Master Thesis

Ushering the Future: Autonomous Follow-Me Bots for Seamless Taxiing guidance

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Preface

As a future product innovator, I believe design should stay a step ahead to predict the future. This thesis reimagine how automation and aviation can meet through human-centered thinking, creating a clearer, more intuitive dialogue between pilots and the vehicles that usher them.

Note:
The content of this thesis report, including the structure, concept, and layout, is drafted by me. AI tools were used solely for grammar checks, language refinement, and improving clarity of expression. “100% AI detected” doesn’t mean using AI for generating all, but means that the text has been linguistically refined using AI.

Acknowledgement

Special thanks to my supervisor team: Elmer and Yan.

Elmer

Thank you for choosing to work with me on this project and for valuing my design sketches from the very start. It was an exciting beginning for me as a designer to work on something I'm truly passionate about and that connects directly to my future career path. I especially appreciate how you encouraged me to be bold and adventurous in the creative process, while ensuring the storytelling remained coherent and well-structured.

Yan

Coming from different faculties, it has been a pleasure to collaborate with you and learn from your perspective on problem-solving. I gained valuable insights into using VR for testing and data analysis, and your critical questions always guided me toward conducting well-considered research and interpreting results in a professional way, thank you for being my mentor!

Usher AI – Simon, Dirk, and Robbert

Thank you for generously sharing your aviation knowledge and actively participating in this project beyond scheduled meetings. I deeply appreciate how you kept me aligned with your vision, and how your passion for transforming the industry through innovation was paired with strong business strategies, networking, and impactful storytelling.

A special thanks for taking me to Lisbon for Airspace World 2025 – an inspiring opportunity to witness the latest advancements and existing solutions in the field. This experience brought me closer to the industry and helped me reflect on how design and innovation can bring tangible value to aviation.

It has been an incredible journey to work with all of you. I wish Usher AI the very best as you continue shaping the future of autonomous airport operations.

XR Zone, TU Delft New Media Center

Developing the VR simulation in the XR Zone was an incredible learning experience. Special thanks to Josh, who patiently guided me step-by-step through Unreal Engine and coding logic. Without a programming background, this was a challenging process, but your systematic approach helped me reach the point where I could work independently and truly understand the logic behind.

Other support: Family & Friends

Beyond those directly involved in the design development, I like to specially thanks to my parents for emotionally support me on chasing my dream and fly to Delft for my graduation. I am also deeply grateful to my boyfriend and all my wonderful friends, whose companionship, encouragement, and shared 'study buddy' moments made this thesis journey so much more meaningful.

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BACKGROUND

In this chapter, the foundation of the graduation project is introduced, outlining the context, core challenges, and project scope. It presents the key stakeholders involved, formulates the central research question, and explains the user-centered methodology that guides the design and evaluation of an autonomous follow-me vehicle for airport ground operations.

1

1.1 Project Overview

This graduation thesis project is a collaboration between the Faculty of Industrial Design Engineering at TU Delft and Usher AI, an emerging AI startup aiming to revolutionize airport ground operations through automation. The project focuses on designing an autonomous follow-me vehicle, referred to as the UsherBot, that provides trustworthy taxiing guidance to pilots through its physical form, motion behaviors, and light-based signaling.

The final deliverables include both the interactive mobility concept of the autonomous vehicle and an evaluation study using Virtual Reality (VR) to assess the system’s performance from a pilot’s perspective.

Through an iterative, user-centered design approach, the project aims to contribute to future airport mobility by enhancing safety, efficiency, and communication on the ground.

1.2 Problem Framing

Airport Context

Modern airports operate at high capacities, with hundreds of aircraft taxiing simultaneously across shared ground infrastructure. However, Current taxiing procedures remain largely inefficient, as they depend on manual radio communication between pilots and air traffic control (ATC), without the support of integrated, real-time system updates (Eurocontrol, 2022; ICAO, 2004). This lack of structured, integrated guidance leads to unnecessary stops, route deviations, and increased fuel consumption, undermining both operational efficiency and environmental sustainability.

Challenges

Specifically, three key challenges highlight the pain points of the current taxiing process:

01 Safety Risks from Verbal Communication

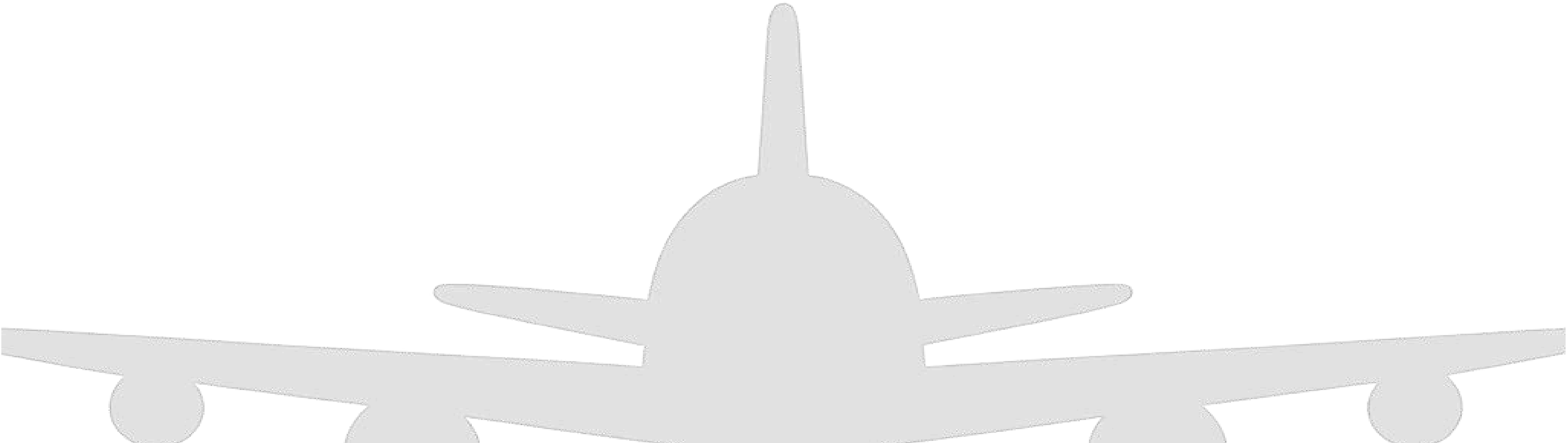
The continued reliance on verbal radio communication between pilots and ATC creates high cognitive and auditory load, increasing the risk of misinterpretation, particularly in complex or time-sensitive situations. This limitation contributes to surface incidents and runway incursions (ICAO, 2004; Pang et al., 2025).

02 Inefficiency from Fragmented Coordination

The continued reliance on verbal radio communication between pilots and ATC creates high cognitive and auditory load, increasing the risk of misinterpretation, particularly in complex or time-sensitive situations. This limitation contributes to surface incidents and runway incursions (ICAO, 2004; Pang et al., 2025).

03 Sustainability Challenges from Excessive Fuel Burn

Unstructured taxiing procedures lead to unnecessary stops and delays, with aircraft idling while waiting for clearance. This contributes to higher fuel consumption, operational costs, and emissions. Sustainable taxiing pilots at Schiphol suggest that structured, vehicle-assisted movement can significantly reduce environmental impact (Royal Schiphol Group, 2020a; 2020b).

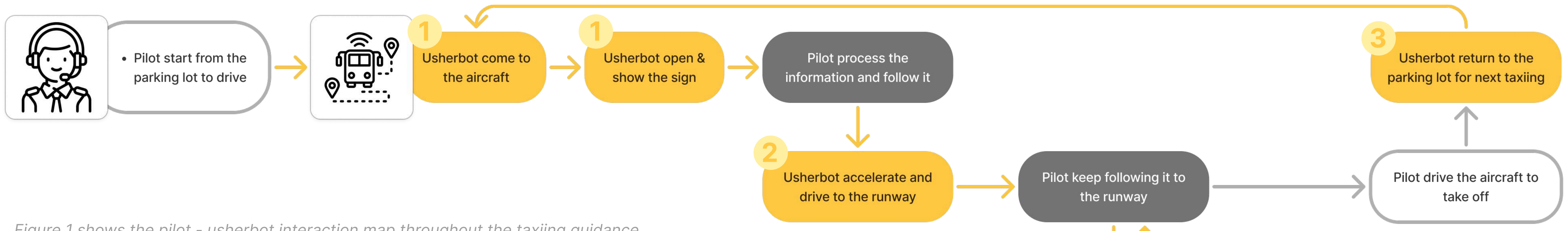


1.3 Project Scope

To clearly define the scope and narrow down the research focus, Schiphol Airport is used as a reference point for mapping the interaction between the UsherBot and human stakeholders. While the broader airport ecosystem involves multiple actors—including the vehicle, air traffic control (ATC), pilots, and ground operations staff—this graduation project focuses specifically on the interaction between the UsherBot and pilots, who are the primary and direct users of the system.

The scope is centered around two critical taxiing scenarios where the vehicle provides guidance:

1. From the start of the taxiway to the runway entrance for takeoff.
2. From the taxiway exit after landing to the gate, guiding the aircraft through the designated ground route


- Pilot start from the parking lot to drive

1 Usherbot come to the aircraft

1 Usherbot open & show the sign

Pilot process the information and follow it

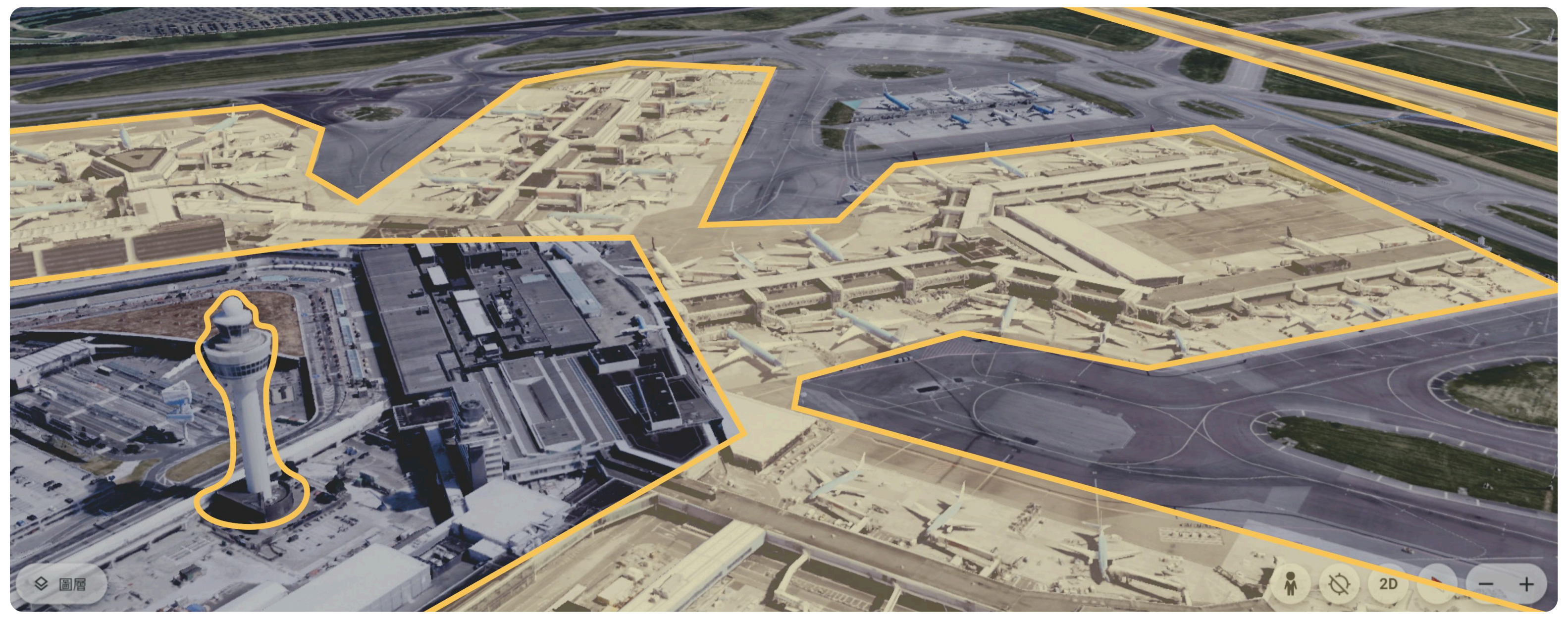
2 Usherbot accelerate and drive to the runway

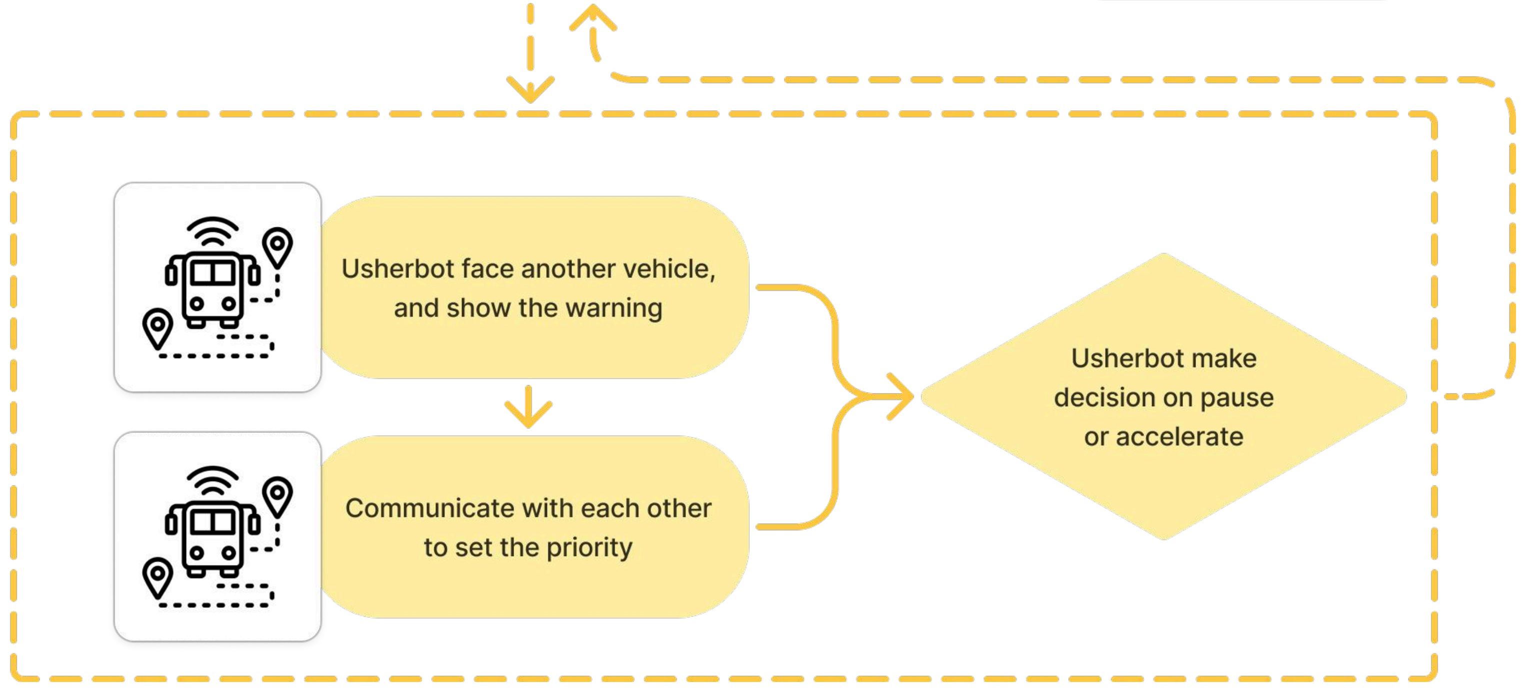
Pilot keep following it to the runway

Pilot drive the aircraft to take off

3 Usherbot return to the parking lot for next taxiing

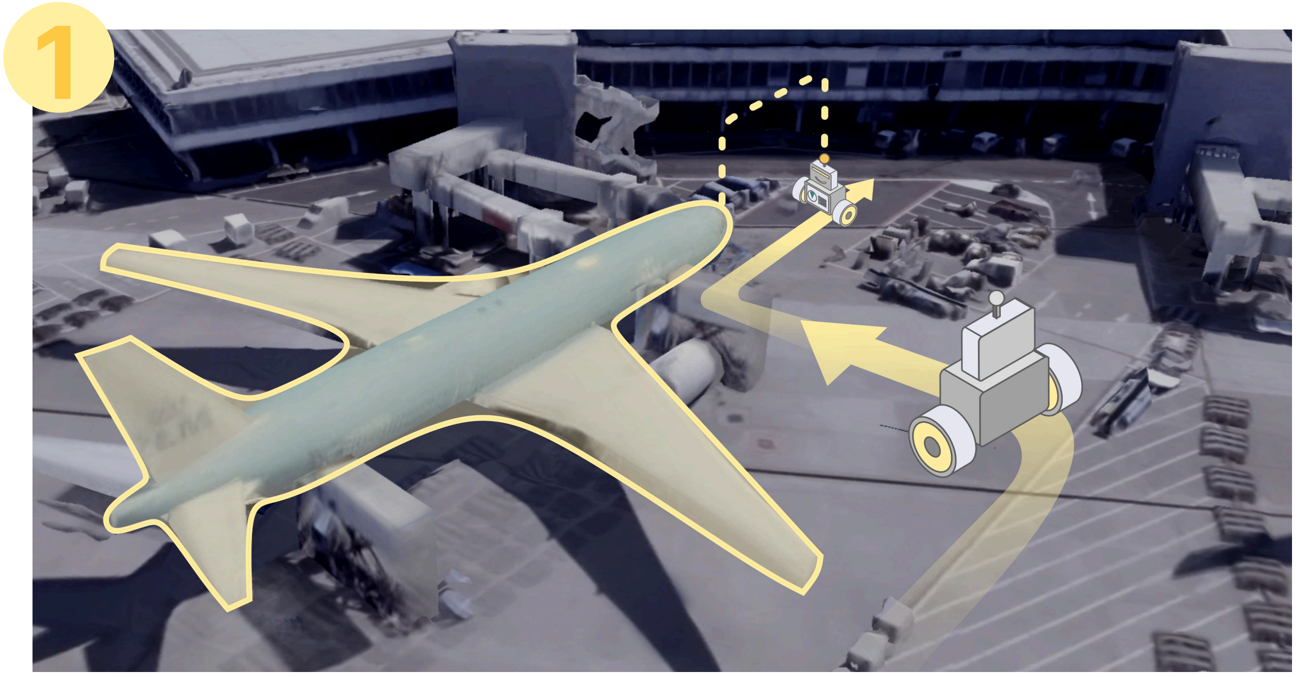
Figure 1 shows the pilot - usherbot interaction map throughout the taxiing guidance

