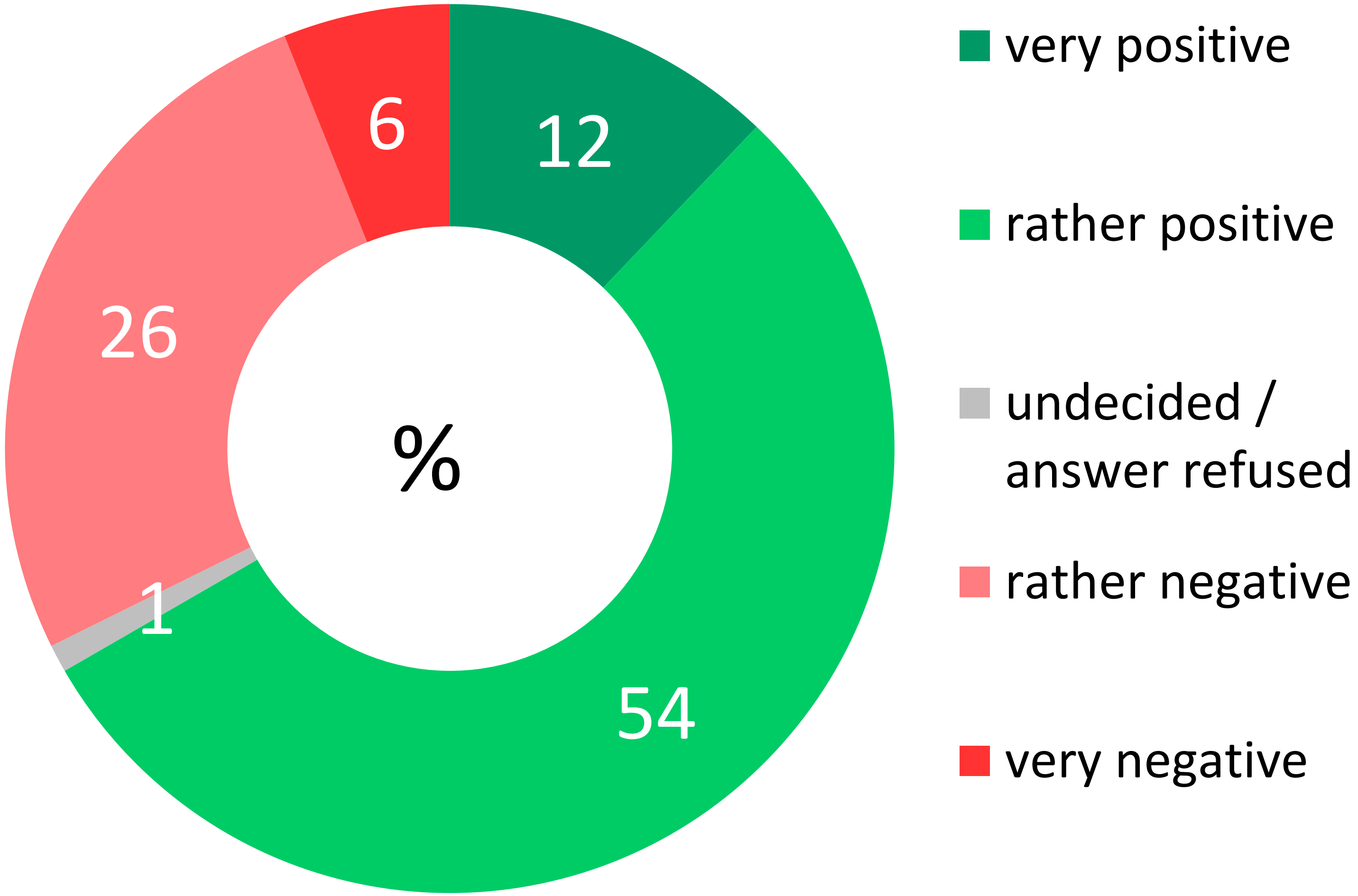
General Attitude Towards Civil Drones

2018



2022



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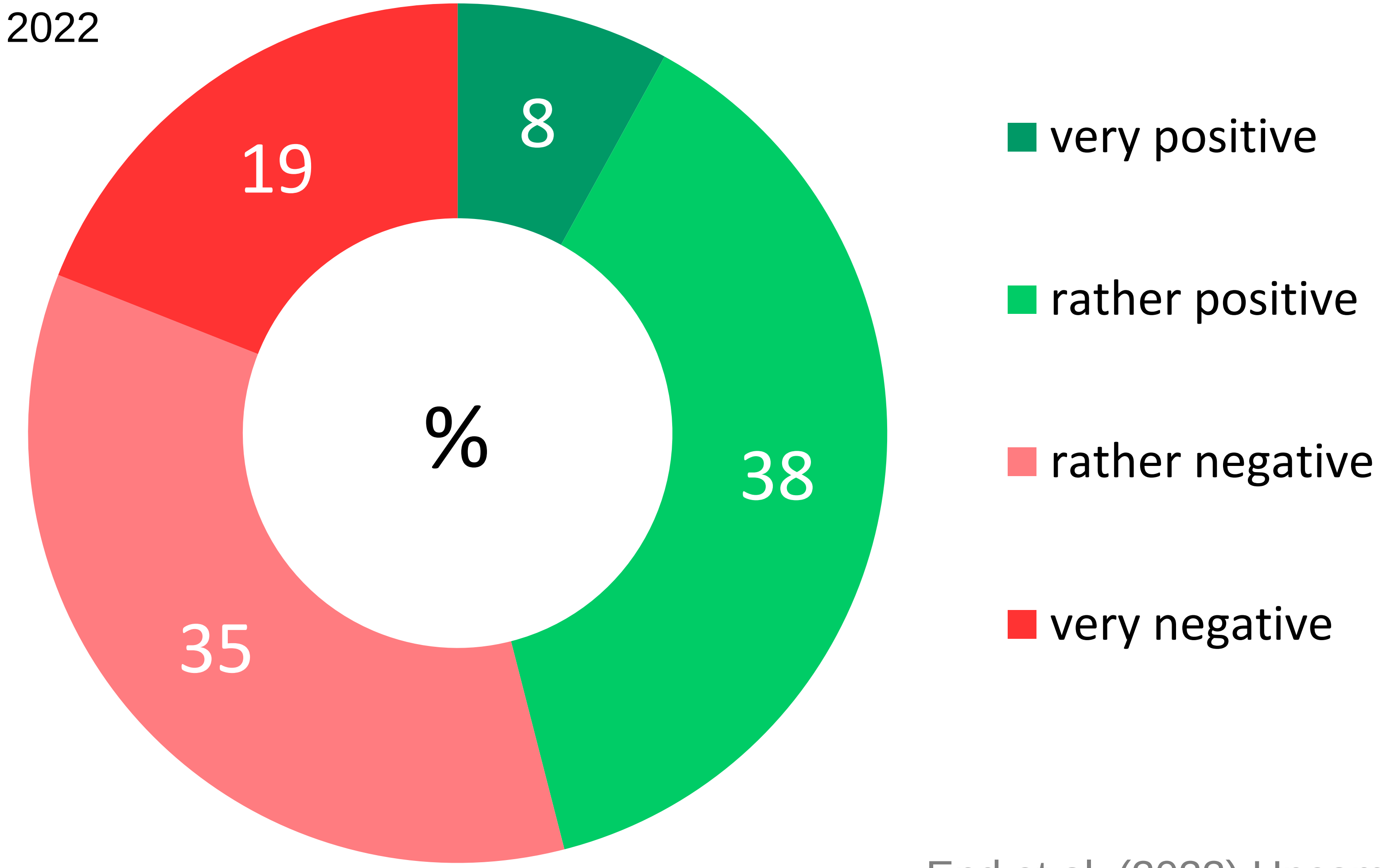