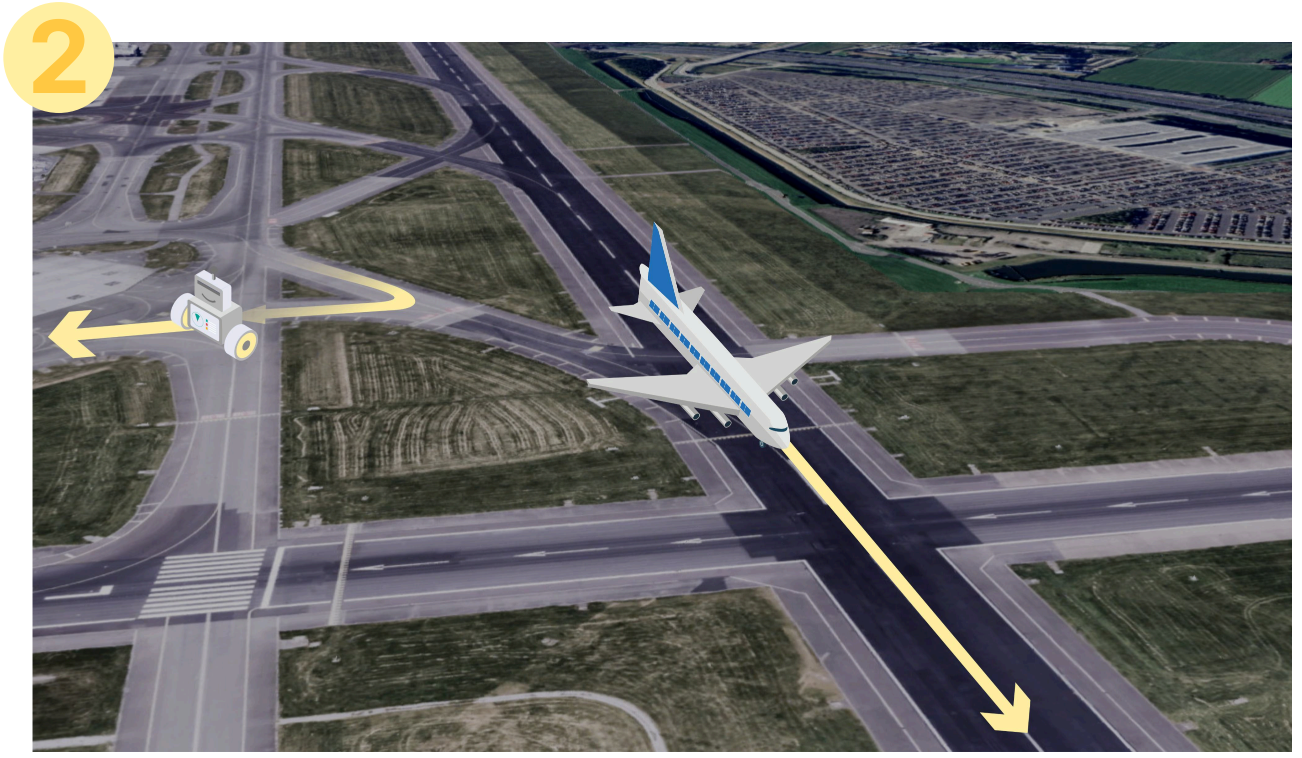


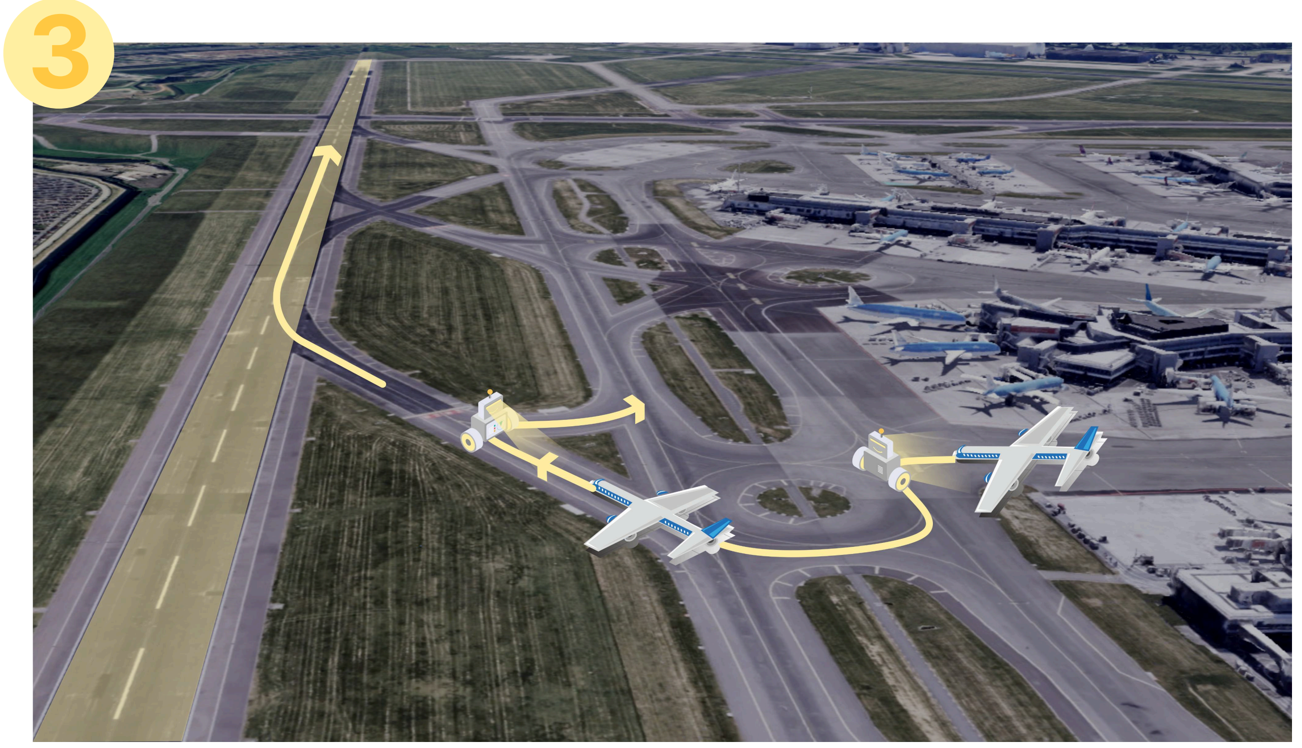

Usherbot face another vehicle, and show the warning

Communicate with each other to set the priority

Usherbot make decision on pause or accelerate







1.4 Stakeholders

To address these challenges within the scope, several key stakeholders are involved in shaping a robust and future-oriented design solution:

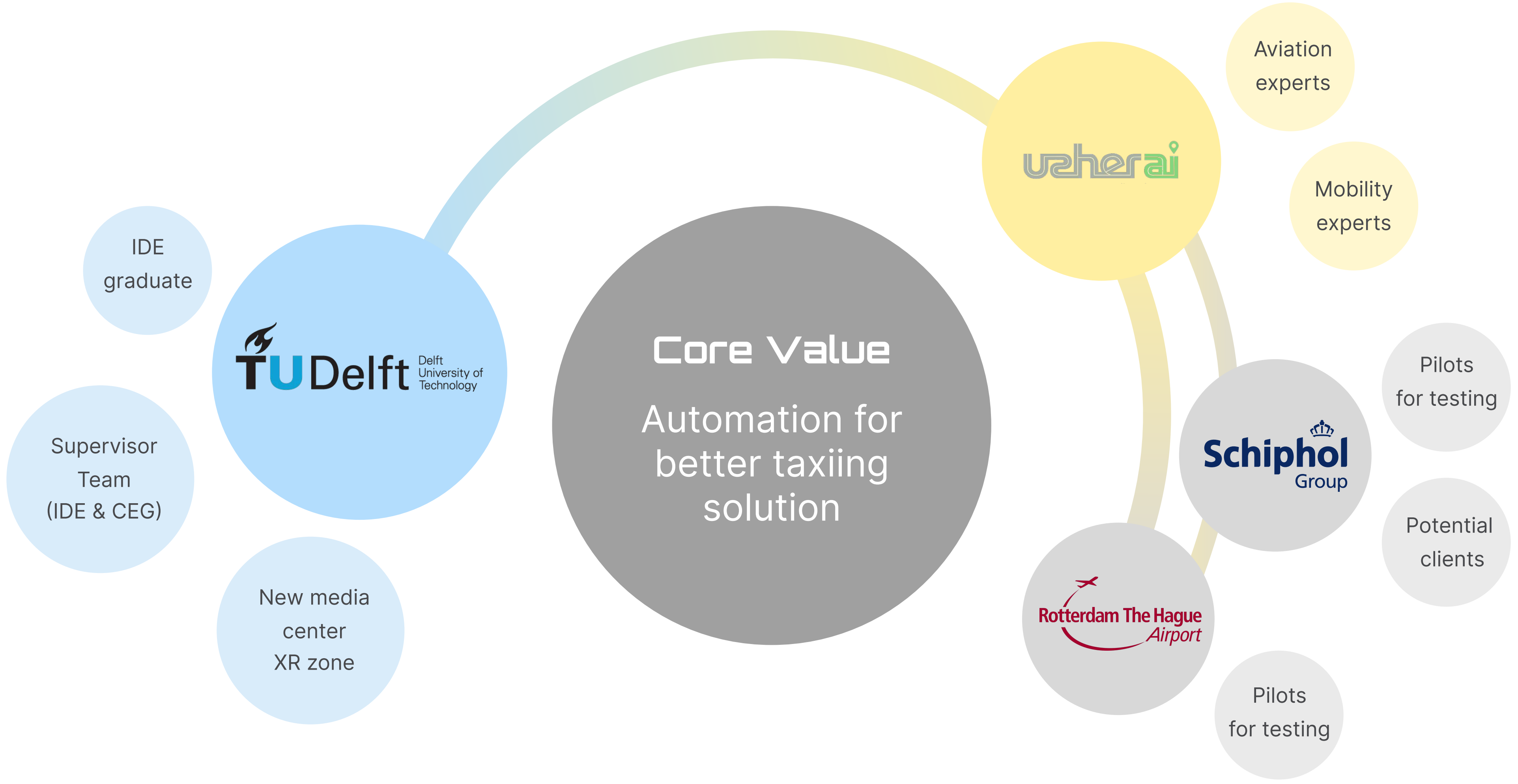


Figure 2 shows the stakeholder mapping and their roles on this thesis

TU Delft Supervision Team

Consisting of E.D. (Elmer) van Grondelle and Y. (Yan) Feng, together with myself as the graduation student, forms the academic foundation of the project. The supervisors offer structured guidance, design critique, and valuable insights throughout the process.

Usher AI

An AI-driven startup specializing in advanced ground movement solutions through the development of an Advanced Surface Movement Guidance and Control System (A-SMGCS). As the industrial partner in this project, Usher AI contributes professional aviation knowledge and continuous support.

Schiphol and Rotterdam The Hague Airports

Serve as real-world environments for field observations, stakeholder interviews, and potential testing grounds. Their complex operational settings provide essential real-life contextual input.

Building on stakeholder expertise and my own academic and design goals, I will develop a tangible solution based on Usher AI's proposed system. This will take the form of an automated, future-oriented follow-me vehicle, with a core focus on its role as a communication bridge.

The design will prioritize the delivery of clear, trustworthy, and intuitive guidance to pilots through a combination of light signals, motion behaviors, and digital taxiing instructions, ultimately enhance ground communication, contributing to a more structured, intelligent, and efficient taxiing system through purposeful interaction design.

1.5 Research Questions

Following the identification of key challenges and the definition of the project scope, focusing on the interaction between the pilot and the autonomous follow-me vehicle, this graduation thesis aligns with the initial brief from UsherAI: Designing an Automated Follow-Me Vehicle for Airport Ground Movement Guidance.

To move forward with the design process, it is essential to investigate how this vehicle can effectively communicate with pilots in a complex and time-sensitive taxiing environment. This leads to the central research question guiding this project:

How can an autonomous follow-me vehicle provide clear and trustworthy motion and signal-based instructions to pilots during taxiing?

To explore this main question, several sub-questions are formulated, addressing both the psychological and communicative aspects of the interaction:

Pilot Perception & Trust:

- How do pilots currently interpret and respond to taxiing instructions, and what are the challenges?
- What factors influence a pilot’s trust in an autonomous follow-me vehicle during taxiing?

Motion & Signal-Based Communication:

- What motion cues (e.g., speed adjustment, positioning, turning behavior) best communicate clear and trustworthy taxiing guidance to pilots?
- How can an autonomous follow-me vehicle use light signals and movement patterns to replace or supplement traditional radio-based taxi instructions?
- What design features enhance pilot confidence and reduce uncertainty when interacting with an autonomous follow-me vehicle?

Figure 3 defines the interaction between pilot, taxibot, and the aircraft

1.6 Methodology

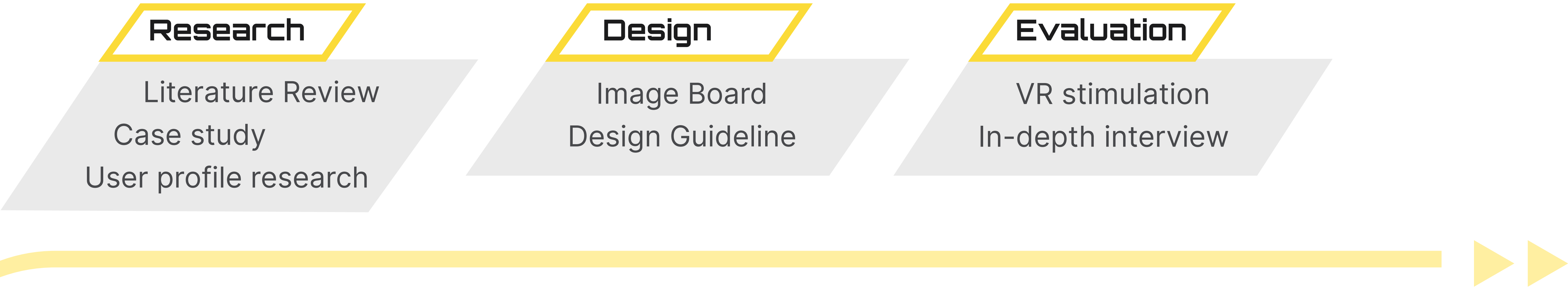
This graduation thesis adopts a user-centered design approach, combining both qualitative and experiential methods across three key phases: research, design, and evaluation.

Research

The project begins with a literature review and case study analysis focused on autonomous vehicle design and Human-Agent Interaction (HAI). These investigations explore how existing systems communicate with users through motion, light, and interface cues, providing foundational insights into the current state of interaction design.

Guideline for Design

During the ideation and development stage, methods from the Delft Design Guide are applied, such as image board analysis, mood mapping, and form exploration to define the product identity and establish a coherent visual and behavioral language. These methods guide the translation of conceptual direction into tangible design proposals, ensuring alignment between functionality, aesthetics, and context.