General Attitude Towards Air Taxis



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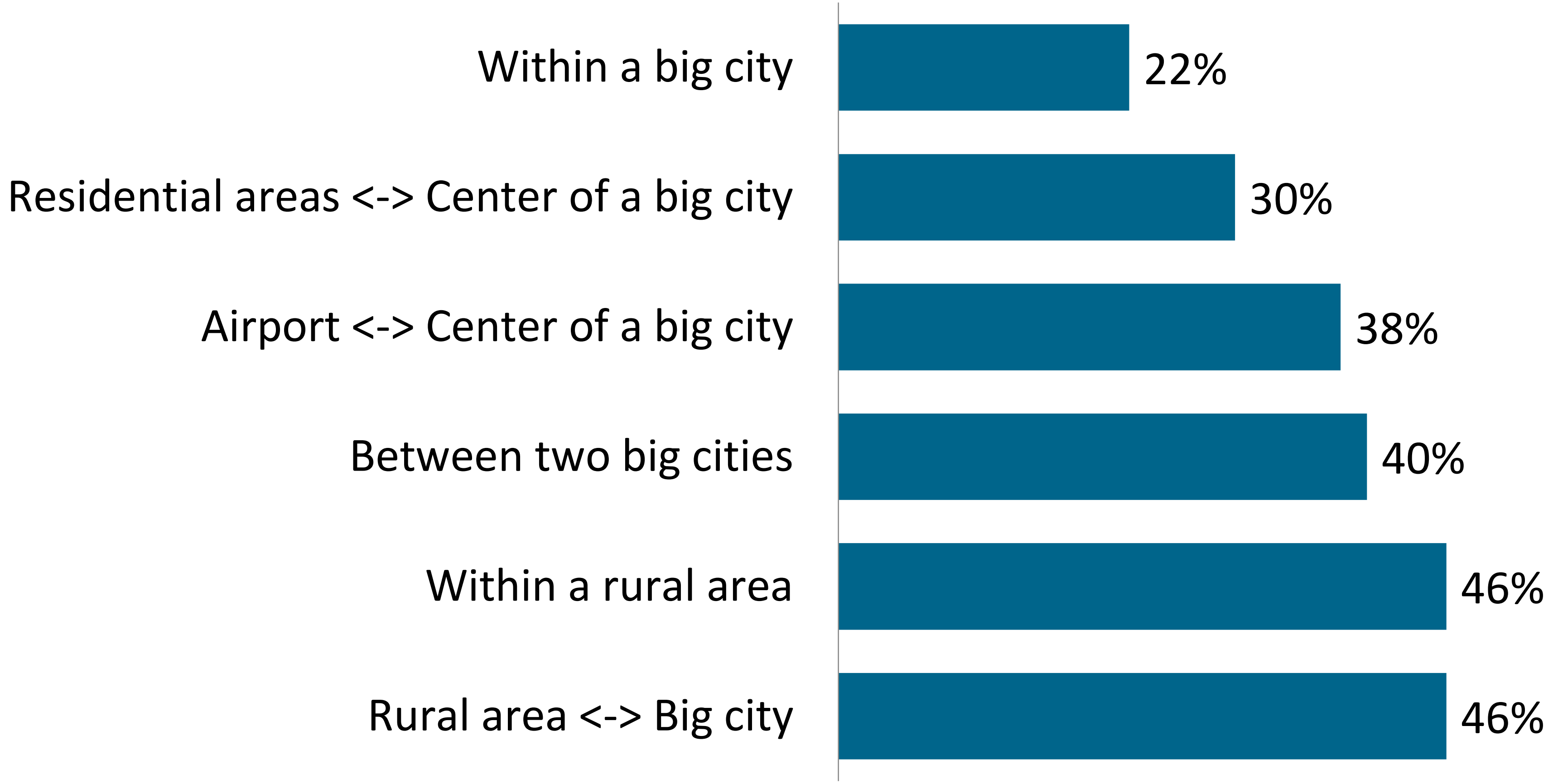
Willingness to Use an Air Taxi