Research

Literature Review
Case study
User profile research

Design

Image Board
Design Guideline

Evaluation

VR stimulation
In-depth interview

VR for Evaluation

In the final phase, Virtual Reality (VR) is used as an immersive simulation and evaluation tool. By placing participants in a first-person cockpit perspective within a taxiing scenario built using Unreal Engine, the study assesses the clarity, intuitiveness, and trustworthiness of the UsherBot’s motion and light-based signaling system. Cognitive response and behavioral feedback are collected through think-aloud protocols and semi-structured interviews to evaluate pilots’ reaction, responding to both qualitative feedback and quantitative score analysis.

first person perspective

Think out loud

Semi-structured interviews

Research & Analysis

In this chapter, theoretical and visual references are explored to build the foundation for designing trustworthy communication between the UsherBot and pilots. Through a literature review on trust in human–autonomous interaction, eHMI strategy, visual case studies of expressive mobility systems, and user profile analyzation, this chapter uncovers key principles that guide the development of motion- and signal-based interaction strategies.

2.1 Literature Review

Outline

Autonomous systems are transforming high-stakes environments such as aviation, mobility, and industrial operations. For successful adoption, their interaction with human operators must foster trust, transparency, and intuitive understanding. This section explores two key domains:

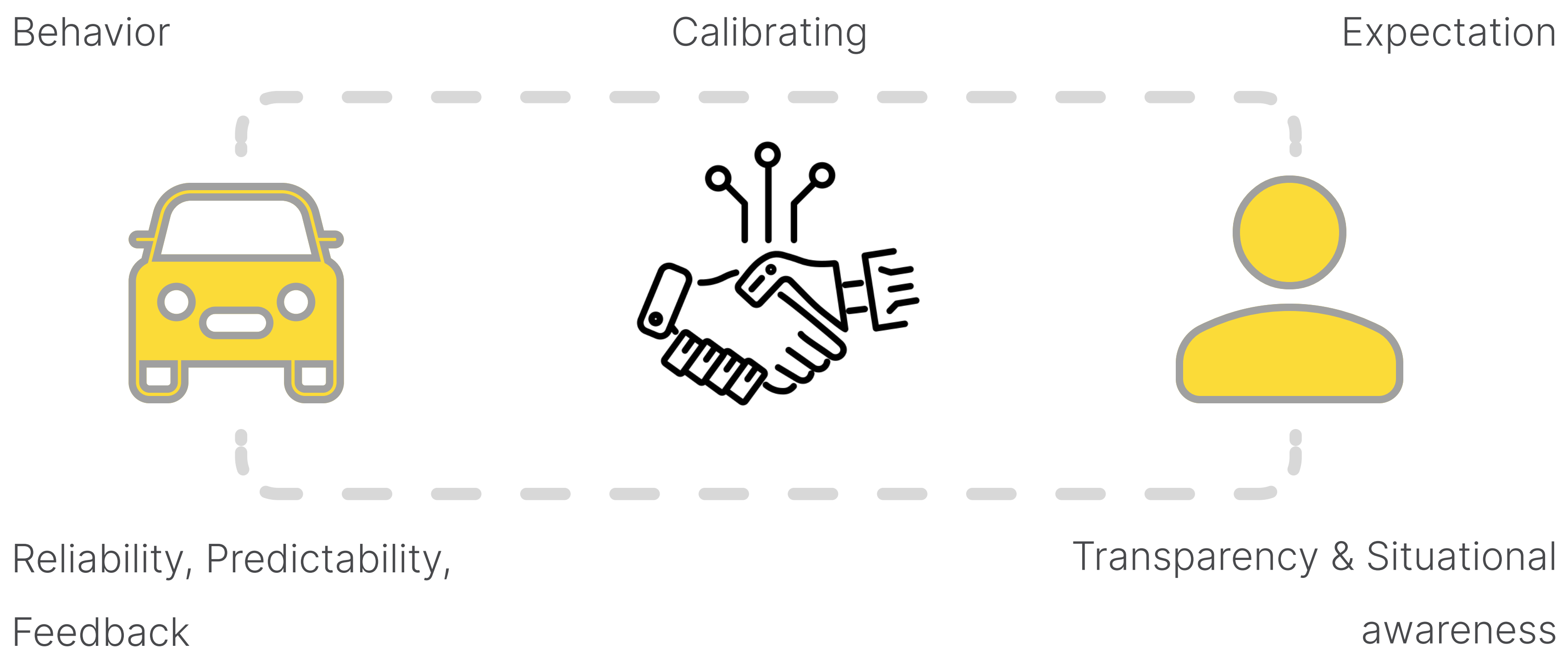
1. Trust in Human–Autonomous Interaction (HAI)
2. Use of external Human-Machine Interfaces (eHMI) in autonomous vehicles

These areas provide foundational knowledge for designing an autonomous follow-me system that guides pilots safely and clearly during taxiing.

Trust in Human–Autonomous Interaction

Trust is a central psychological construct in Human–Autonomous Interaction, especially in safety-critical environments. According to Lee and See (2004), trust in automation is shaped by the system's perceived reliability, predictability, and the appropriateness of its feedback. Muir (1994) highlighted the importance of ongoing calibration between user expectations and system behavior, while Hoff and Bashir (2015) emphasized transparency and situational awareness as key contributors to trust.

In aviation, where procedural clarity is essential, automation should match or exceed the clarity of traditional communication. Misaligned expectations, such as unclear or delayed signaling, can undermine trust, resulting in hesitation or non-compliance. Therefore, systems like the UsherBot should provide continuous, easy interpret feedback through motion, light, and behavior. This helps build a mental model for the pilot, making the bot’s actions predictable and trustworthy in a variety of airport conditions.



Behavior

Calibrating

Expectation

Reliability, Predictability, Feedback

Transparency & Situational awareness

Figure 4 shows a visual summary of Trust in Human–Autonomous Interaction

eHMI in Autonomous Vehicles: Design Strategies and Interaction Modalities

Acting as an intermediate between human and machine, eHMI enables autonomous systems to communicate with surrounding users and enhance interaction clarity through visual and motion cues.

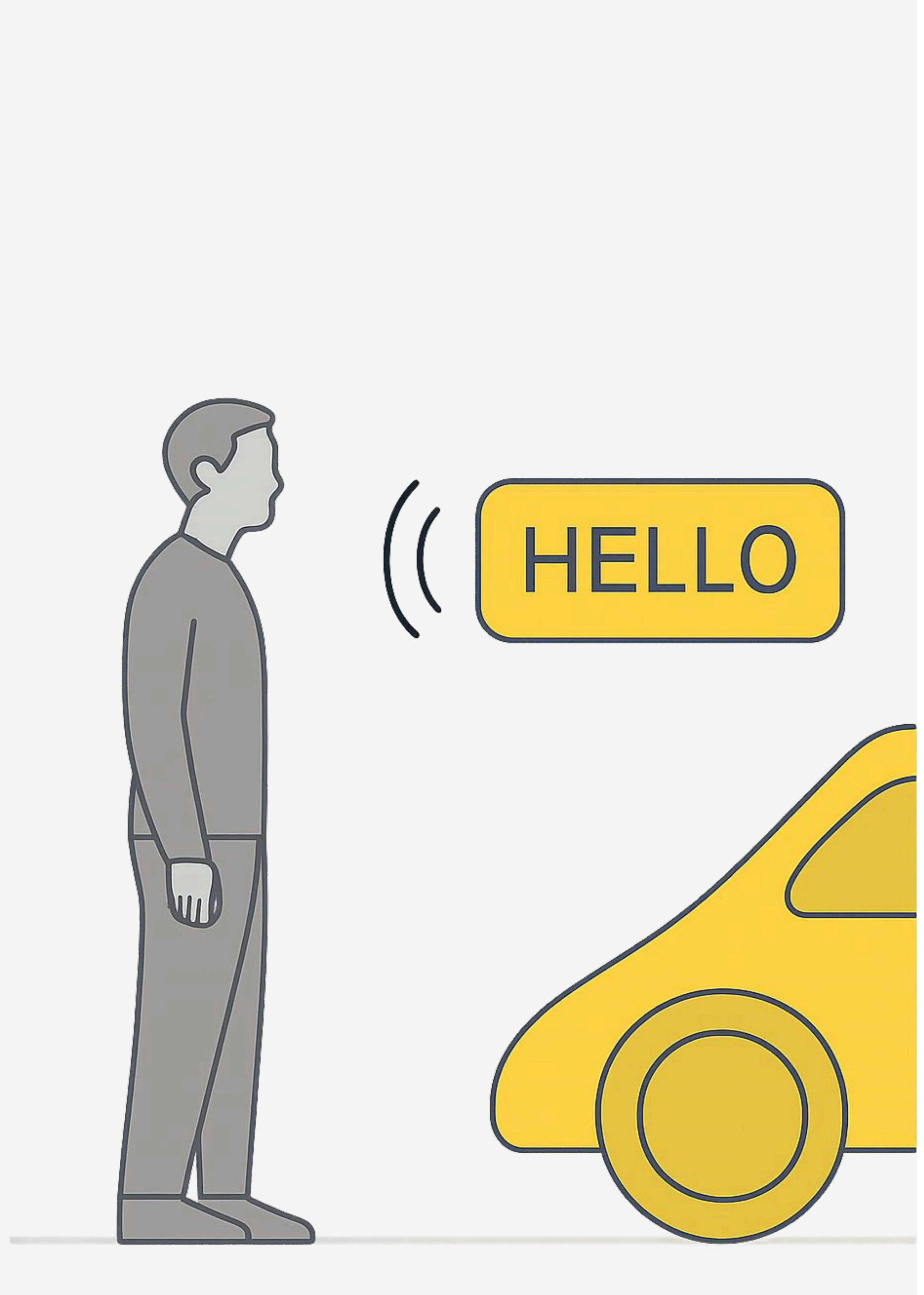
Studies by Dey and Terken (2017), Mahadevan et al. (2018), and Ackermann et al. (2019) show that behaviorally aligned cues, such as light color, blinking patterns, and coordinated motion, improve users' interpretation and trust.

Light and motion offer universally readable communication, ideal for noisy or multilingual environments. In addition, bio-inspired or metaphor-based motion (e.g., leading gestures, pausing to signal attention) has been shown to improve perceived intention clarity.

Recent studies have extended these findings: Chen et al. (2020) confirmed that animated light patterns and rhythm affect perceived urgency and safety, while Feng et al. (2025) showed that defensive motion behaviors improve trust in autonomous vehicle interactions. These insights support the development of UsherBot's signaling and motion logic.

While most eHMI research focuses on urban road contexts, the principles are transferable to airport environments. In particular, the use of lighting patterns and motion enables information to be conveyed directly without verbal interaction, which is especially useful in high-pressure and busy scenarios like airport taxiing.

These design strategies align closely with the goals of UsherBot, which aims to serve not just as a pathfinder but also as a readable interface for human pilots.

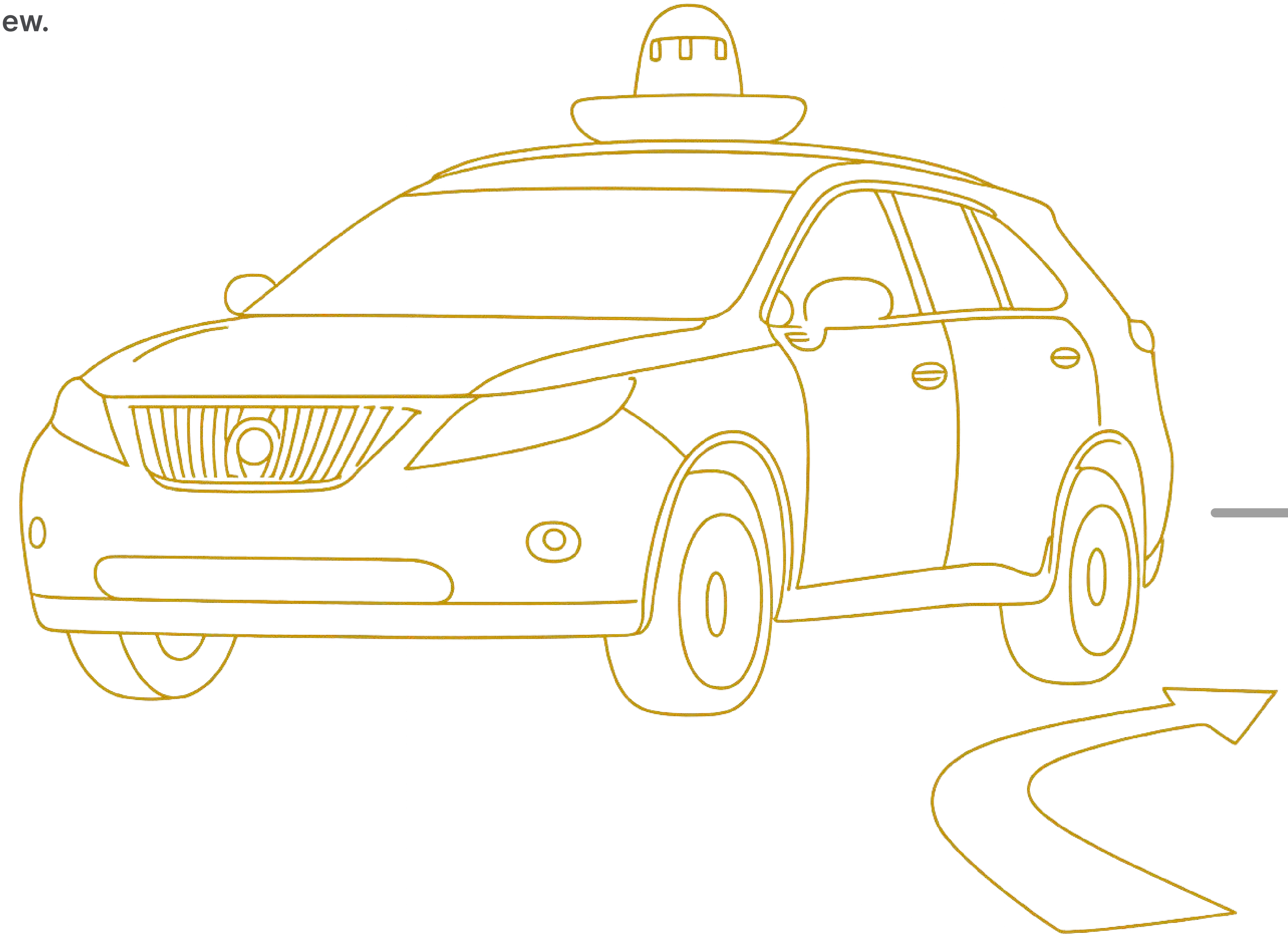


Practical application insights

SIGNAL & Perception

UsherBot’s lighting should balance visibility, emotion, and urgency, adapting to context and cockpit view.

- Dynamic patterns increase visibility: Blinking, chasing, and animated light patterns improve peripheral awareness and clarity (Chen et al., 2020).
- Blinking rhythm indicates urgency: Fast blinks deter approach; slow, continuous animations foster trust (Chen et al., 2020).
- Distance-based visual behavior: Closer distance triggers more assertive signals (Dey & Terken, 2017).
- Real-time navigation and contextual motion planning: integrating LIDAR and ROS-based architectures (Barbosa et al., 2020).



Motion

UsherBot’s motion should be smooth, readable, and purpose-driven, especially during initiation, turns, and stops.

- Defensive motion improves trust: Slowing, yielding, and cautious approaches enhance clarity and confidence (Feng et al., 2025).
- Bio-inspired gestures are intuitive: Leading gestures or pausing to signal “wait” improve intention recognition (Mahadevan et al., 2018).
- Smoothness matters: Sudden starts or stops confuse users; predictable transitions aid interpretation (Ackermann et al., 2019).

Trust

Trust emerges from clarity, testing, and consistence, VR-based validation ensures signals are interpreted as intended.

- Consistency and predictability build trust: Repeated, reliable behavior supports confidence (Lee & See, 2004; Hoff & Bashir, 2015).
- VR proves useful for testing: Simulated environments help validate how pilots interpret eHMI cues under stress (Tran et al., 2021).
- Multimodal integration improves comprehension: Synchronizing light with motion enhances overall interaction clarity (Ackermann et al., 2019).

Conclusion: The Iceberg Analogy

To sum up, Interaction with autonomous systems should go beyond technical performance by building trust and clarity from the user's perspective. Take iceberg as reference, pilots see only the lights and motion interaction from the vehicle, while its effectiveness depends on deeper layers: visibility level, cognitive processing, expectation alignment, and decision confidence.

From the first domain, trust emerges through transparency, consistency, and predictability, especially under dynamic conditions like taxiing. From the second, effective eHMI relies on intuitive, multimodal cues, particularly light and movement, to convey intent, reduce miscommunication, and support pilot confidence.

In this view, the UsherBot is not just a tool but an expressive interface, balancing rational clarity (e.g., signal visibility, route precision) with affective communication (e.g., body language, timing). Through predictable motion and legible light behavior, it becomes a trustworthy agent bridging automation with human interpretation. This layered understanding sets the stage for defining the interaction qualities and design criteria that guide the next development phase.