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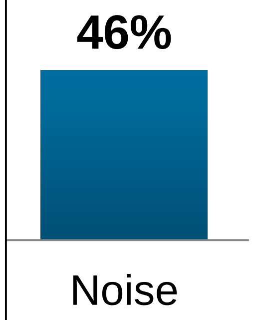
Concerns About Civil Drones

Noise

"..there are certain threats that could impede the sustainable and thus successful introduction of UAM to our cities, with noise being a prominent limitation." (26)



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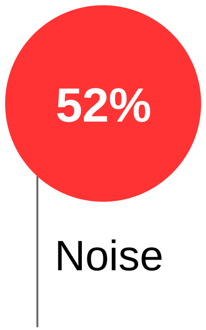

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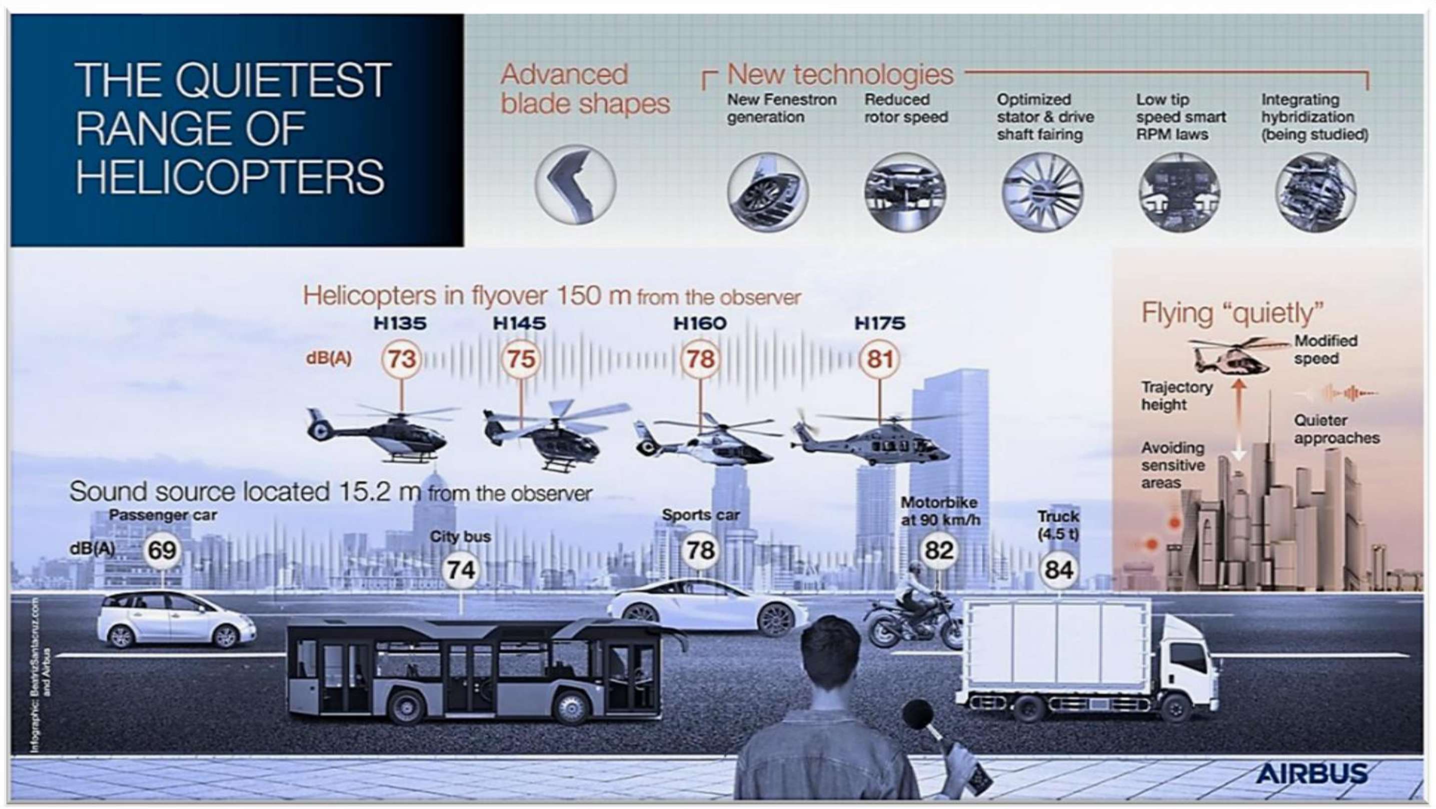
Noise of Helicopters

The main source of sound emissions from helicopters is the rotors

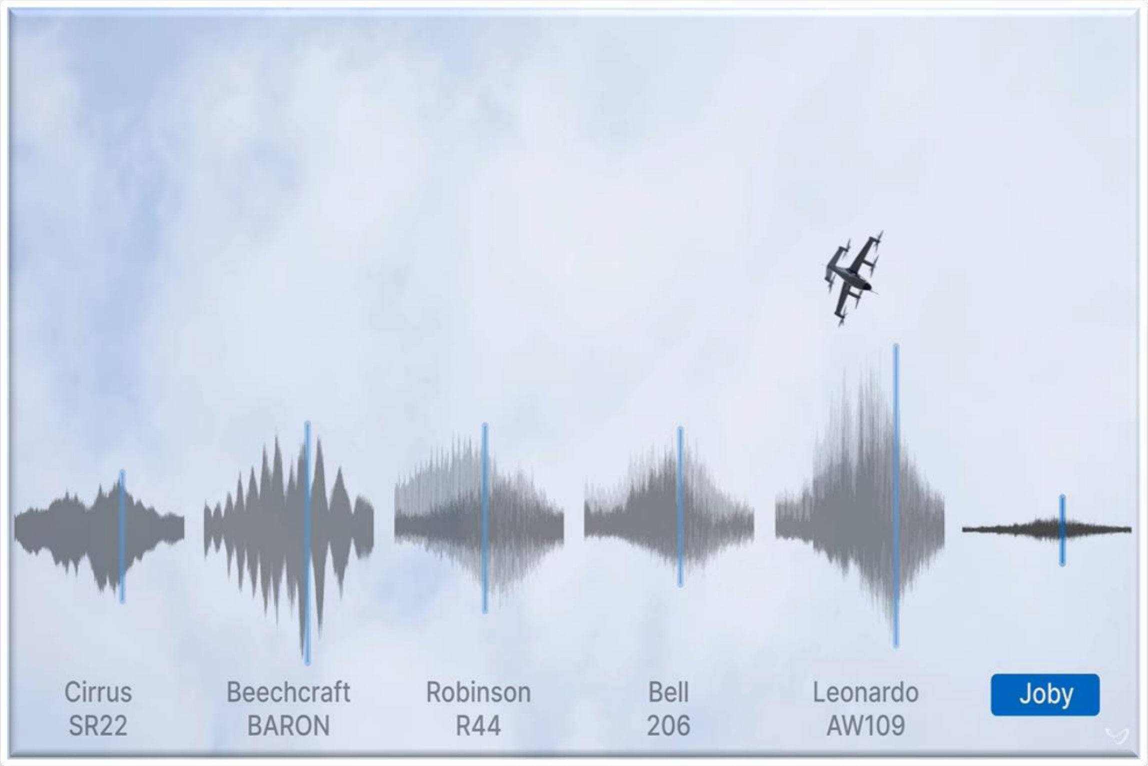


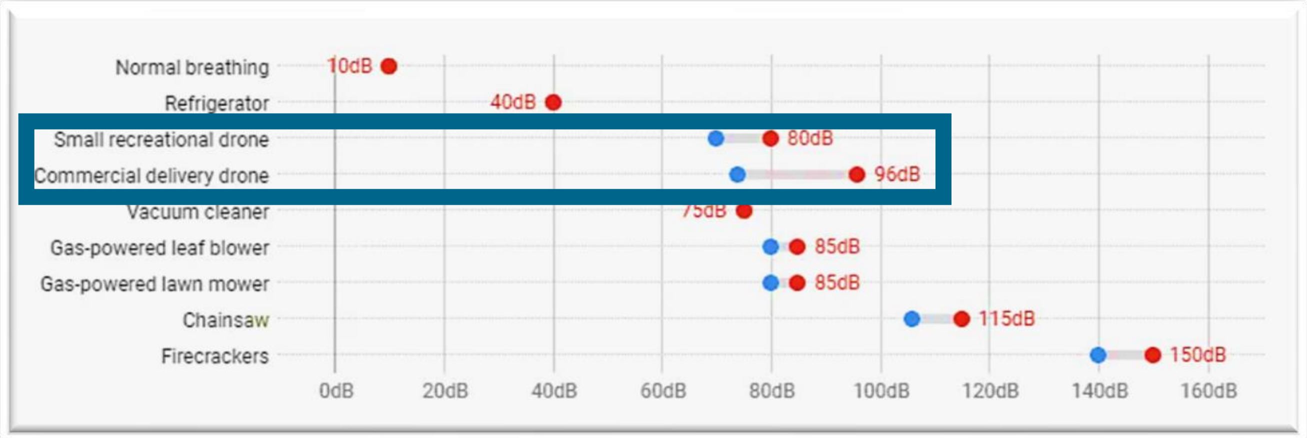
Source: https://www.airbus.com/en/sustainability/environment/helicopter-sound-footprint

- Flying at 500 feet is approximately 87dB.At 1,000 feet, the sound level drops to 79dB (HAI).