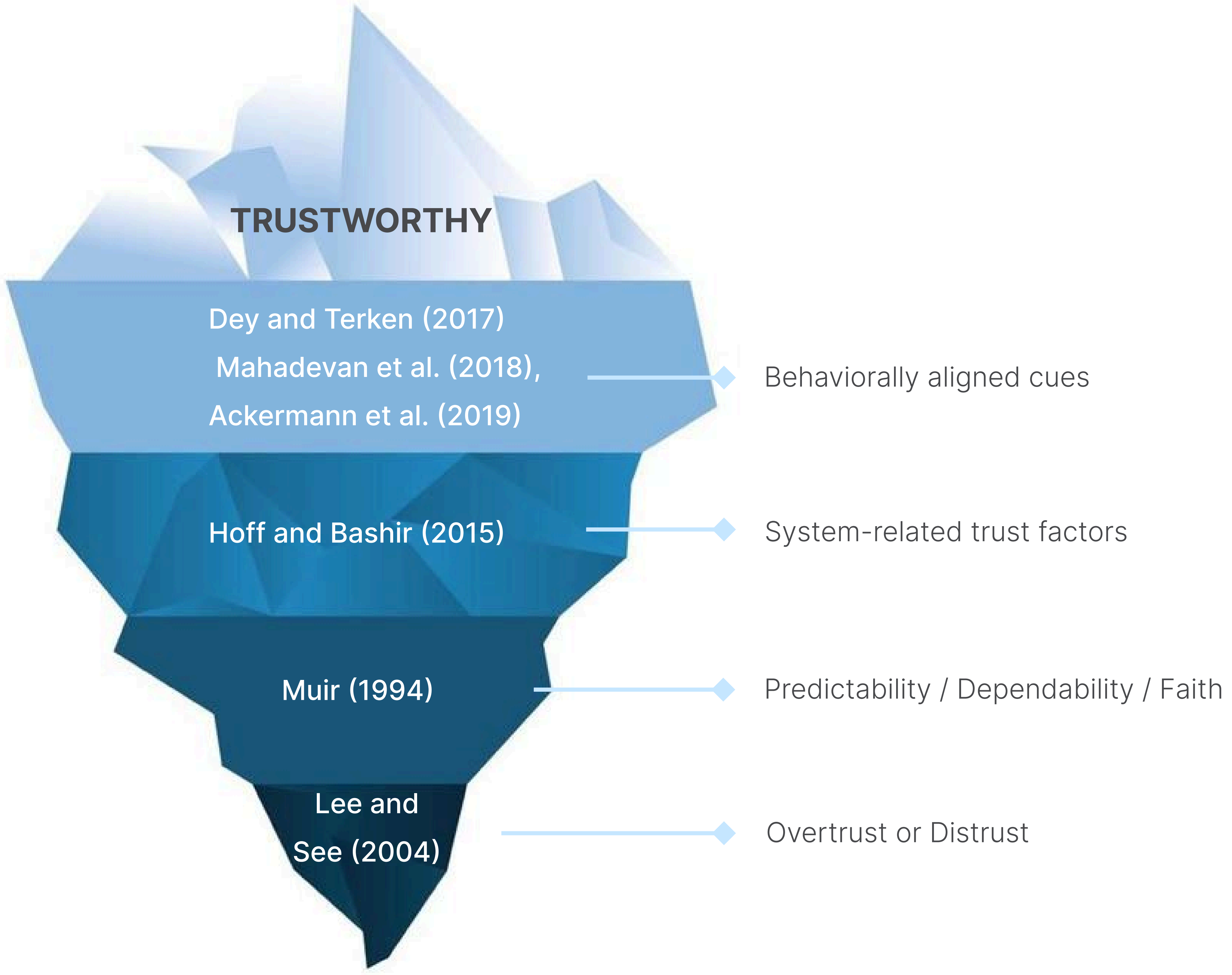
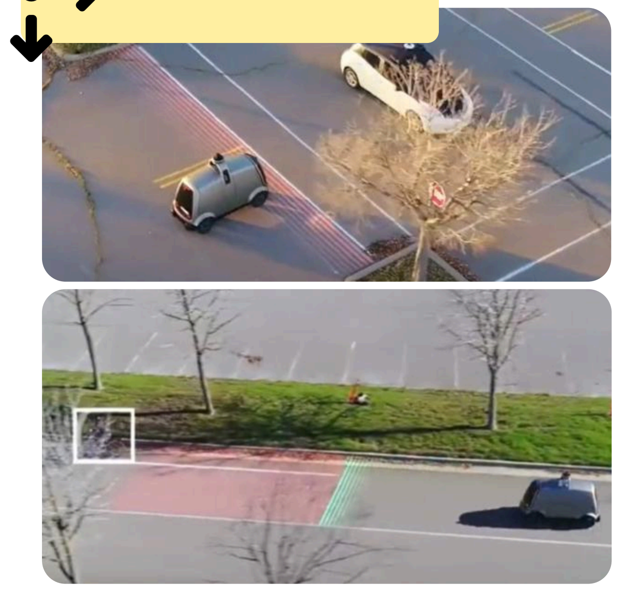


Figure 5 shows the literature insights in iceberg layer

2.2 Case Study

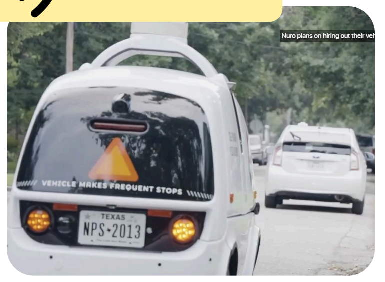
To inform the communication design of the UsherBot, visual case studies were conducted to analyze how autonomous systems convey intent through light, motion, and form. These references help translate abstract trust-building principles into tangible design cues.

Motion Cues



- Detect objects on road to adjust movement
- Recognize human activities and maintain safety distance

Signals



LED-Based Signaling System

- Directional indicators (turning, stopping)
- Interactive display for road users

Key Interaction

Introduction

01 Active device for communicating intention

02 LED screen display system, dynamic signal

03 Scanning for real time context data

Nura R2

Small autonomous delivery bot designed for road-based logistics focusing on safe, low-speed neighborhood operations.

01 Active device for transmitting information

02 Light Projection, dynamic signal

03 Human-like features, with breathing rhythm

Mecendiz Benz AVTR

Inspired by the film Avatar, emphasizing biomimicry, gesture interaction, and emotional connection

Starship Technologies

A compact sidewalk delivery robot used in urban areas and campuses to autonomously deliver food and packages.

01 Mix senses experience for communication

02 Blinking indicator fin for positioning & notification

03 Adaptive movement and speed for safety

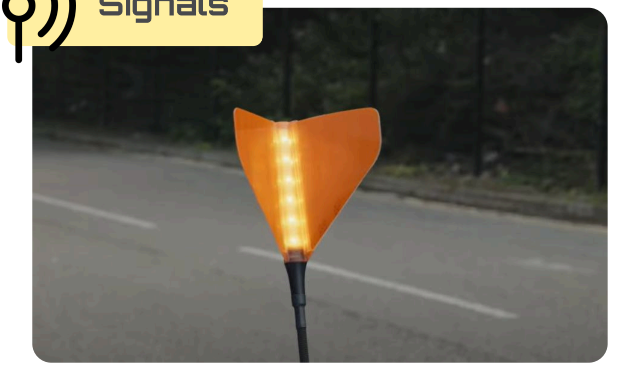
Signals

- Using Light and **Projection** to show vehicle's intention or guide pedestrian

Motion Cues

- Using Physical Scales to show the direction, and use the light to show **accelerate or brake**

Signals



Sound & Eye Contact for Trust Building

- Uses **beeping** sounds to signal movement, stopping, or warning
- "**Eyes**" on screens to mimic eye contact, increasing users' trust

Motion Cues

Speed & Proximity Awareness for Human Comfort

- Adaptive **speed control** to slow down in crowded areas.
- **Stops smoothly** when pedestrians approach, using motion as a soft cue.

Conclusion

The analysis of existing autonomous vehicle (AV) cases reveals several recurring interaction strategies and design languages that contribute to enhancing user trust and comprehension. These patterns offer valuable insights for shaping the communication and behavior of the Usherbot. (See Figure 6 for a visual summary of these findings.)

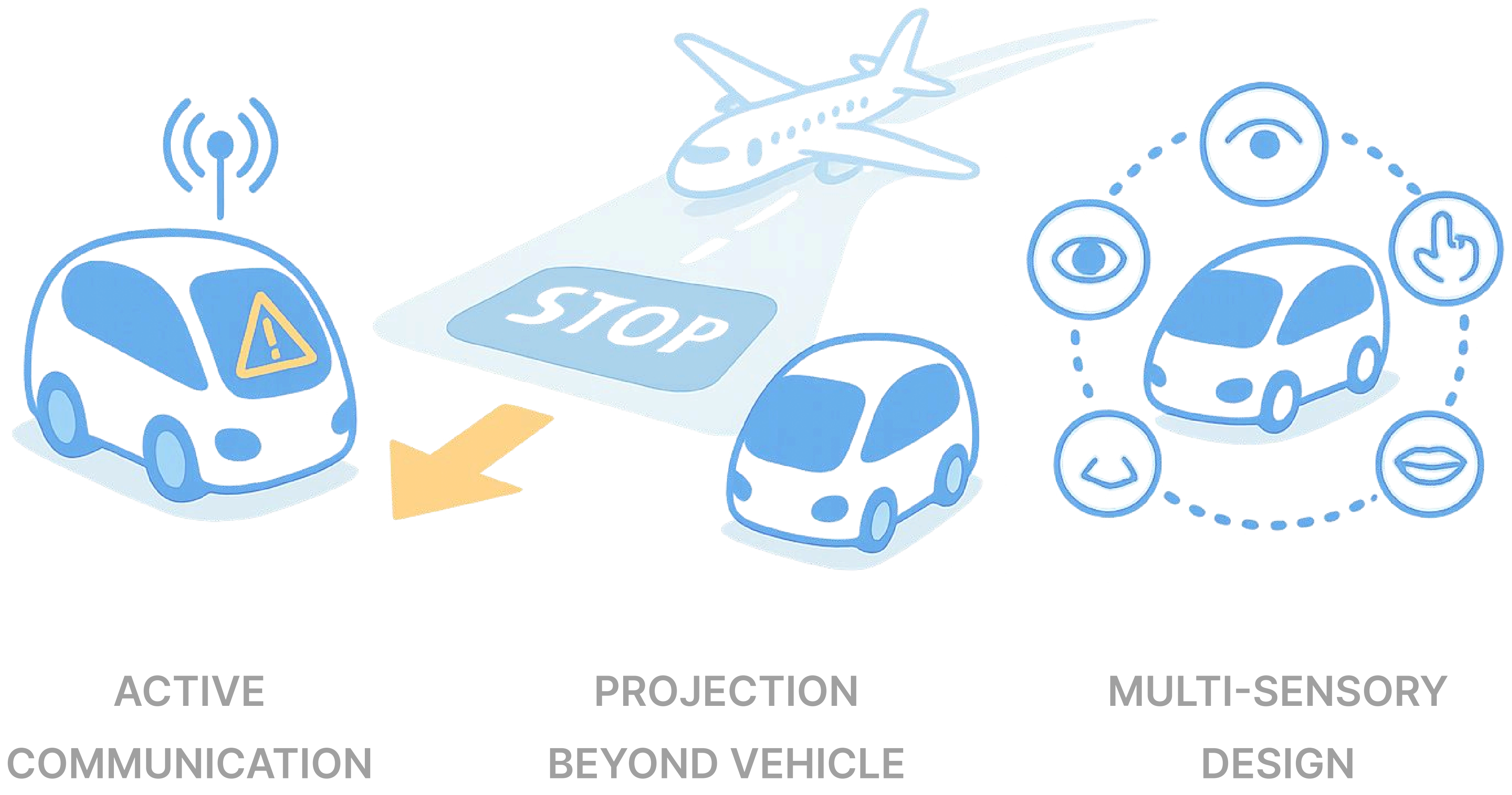


Figure 6 shows a visual summary of the case study findings

ACTIVE COMMUNICATION

Modern AVs are shifting from being passive machines controlled solely by humans to becoming active communicators within the environment. These vehicles proactively convey their intentions through digital displays, color-coded signals, icons, and text-based messages. This proactive communication helps reduce ambiguity and fosters mutual understanding between human users and autonomous systems.

PROJECTION BEYOND VEHICLE

Projection technologies are increasingly used to extend the vehicle's communication beyond its physical boundaries. Particularly effective in low-visibility or nighttime scenarios, projection helps clearly signal intentions such as yielding or stopping, by illuminating the ground or creating visual cues in the surrounding space.

MULTI-SENSORY DESIGN

To increase engagement and recognizability, some AV designs integrate human-like features (e.g., eye-like elements or gesture-inspired shapes) and leverage multiple sensory channels. These multisensory cues including visual, auditory, or spatial, support more intuitive interaction by mirroring familiar human communication behaviors.

2.3 User Profile Define

Target User

Role

Licensed commercial airline pilots and private pilots operating in controlled airport environments.

Experience level

Licensed commercial airline pilots and private pilots operating in controlled airport environments.

Operating environment

Noisy, high-traffic, and often multilingual contexts, with varied weather and lighting conditions.

Beyond theoretical trust building and the practical applications of autonomous vehicles, it is essential to define the specific user profile and needs for this context.

In airport ground operations, the primary users of the UsherBot are commercial aircraft pilots engaged in taxiing procedures. While taxiing is a relatively low-speed phase of flight, it unfolds in a highly dynamic and spatially complex environment, where situational awareness, precision, and clear communication are critical.

Analysis of pilot attitudes and operational behavior reveals that commercial pilots consistently place safety as their highest priority, valuing adherence to established procedures and minimizing risk. However, this strong professional discipline often comes with a conservative mindset, meaning that innovations must demonstrate reliability and integrate seamlessly into familiar workflows to gain acceptance.

Goals

Heading to the destination with a safer, and more efficient way, feeling at ease during the taxiing guidance, feeling confident on every movement of the aircraft.

Pain points

- Need to remember all the information from the ATC
- Need to read back the message through radio
- No direct guidance from the taxiing car
- Low visibility during bad weather during the guidance

Opportunities

- High recognizability instruction
- Intuitive guidance
- All weather readiness

2.4 Vision Statement

To synthesise insights from the literature review, covering trust in human–autonomous interaction, eHMI strategies, case studies, and the user needs, this vision statement frames the UsherBot's design direction around the research question on providing clear and trustworthy motion and signal-based instructions to pilots during taxiing. The statement is:

> **“Ushering the future, usherbot as a smart companion delivering intuitive guidance for fast-pace airports.”**

SMART
Capability
Functional

FAMILIARITY
Predictability
Functional

INSTINCT
User Friendly
Affactive trust

SMARTNESS

The UsherBot must demonstrate sufficient capability to carry out the taxiing task autonomously. This includes intelligent sensing, real-time decision-making, and the ability to adapt to complex ground operations.

FAMILIARITY

To foster predictability and reduce uncertainty, the vehicle should adopt recognizable behaviors and interaction cues. Familiar patterns help pilots intuitively understand the vehicle's intentions, reducing cognitive load and hesitation.

INSTINCTIVENESS

The vehicle's interaction design should align with human instinct, particularly in high-stakes environments like airport taxiing. By presenting information in a way that feels natural and emotionally reassuring, the UsherBot can support affective trust—making pilots feel safe, confident, and in control throughout the interaction.

These criteria serve as the foundation for the design direction and are consistently reflected in both the form language and communication strategy of the UsherBot.

2.5 Synthesized Design Criteria

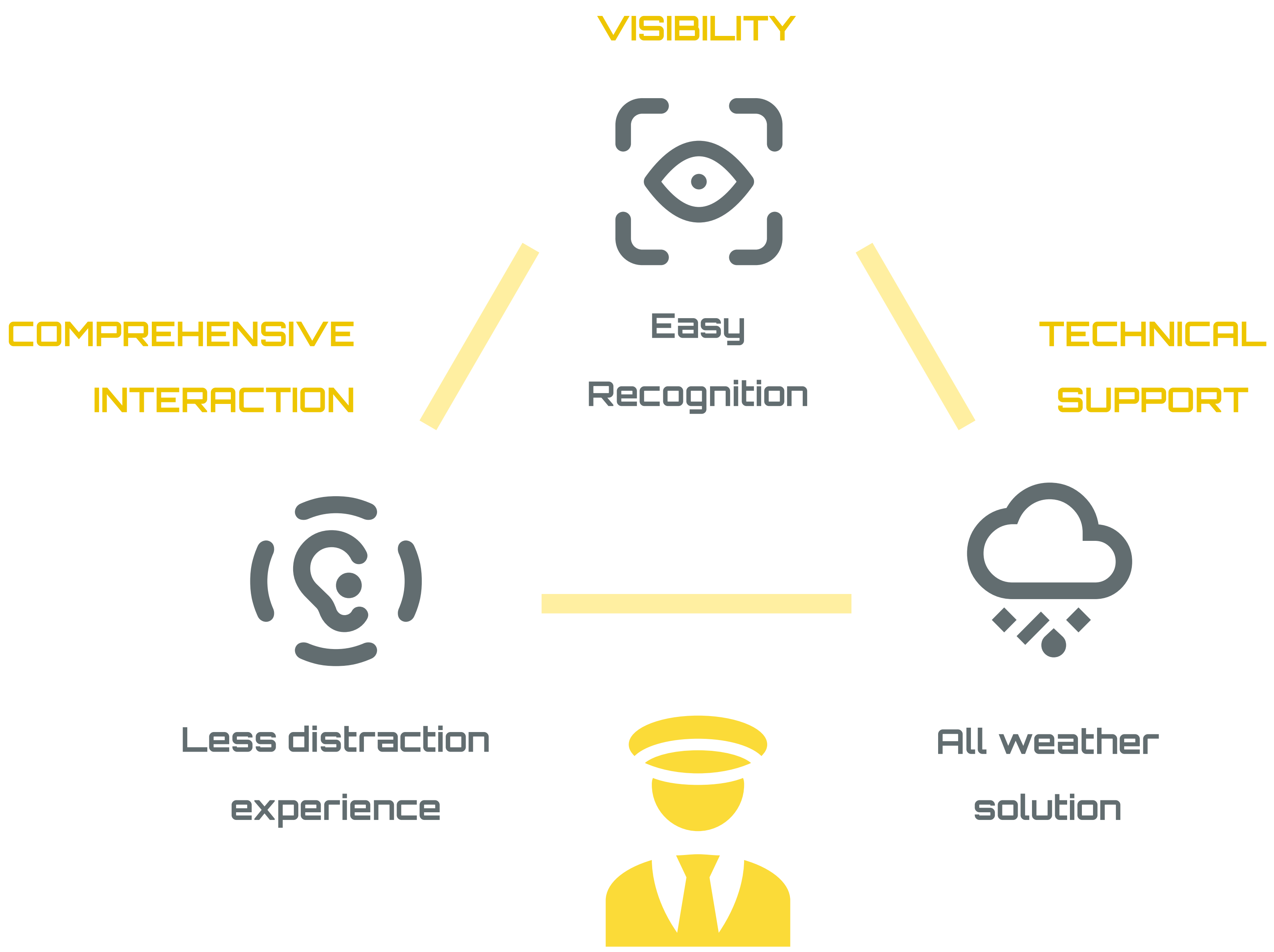


Figure 7 shows the three key design criteria for usherbot development

To translate the vision into actionable guidance, three core design criteria were established for the UsherBot.

Easy Recognition
ensures the vehicle remains visually distinct in the busy airport environment through high-contrast forms, lighting contours, and instantly legible signals.

Less Distraction Experience
Focuses on reducing pilots’ cognitive load by delivering comprehensive guidance without excessive visual or verbal input, enabling them to stay focused on situational awareness.

All-Weather Solution
Addressing the technical demands of varied light and weather conditions, ensuring signals remain visible, consistent, and reliable at all times.

Together, these criteria form the foundation for the UsherBot’s design, ensuring it not only performs its navigational role effectively but also strengthens pilot confidence and trust through clear, intuitive interaction.

Concept Development

In this chapter, the concept development process is documented, from early ideation to refined design directions. Using methods such as mood mapping, form exploration, and scenario building, the chapter translates research insights into a tangible concept that balances usability, aesthetics, and contextual fit for autonomous ground guidance.

3

3.1 Product Characteristic

As this project is centered on interaction with pilots, the design of the UsherBot must not only deliver functional clarity during taxiing but also convey the right visual impression from the pilot's point of view.

The vehicle will be interpreted through a limited, cockpit-framed perspective, making its form language, materiality, and signal behavior crucial elements in establishing **trust, clarity, and authority.**

To guide the design direction, an image board (see figure x for the board) was curated to explore visual characteristics that align with the airport environment, while also reflecting the **forward-thinking identity** of Usher AI.

Although the UsherBot is a mobility solution, the reference products on the board were deliberately selected from the domain of iconic electronic products, such as consumer tech, computing, and lighting design. This approach allows for broader exploration beyond conventional vehicle aesthetics, while still staying relevant to the autonomous, digital nature of the UsherBot.

From analyzing the board, two primary design values emerged: Authority and Futuristic.

- **Authority** captures the structured, regulated, and high-stakes nature of the airport environment. Products that visually convey authority often feature sharp edges, speedlines, chamfers, and are constructed with glossy or glare materials—signaling precision, control, and confidence.

- **Futuristic** reflects the innovation and autonomy at the core of Usher AI's vision. Products embodying this value often use dynamic forms, integrated lighting elements, and convey a sense of minimalism and intelligence through their surfaces and gestures.

The image board analysis also revealed that products perceived as more friendly tend to use rounded forms and matte materials. However, for this design, the focus intentionally leans toward the quadrant where "authoritative" and "futuristic" qualities intersect, supporting both functional credibility and visionary impact.

In summary, the design of the UsherBot draws inspiration from high-tech electronic products that balance clarity with innovation. This foundation supports the development of a form language that is visually commanding, technologically advanced, and well-suited to establishing pilot trust within the highly structured context of airport taxiing.

Authority

matte material
Friendly
Rounded

Chamfer
Speedline
Light stripe
Glare material

Futuristic

Figure 8 shows the image board developed for the UsherBot, mapping reference products across two dimensions: Authority and Futuristic.

3.2 Biological Metaphor for Trust & Intuition

Beyond high-tech visual characteristics, it is also essential to consider how form can intuitively communicate trust and capability—particularly in high-stakes environments like airports, where users must rapidly interpret meaning from minimal input.

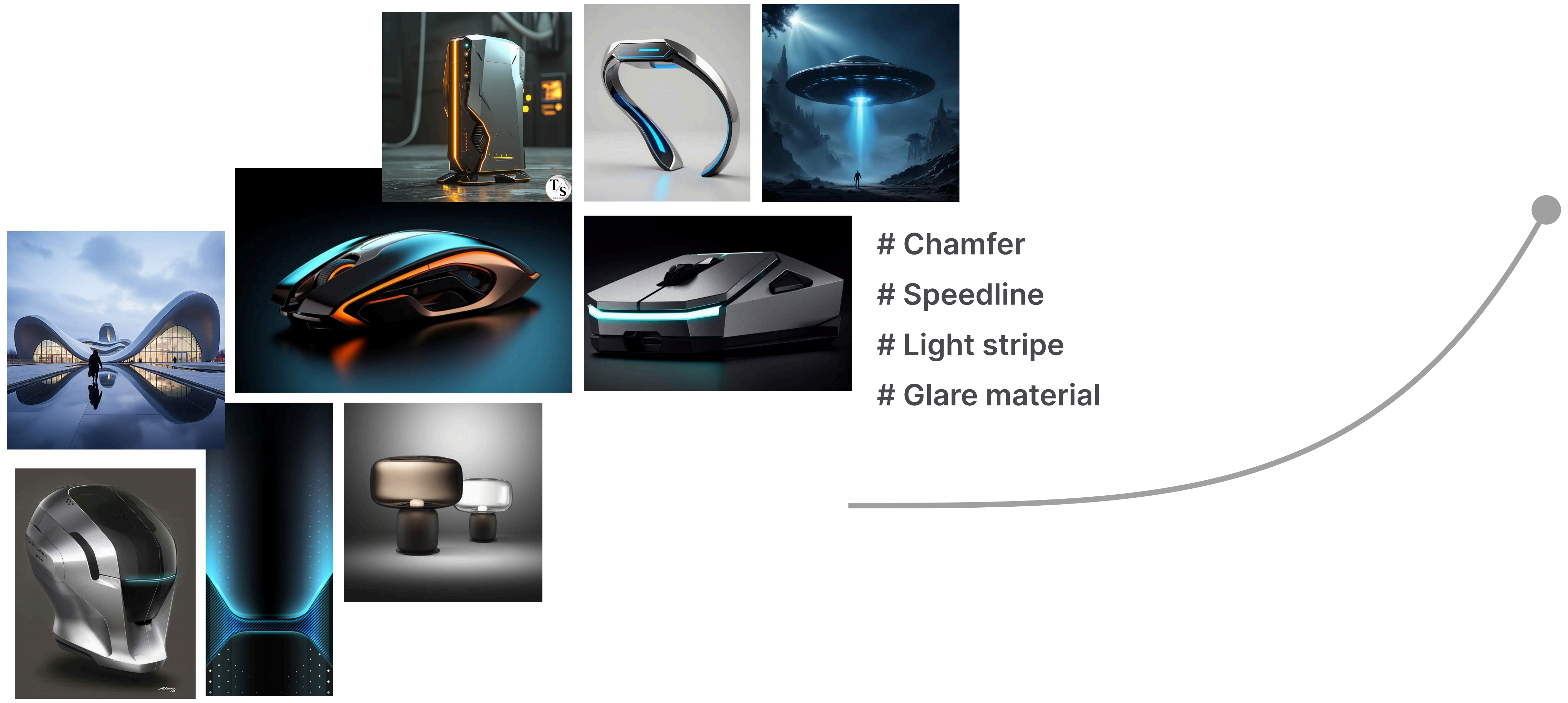
Research in cognitive psychology suggests that:
“Familiar or nature-inspired forms can subconsciously evoke calmness and trust, especially when compared to unfamiliar or overly technical shapes.”

Drawing on this insight, the design process was expanded to include metaphorical references from nature. Specifically, the focus shifted to animals with naturally aerodynamic or visually commanding forms such as stingrays, sharks, and orcas, which metaphorically embody qualities like agility, strength, and instinctive movement.

The visual board on this page illustrates two complementary domains:

- On the left: a selection of futuristic electronic products, characterized by chamfers, speedlines, lighting strips, and glossy materials established in the previous section and serve as anchors for high-tech credibility.
- On the right: a set of biologically inspired forms that reinforce intuitive, movement-based communication. These creatures exhibit fluid curvature and gliding locomotion—serving as metaphors for trust, calmness, and precision.

Together, these references expand the form language of UsherBot beyond aesthetics, enabling the design to communicate both visual authority and intuitive behavior. The biological metaphors contribute not only to how the vehicle looks, but also to how its motion can be perceived and interpreted, reinforcing trust and clarity in interaction with pilots.



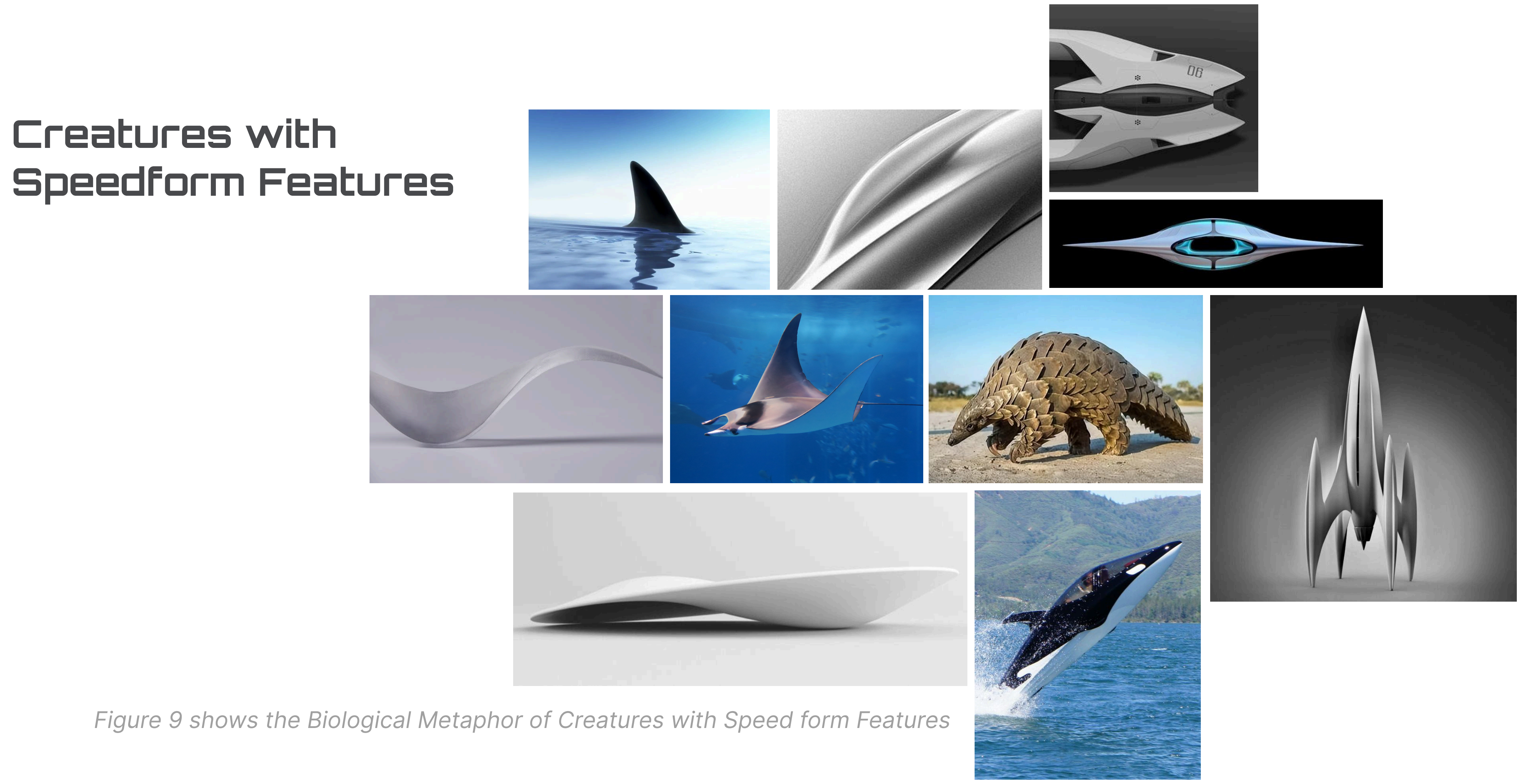


Figure 9 shows the Biological Metaphor of Creatures with Speed form Features

3.3 Design Direction

SMART

FAMILIARITY

INSTINCT

Route 1

Maximum the screen for showing digital instruction

Route 2

Using **physical metaphor** to show the instruction

Route 3

Transparency for spatial signal guidance

Building on the previous research, the design direction for UsherBot aims to create a visually compelling and trustworthy vehicle that enhances airport ground operations while remaining intuitive for pilots. The ideation was guided by the previously defined design criteria: Smartness, Familiarity, and Instinctiveness, alongside the visual values of Authority and Futurism. These principles informed the development of three exploratory concept directions:

Route 1: Maximizing screen-based communication
This direction explores the integration of large, embedded display surfaces, positioned to accommodate various viewing angles, in order to project digital instructions clearly to the pilot.

Route 2: Physical metaphor for guidance
This approach leverages recognizable physical cues such as fins, body orientation, or gestural forms, to communicate directional intent in a more intuitive, metaphor-driven manner.

Route 3: Transparency for spatial signaling
This concept utilizes transparent or semi-transparent elements to guide the pilot's attention through projection-based signaling and spatial emphasis, offering a futuristic yet functionally effective communication experience.