- The difference in sound level may not seem that great, but it is in fact significant. This is because sound levels are measured according to a logarithmic scale.

Noise in the context of UAM

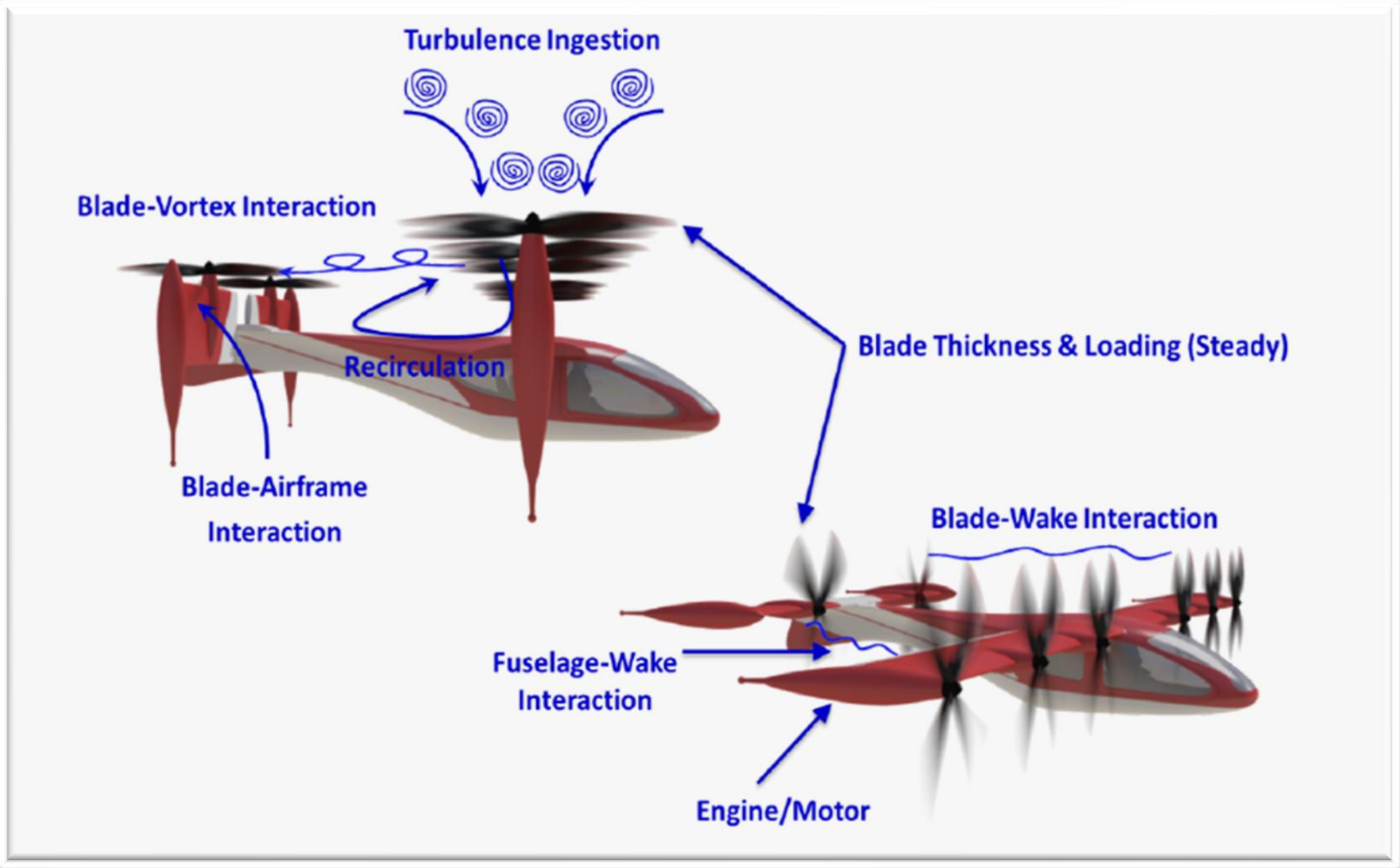




Source: https://www.volocopter.com/wp-content/uploads/Volocopter-WhitePaper-1-01.pdf

Source: Chart: The Conversation, CC-BY-ND Source: U.S. CDC, HealthLink BC, WeTalkUAV, RAND Corp., ACT Parliament, U.S. Patent Office

Noise in the context of UAM



Source: researchgate.net/publication/344493775_Urban_Air_Mobility_Noise_Current_Practice_Gaps_and_Recommendations

Concerns About Civil Drones

- Respondents with **lower subjective noise annoyance** with respect to the last 12 months and all sources of noise in total had a **more positive general attitude towards civil drones** ($p < .001$)
- Chi-square automatic interaction detection (CHAID) tree models:
  Concerns about the violation of privacy (on 1st level; $p < .001$) and concerns about bird/animal welfare (on 2nd level ; $p < .001$) predicted the general attitude towards civil drones best among all eight assessed concerns. Depending on the variables' scale levels used for analysis, additional predictors existed on 2nd and 3rd level (e.g., noise concerns)

End et al. (2023) Upcoming Preprint

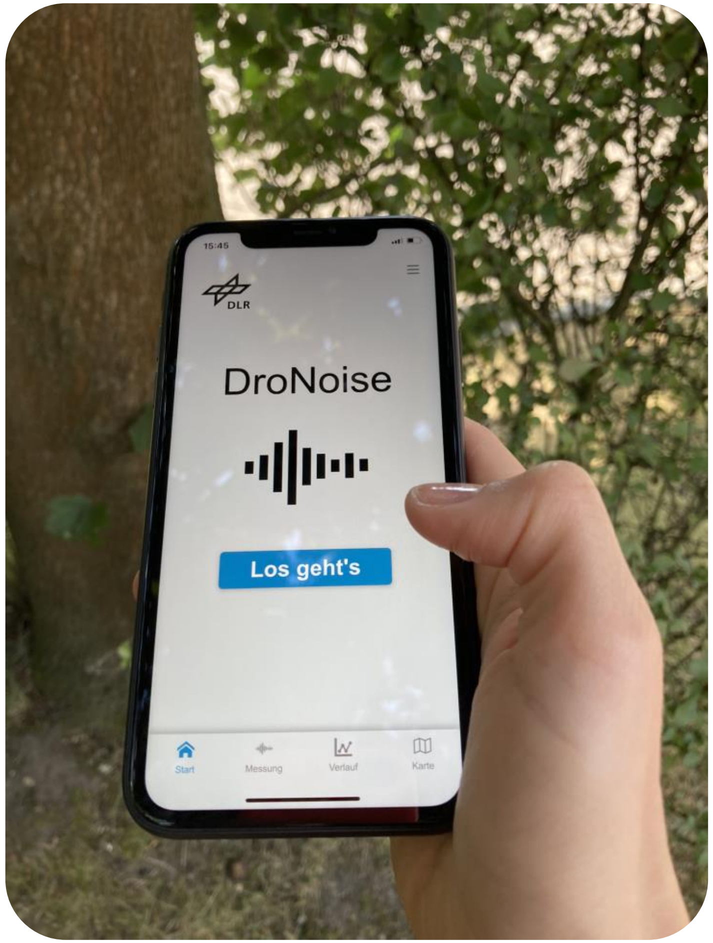
- cf. CHAID results of Eißfeldt et al.: **Noise concerns explained the general attitude towards civil drones best** among all seven assessed concerns ($p < .001$)

Eißfeldt et al. (2020) CEAS Aeronaut J

DroNoise – A Smartphone App for Assessing Drone Noise

- Development of a smartphone app for Android and iOS to measure drone noise and assess subjective annoyance
  (according to concept of Eißfeldt, 2020, Sustainability)

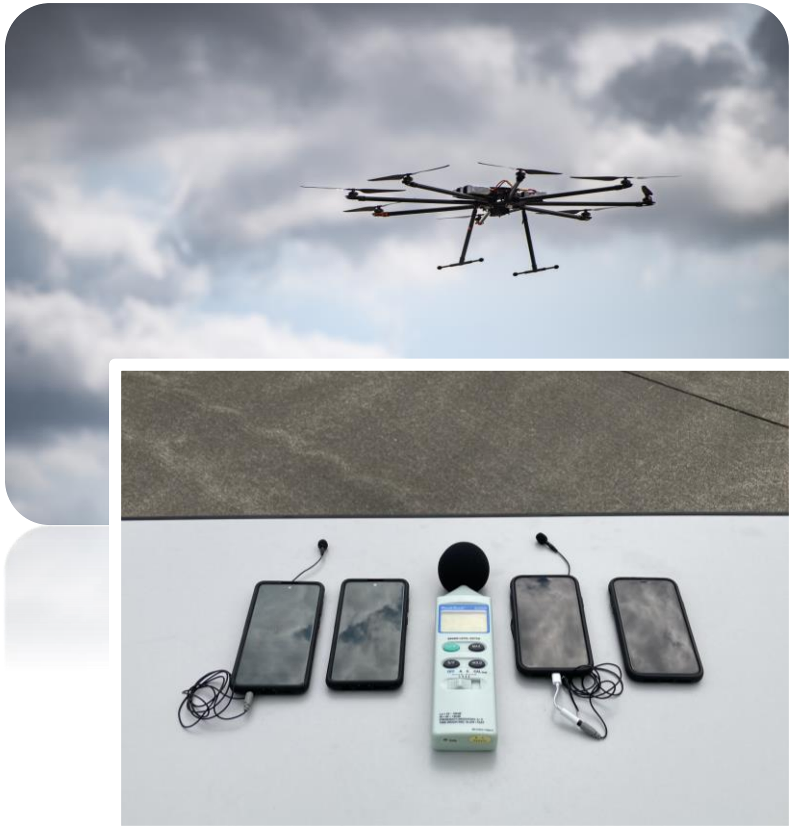
- Uses the smartphone's internal or a connectable external microphone for measurements
- When measuring, maximum value of the A-frequency-weighted and F-time-weighted sound level is recorded (L_{AFmax})
- Additionally assesses noise annoyance ratings
- History of measurements can be displayed
- User’s location can be displayed on a map



DroNoise – Tests

- Tested during live drone flight demonstrations at DLR's National Experimental Test Center for Unmanned Aircraft Systems in Cochstedt 2023