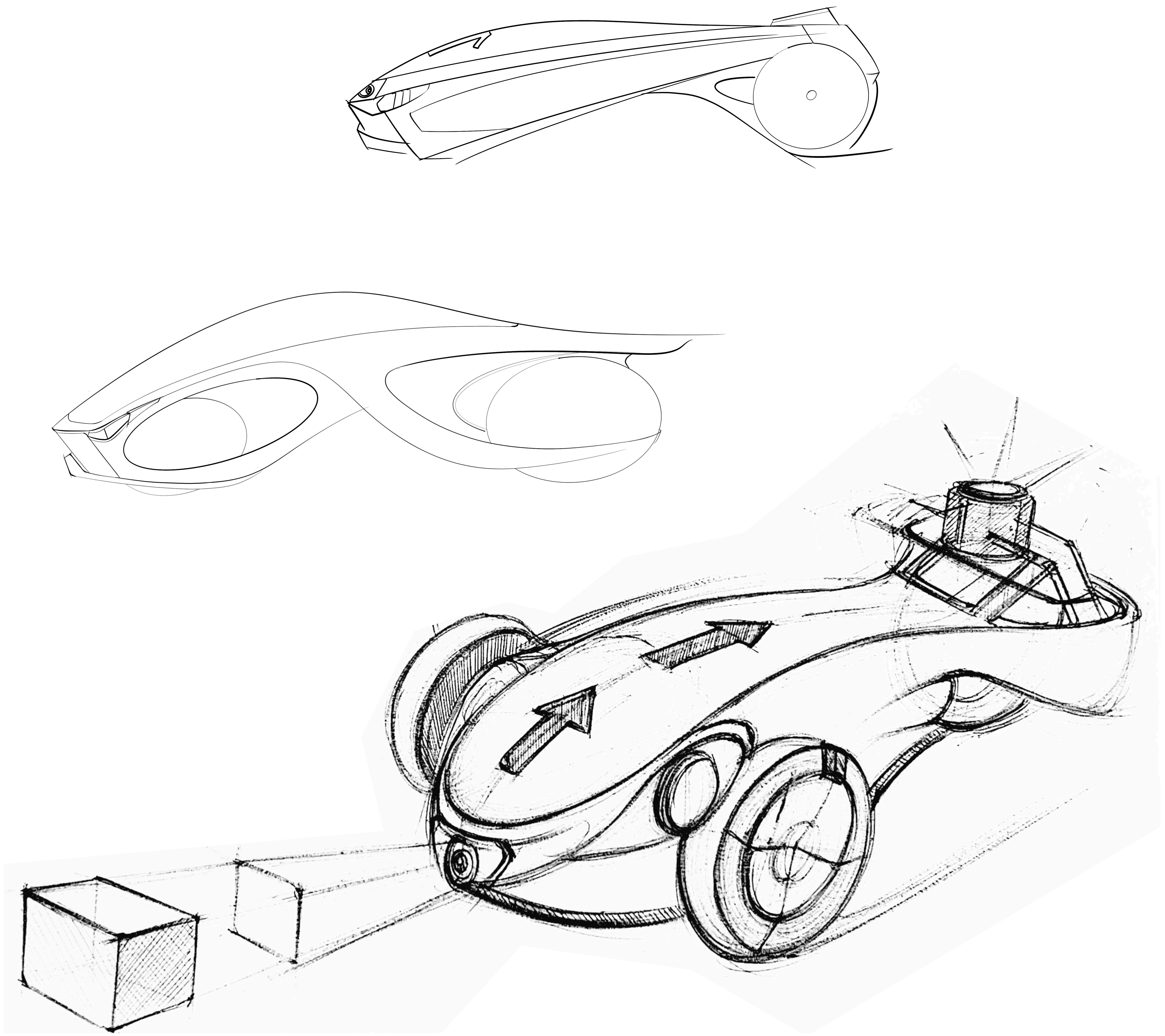
3.4 Route 1 - Rolling

Curve Screen x Light Strip

This concept explores the use of a full-width, curved rooftop display as the primary interface for communication. Unlike current taxiing vehicles that rely on a small LED panel to display static "FOLLOW ME" signs, this approach transforms the entire rooftop into an active communication surface, leveraging both curvature for visibility and graphic adaptability for complex signaling.

The curved form is not only a visual design choice but a functional one: it creates an inclined viewing angle optimized for pilots seated approximately 5 meters above ground. This improves legibility from a distance, especially when the bot is 10–20 meters ahead on the taxiway.

In addition, integrated light strips along the body act as peripheral cues or ambient signals, supporting contextual awareness in scenarios where the screen may not be the focal point. Together, the screen and light stripe form a hybrid visual system capable of conveying both explicit instructions and environmental cues.



Concept Features

Strength

- **Maximizes display area** by utilizing the entire rooftop as an information interface, enabling multi-directional visibility.
- **Improves long-distance readability** through the curved screen’s inclined angle, tailored to the pilot’s elevated line of sight.
- **Enables dynamic, adaptable visuals**, including icons, animations, and contextual updates based on operational needs.
- **Aligns with aviation norms** by using familiar, structured signal formats that match cockpit expectations.

Limitations

- May lack emotional expressiveness or physical presence.
- Susceptible to glare or readability issues under direct sunlight.

Design Insight

While functionally rich, this direction benefits from form framing or motion enhancement to increase presence and legibility in varied visibility conditions.

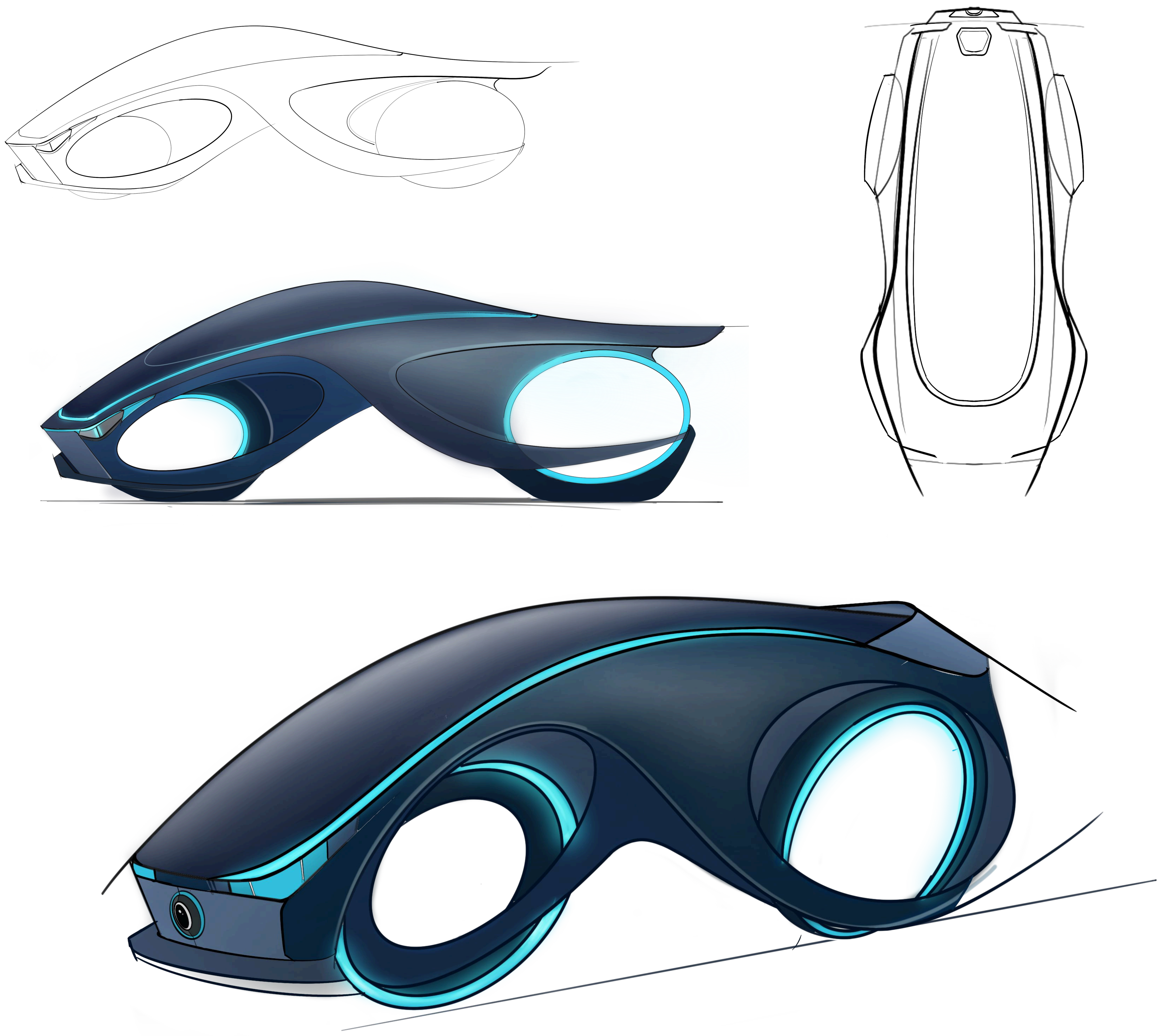
Iterations

Angular Form with Integrated Visual Language

As part of the development of Route 1, this iteration refines the UsherBot's form to achieve both functional feasibility and a coherent visual identity. A more angular body width was introduced, providing enough internal space to accommodate modular battery systems and core structural components, without compromising the vehicle's compact proportions.

A signature feature of this iteration is the infinite-loop shape that defines the vehicle's side profile. This form elegantly wraps around the wheels, maintaining their contour while seamlessly aligning with the curved rooftop screen. The resulting geometry not only unifies the top and side visual layers but also creates a clear path for the light stripe to flow, enhancing the vehicle's side visibility and motion readability, especially when seen from the cockpit at a distance.

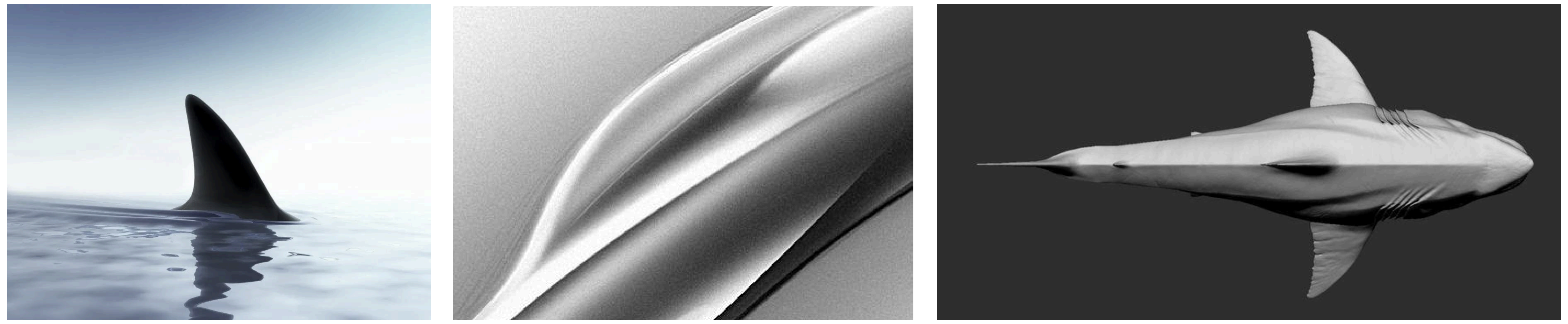
Together, the angular stance, infinite side icon, and integrated lighting form a concept that is structurally grounded, aerodynamically fluid, and visually communicative, laying the foundation for expressive, light-based interaction on the airport taxiway.



Context Rendering: Communication on the Taxiway

This rendering illustrates how the concept performs in its intended environment, positioned ahead of an aircraft on the taxiway. It quickly validates the scale, visibility, and visual presence of the UsherBot, especially in low-light conditions. The curved rooftop screen and flowing light stripe clearly demonstrate the vehicle's potential for real-time, non-verbal communication, reinforcing its suitability for further development.

3.4 Route 2 - SHARK FIN



Arrow and Directional Positioning

This concept explores the use of physical metaphor to express intent, specifically, a directional “shark fin” feature as a visual guide for movement. Inspired by the positioning clarity of dorsal fins in aquatic animals, this route translates that instinctive spatial reference into a directional design language for the taxiing context.

The central idea is to make directionality visible and unambiguous through sharp, layered forms and motion-aligned sculpting. The fin element is positioned centrally to reinforce heading and act as a passive signal—helping pilots intuitively align their path with the vehicle’s movement. This makes the UsherBot’s orientation clear, especially when viewed from a cockpit under time pressure.

Strength

- The fin as a spatial metaphor offers intuitive guidance without requiring text or symbols.
- Arrow-shaped sculpting reinforces motion direction and aligns with natural pilot instincts.
- Visually distinct and readable from a distance, even in low-visibility conditions.

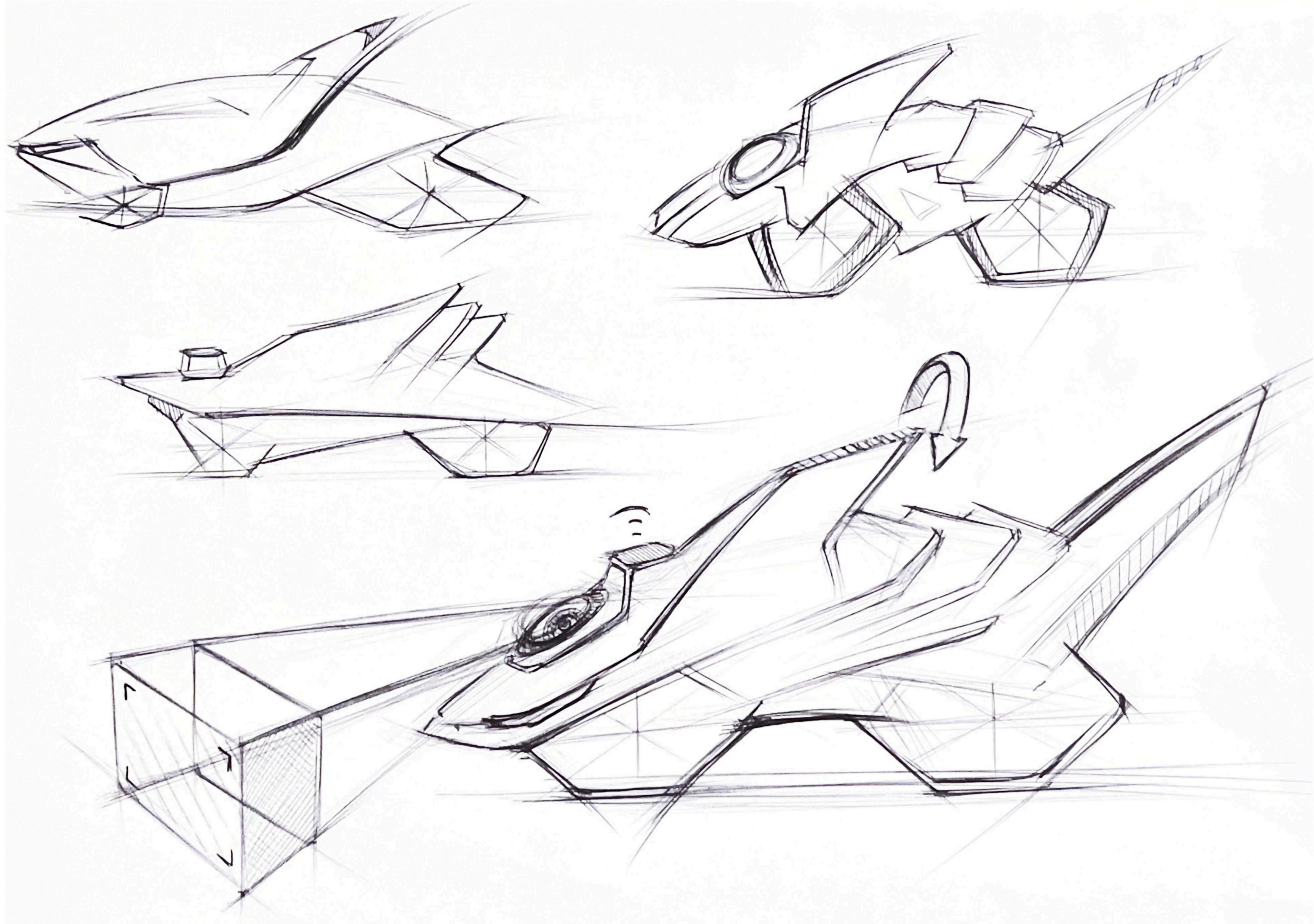
Limitations

- Less adaptable to complex or changing signal types.
- Requires consistent physical alignment to maintain communication clarity.

Design Insight

Ideal for situations where gesture and posture matter more than content. This design excels at positioning clarity, especially during straight-line taxiing and turn indications.