- Smartphones: 2x Samsung Galaxy A51, 2x iPhone 11
- Internal and external microphones (Rode smartLav+)
- Digital sound level meter (PeakTech® P 5055) as benchmark
- Recording time: 30s each
- Measured deviations of smartphones from digital sound level meter can be set as hardware-specific correction values within the app's administration area
- At flights with L_{AFmax} = 60-71 dB(A) at location of user, hardware-specific correction values between -2 and -8 dB(A) were necessary



DroNoise – Outlook

Perspective

- In the long term, it is planned to distribute *DroNoise* in public app stores

→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

Next steps

- Further developing and testing the current software version
- Interested in collaborating? Get in touch with us: Albert.End@dlr.de

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

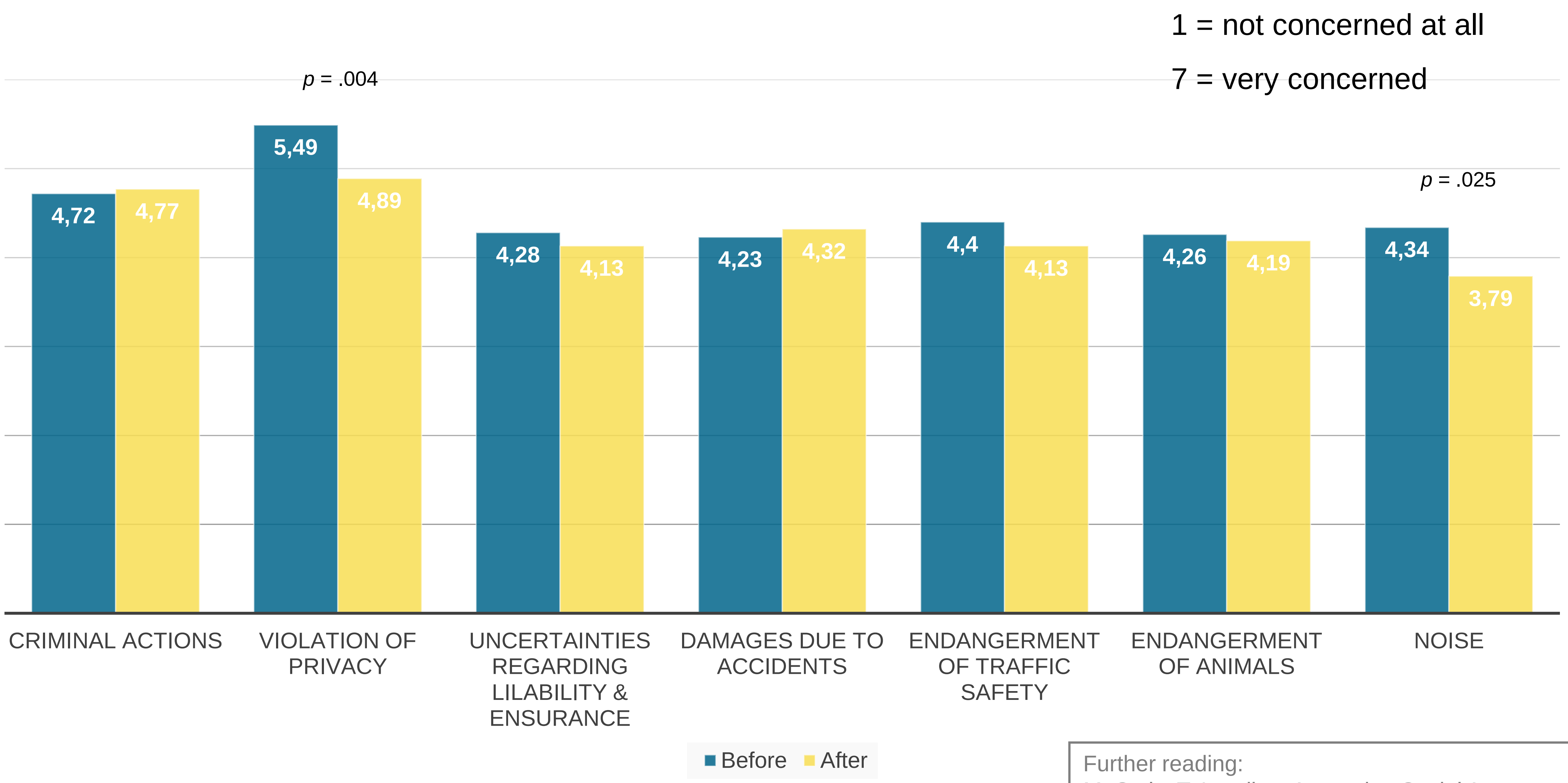
8 items, for example:

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, $p < .05$)