Concept Features

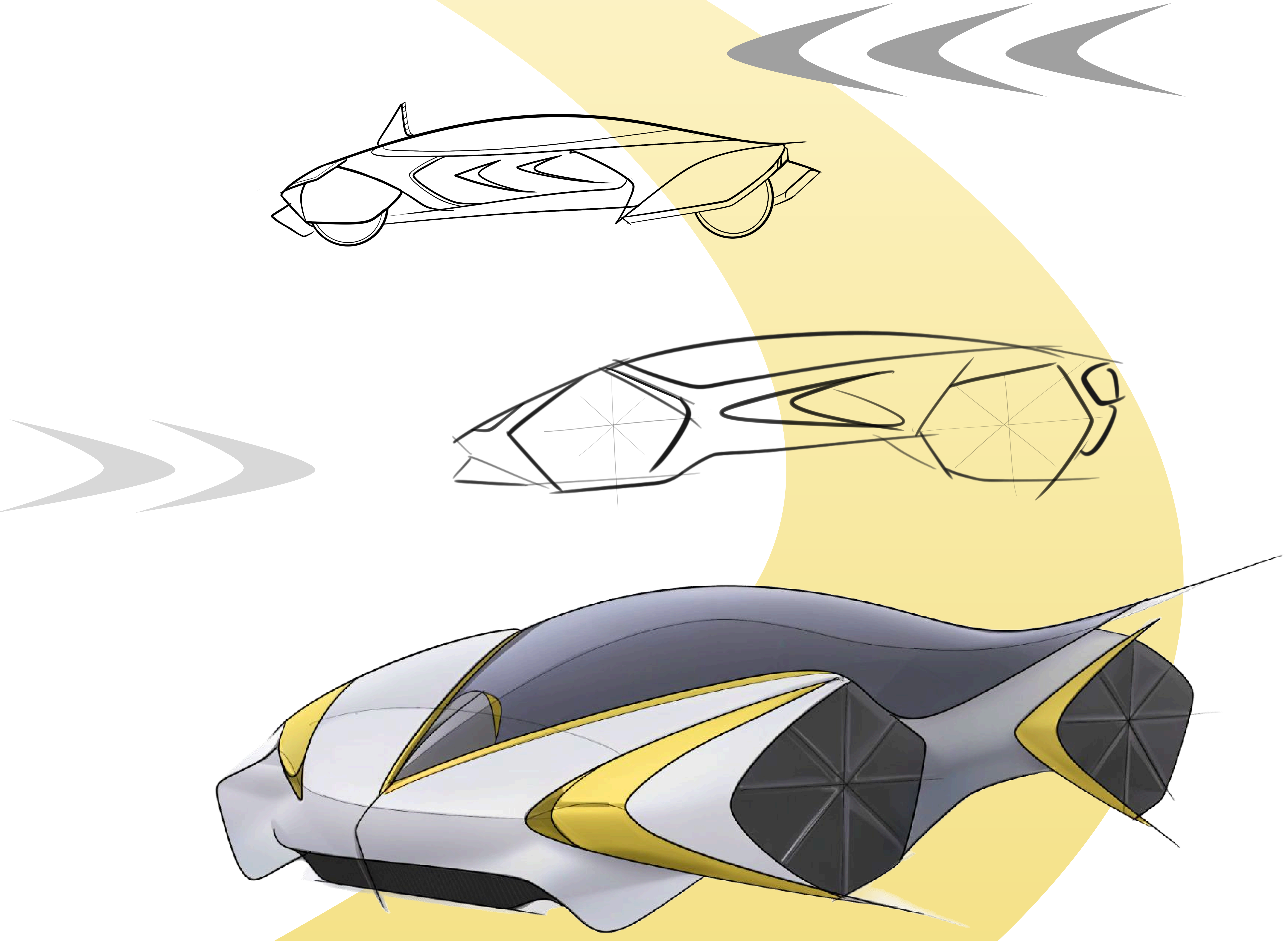


In this iteration, the form was refined to amplify directional readability using a sharp, streamlined geometry. Angular cuts and layered volumes define the front and rear, reinforcing vehicle orientation at a glance.

The shark fin was positioned to function not only as a sculptural element, but as a symbol of forward intent, visually anchoring the taxiing direction.

The side profile of the vehicle naturally forms an arrow-like shape, reinforcing the forward direction and visually connecting with the wayfinding symbols commonly seen on airport taxiways.

- Arrow Features for direction indicate



Context Rendering: Signaling Through Form

This rendering showcases the concept in a simplified runway setting, emphasizing how form alone, specifically the fin and forward-leaning body, can signal motion, position, and direction. Unlike digital interfaces, this approach relies on posture and silhouette to communicate, making it universally readable and language-independent.

3.4 Route 3 - Spaceship

Transparent Projection × Layered Communication

This concept explores a futuristic and visually lightweight approach by combining a transparent body with context-aware projected signals. The design adopts a fusiform form which is streamlined and symmetrical to convey aerodynamic fluency and a neutral, non-intrusive presence on the taxiway.

The structure is composed of two layers:

- A solid hollow outer frame, which serves both as structural support and a way to segment projection zones.
- A transparent inner core, acting as the display source for projected visual cues.

Projections are intentionally cast outward onto the surrounding ground, using the frame as a guide to control direction. For instance, a right-turn signal appears only through the right-hand side of the frame, and the same applies to left-turn or rear stop signals. This spatial segmentation makes the cues inherently intuitive so pilots can instantly understand the bot’s intent based on where the signal originates.

The result is a system that feels lightweight yet expressive, delivering floating, spatially accurate visuals that enhance clarity without relying on text or physical motion.

Strength

- Offers a highly futuristic and minimal appearance.
- The segmented hollow frame supports intuitive, directional signaling.
- Projects signals directly onto the environment, enhancing readability and spatial orientation.

Limitations

- Readability can be impacted by bright daylight
- Requires advanced projection hardware and precise calibration to ensure feasibility
- May feel too abstract or unfamiliar for immediate real-world deployment.

Design Insight

While technically ambitious, this concept proposes a new paradigm for non-verbal, ground-integrated interaction—where signal location becomes part of the message, and visibility is achieved with minimal visual mass.

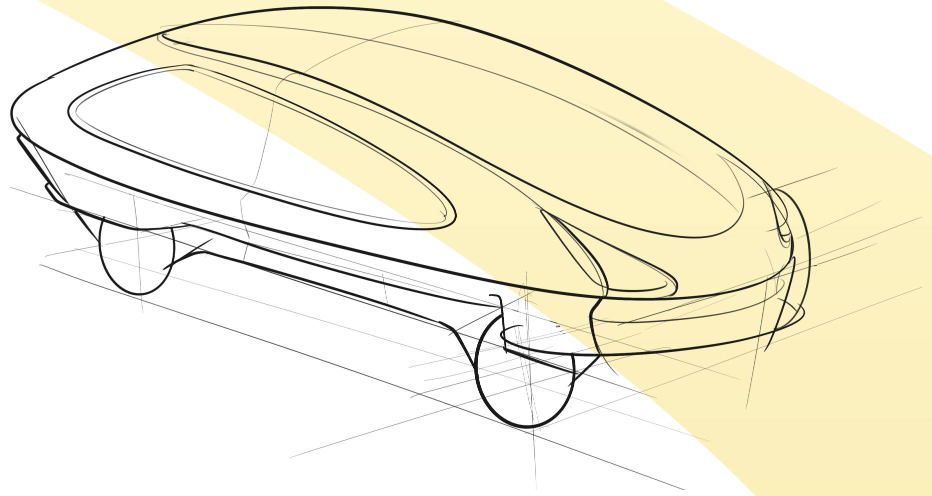
Concept Features

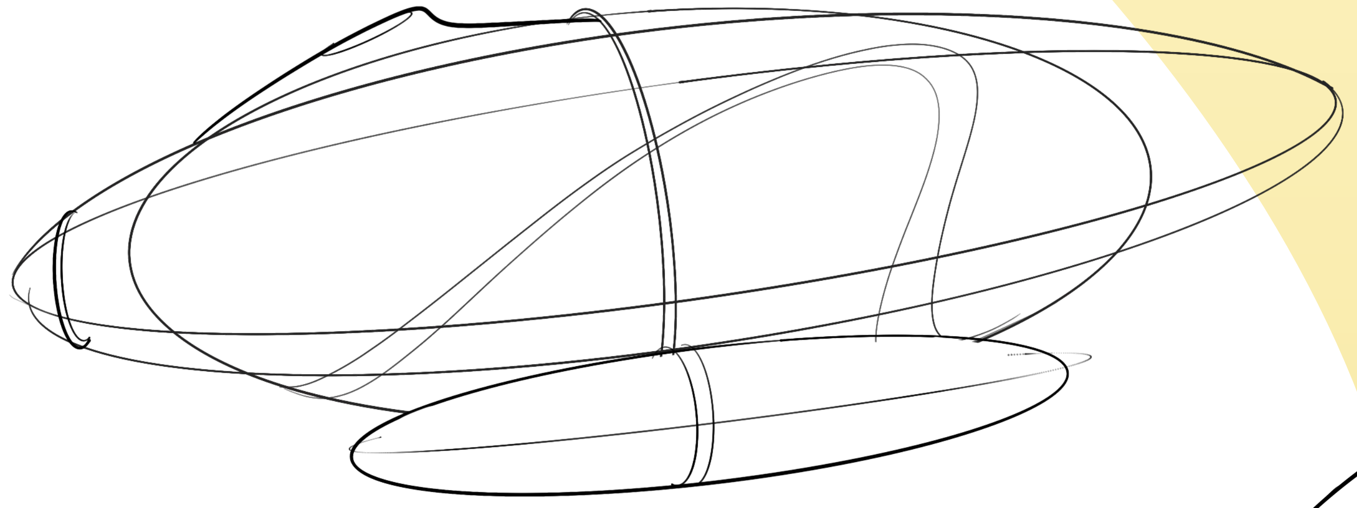
In this iteration, the form is carefully shaped to balance openness and function. The hollow frame defines the vehicle's boundaries and separates projection zones toward front, left, right, and rear, so that signals remain cleanly segmented and contextually grounded.

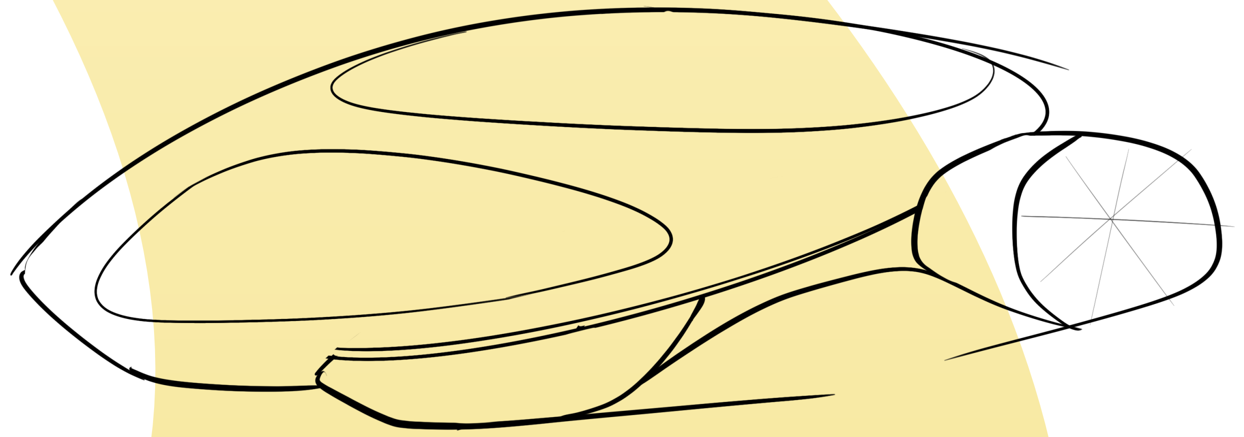
The inner transparent core emits the signals, while the outer frame provides orientation and visual structure.

This layered configuration helps pilots quickly recognize not just what the signal is, but also where it's coming from, enhancing spatial legibility and directional clarity.

- Transparency / Hollow elements:







Concept Rendering

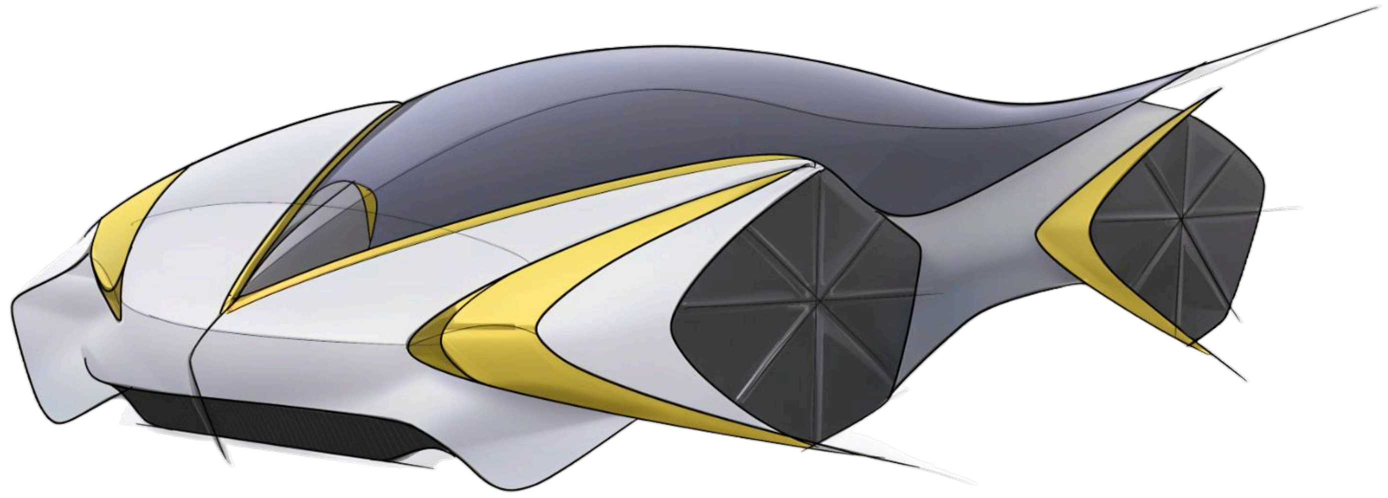
This rendering highlights the material detail and structural layering of the concept, focusing on how transparency, light diffusion, and the hollow frame system work together to create a futuristic yet understandable form.

3.5 Evaluation

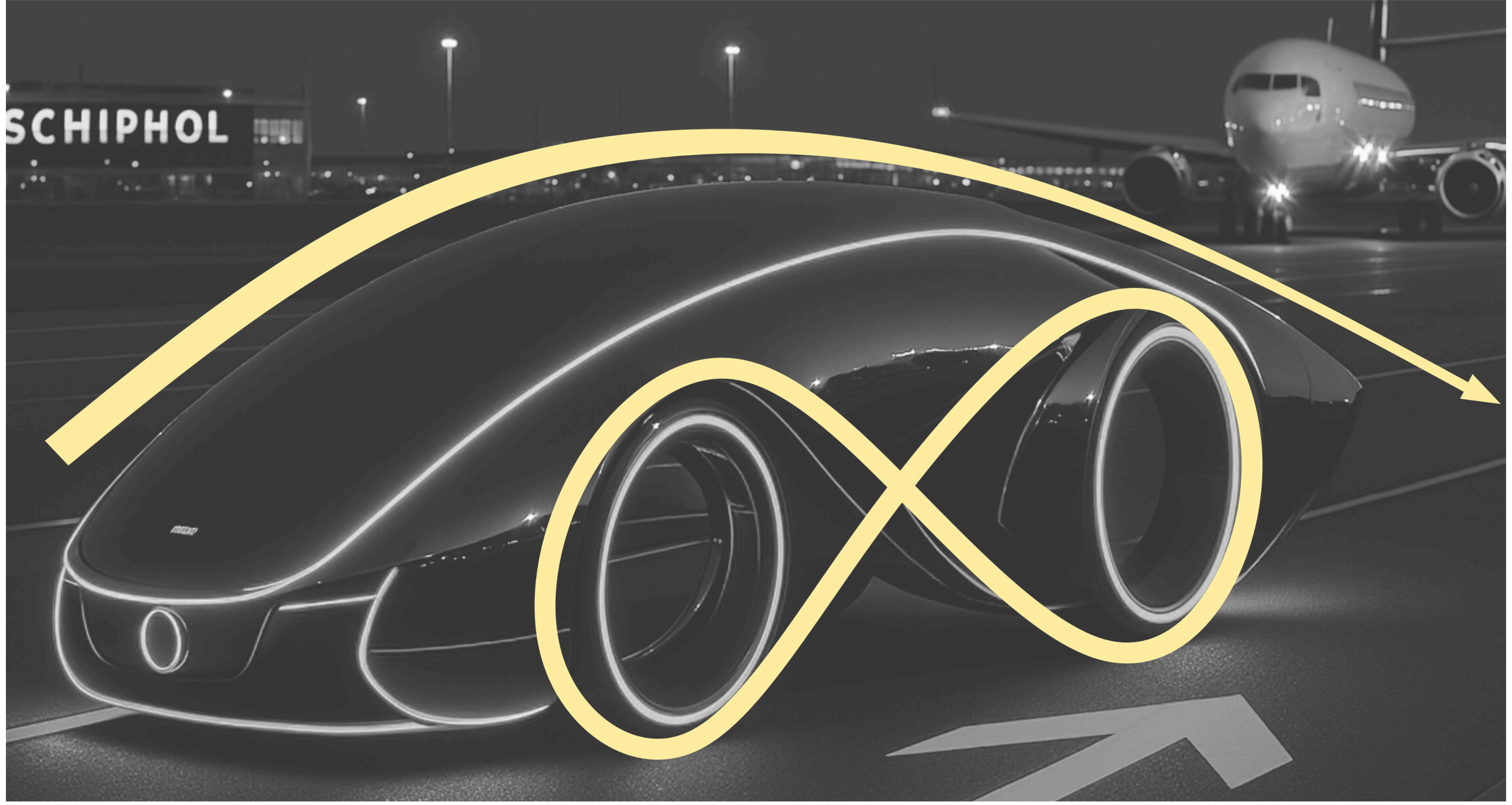
Following the initial ideation phase, each concept was critically evaluated in collaboration with the Usher AI team and the graduation supervisor. The evaluation was based on functional logic, visual communication, and technical feasibility within the airport taxiing context. The discussion led to a hybrid direction, selecting the most effective elements from each route to form the basis of the final design.