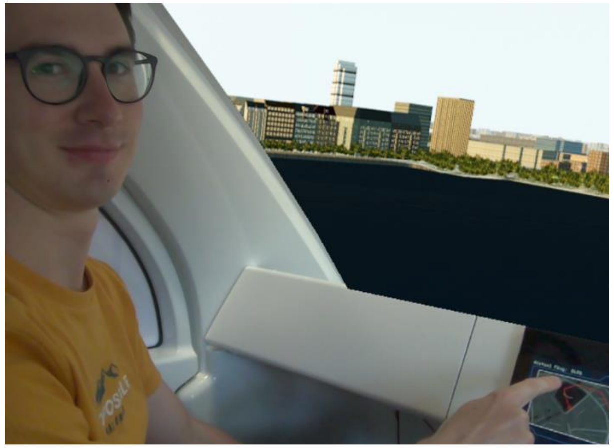
Results on Public Concerns

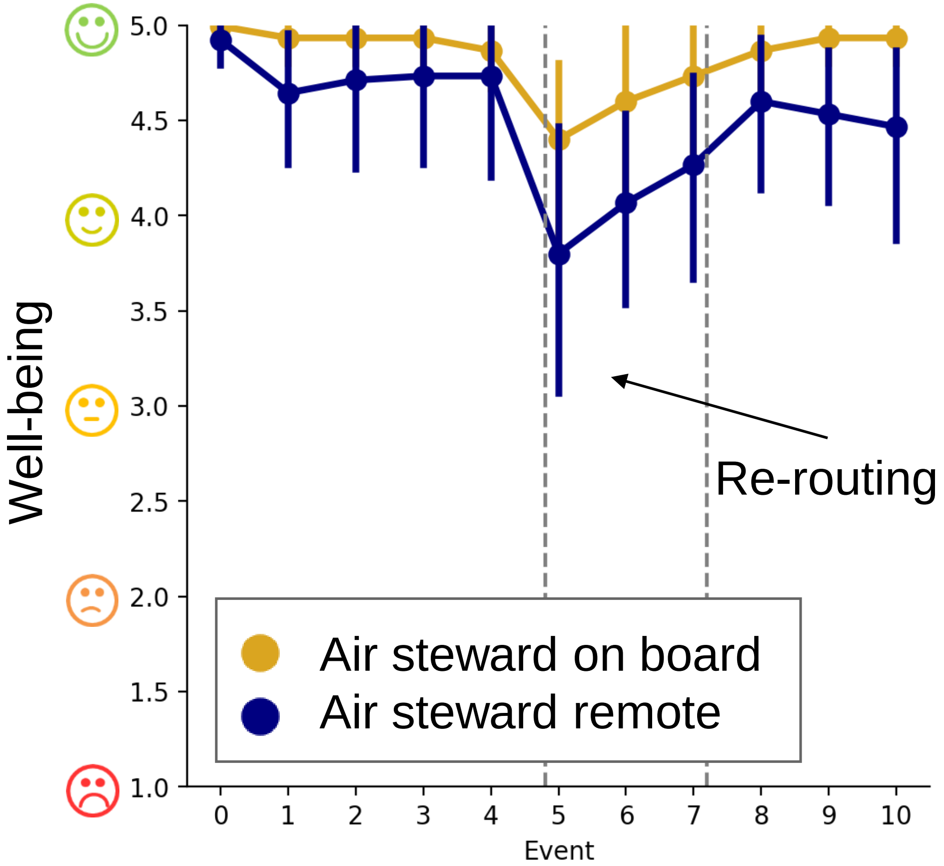


Further reading:
M. Stolz, T. Laudien, Assessing Social Acceptance of Urban Air Mobility using Virtual Reality, DASC 09.2022

Mixed 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 (Papenfuß et al., 2023, Upcoming Preprint)





- 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 ($p = .086$)

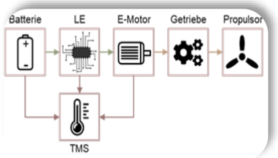
Outlook: DLR project VIRLWINT

Sound emission and psychoacoustic noise perception of distributed propulsion systems

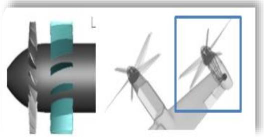
DLR

conceptual design


UAM vehicle



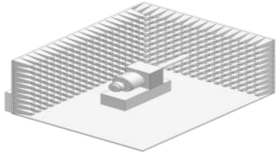
powertrain


fan & propeller

sound measurements on individual components


wind tunnel

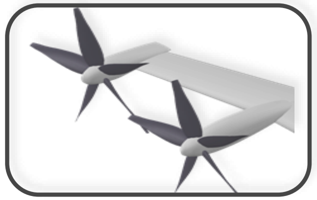

fan test rig

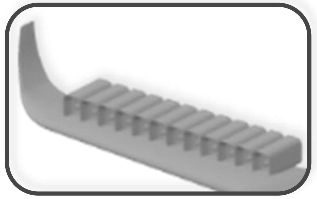

powertrain

virtual assembling of measurement data

combine different measurements on individual components to obtain various distributed propulsion systems

virtual flyover simulations & auralization


wing tip propellers


spanwise fan stages


spanwise propellers

psychoacoustic assessment


listening tests


app to modify and evaluate the aural sound impression

2023 → 2024 → 2025 → 2026

Conclusion

Challenges

- Urban air mobility is a complex system-of-system including vehicles, infrastructure, operation and public acceptance.
- Low ticket prices and short access and egress to vertidromes are key to driving demand for UAM.
- Noise concerns are associated with the general attitude towards civil drones in the German population.
- Further research on the perception of air taxis noise is required.

Opportunities

- Battery-electric air taxi concepts promise a new mode of individual passenger transportation.
- 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.
- There could be market potential for UAM in more than 200 cities worldwide by 2050.

- HorizonUAM -

THANK YOU FOR YOUR ATTENTION

www.horizonuam.dlr.de

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DLR

Imprint

Topic: **Challenges and Opportunities of Urban Air Mobility**
How Much Noise is Acceptable?

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Authors: B.I. Schuchardt, A. End, H. Pak, F. Meller, K. Schweiger, C. Torens

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