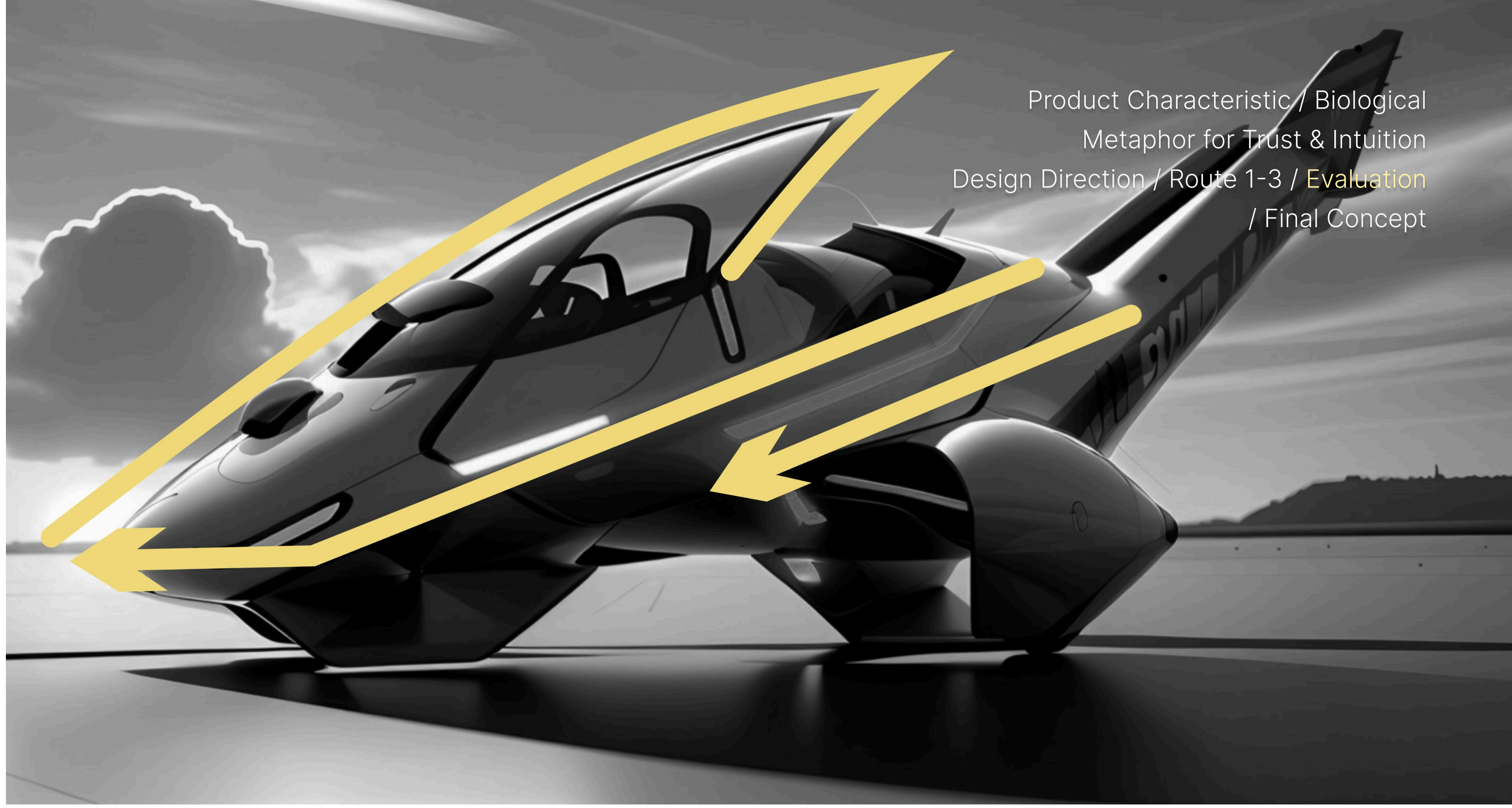
Rolling

Shark Fin



Spaceship





Key elements

/ Positioning / Curve Screens / Authority

Curved Display Surface (Route 1)

Route 1 proposed a large, curved rooftop screen to serve as the primary information display. Its inclined geometry aligned well with the pilot's elevated viewpoint, enhancing signal visibility and supporting clear, dynamic communication. The ability to integrate light-based instructions across the roof made this feature highly valuable in both day and night operations.

Positional Clarity (Route 2)

Route 2 contributed a strong front–rear distinction through its “shark fin” speedform. This directional cue helps pilots quickly recognize the UsherBot's movement orientation, which is essential for safety and intuitive understanding during taxiing. Maintaining this clear physical positioning in the final design was considered critical.

Light Integration (Route 1)

The infinity-shaped side form wrapping around the wheels was retained for its visual fluency and functional framing. It aligns the light stripe with the overall body gesture and creates a clear visual rhythm when viewed from the cockpit. This helped strengthen both the aesthetic identity and lateral communication logic of the UsherBot.

Projection Guidance

Projection Concept & Segmentation Logic (Route 3)

Although Route 3 was deemed technically infeasible for near-term application—mainly due to insufficient space for internal components and wheel placement constraints—its approach to projecting signals directionally through the segmented frame was well received. Both the Usher AI team and supervisor valued the clarity and intuitiveness of casting signals to specific sides (e.g., only the right for turning right). This projection logic has been earmarked for future development and partially informs the light signaling behavior in the final design.

Synthesize for final concept

By synthesizing these findings, the final direction emerged as a hybrid concept that balances expressive form, spatial clarity, and operational feasibility. The outcome of this evaluation leads directly into the next chapter: 3.6 Final Concept – Stingray Floating.

3.6 Final Concept

Final Concept Overview

After evaluating the initial concept directions, the final design converges into the Stingray Floating Concept—a form that synthesizes the functional, visual, and interactional strengths from Routes 1, 2, and 3. This concept reflects the collaborative design discussion with Usher AI and project supervisors, resulting in a solution that is both expressive and technically grounded.

Design Metaphor: the stingray

To inspire a form that conveys clarity, trust, and calm authority, the stingray was chosen as a metaphorical anchor. Its fluid, low-slung body and gliding motion represent guidance without aggression—a quality essential for an autonomous vehicle operating in a high-stakes airport environment.

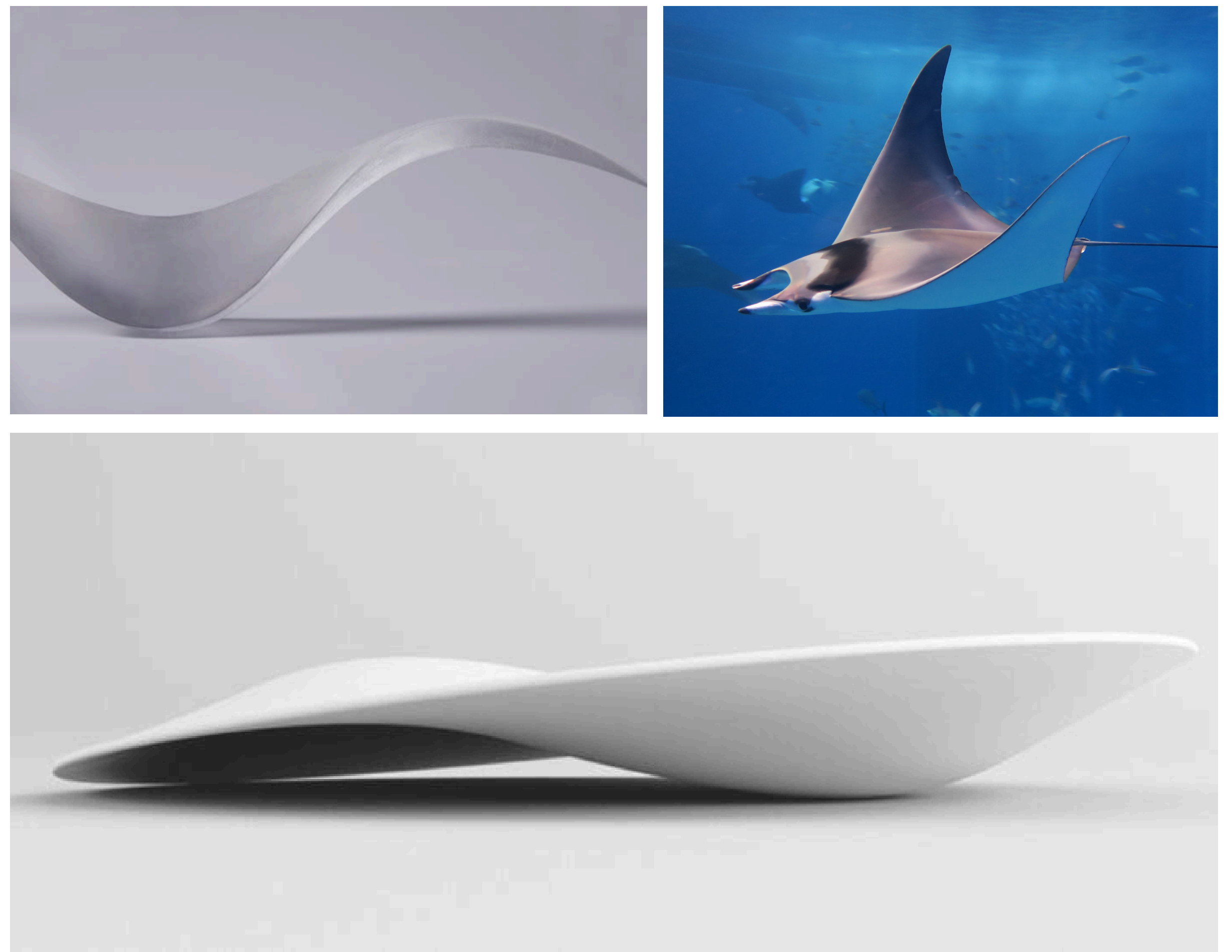
Unlike conventional vehicle archetypes, the stingray offers:

- A flat, wide, and organic body contour that enhances cockpit visibility.
- A sense of aerodynamic and directionality, ideal for non-verbal communication.
- A visual language that communicates authority without harshness, striking a balance between technology and trust.

Fluid Curve **Instinct Use Cues** **Extended Space**

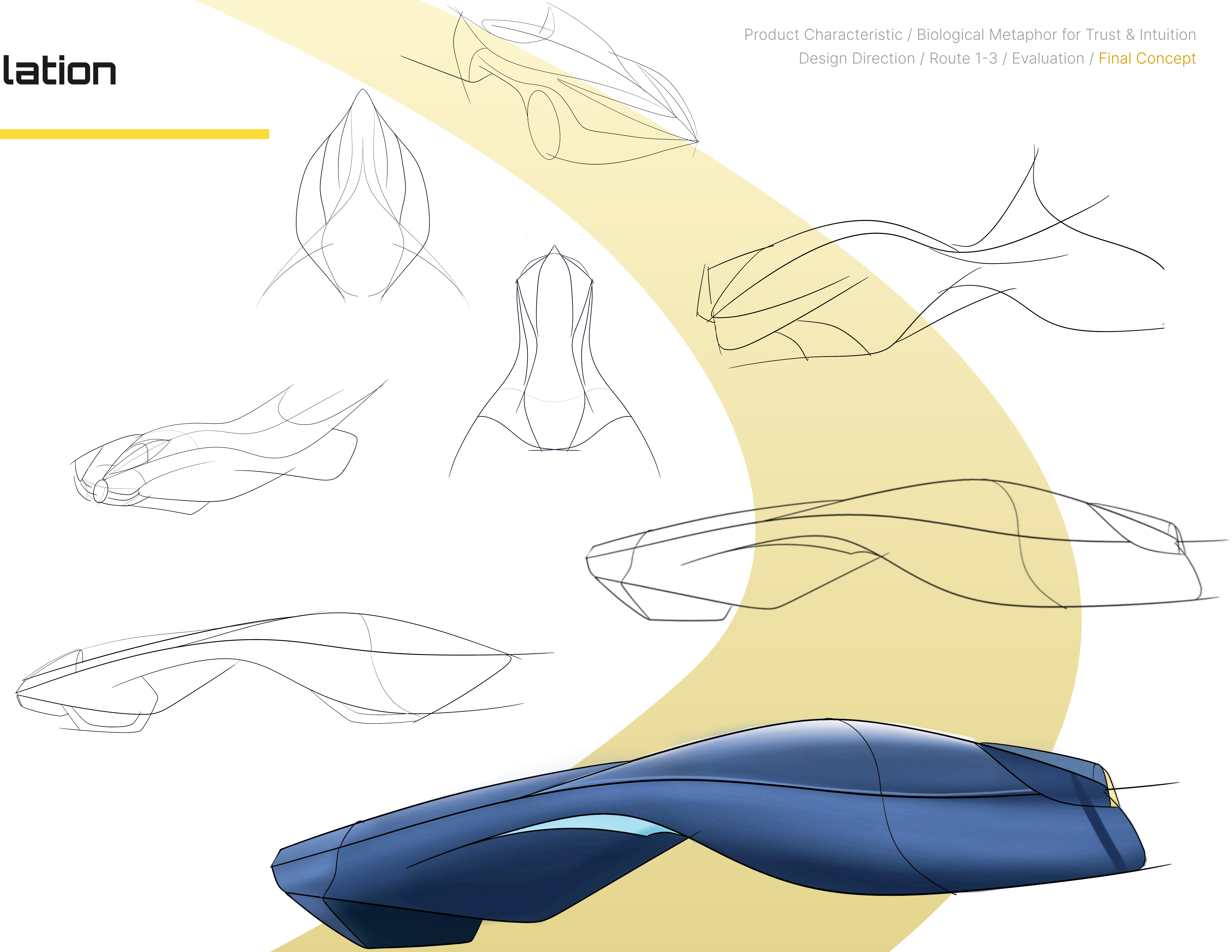
Form Iteration & Translation

Stingray Floating



This metaphor was gradually translated into form through sketch iterations and proportion testing:

- The widened horizontal body maximizes surface area for signal display.
- The lifted rear and tapered nose help define clear orientation from any cockpit angle.
- The fluid side curves frame the wheels while creating natural channels for light strip integration.



3D Design Iteration

Through multiple 3D iteration stages, the concept evolved from a sculptural form into a fully feasible design

Baseline form language

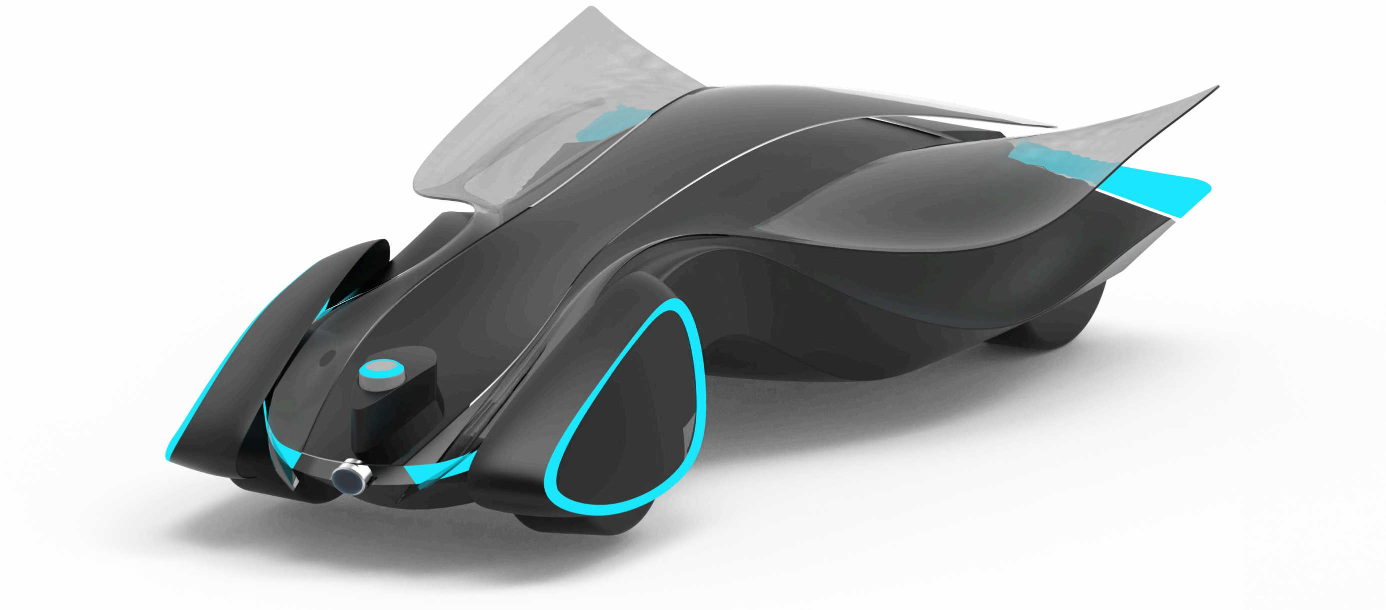
Initial models focused on defining the core form language, with a smooth, continuous rooftop surface establishing the baseline for aerodynamic flow and visual clarity.

System Integration Phase

In the mid-phase, system components such as lidar, screen curvature, and internal housing were integrated. While this brought the design closer to feasibility, adjustments were needed—particularly in lidar height and modularity for maintenance access.

Feasible Final Model

The final model features a roof-mounted lidar, modular vision units, and a refined curved screen, all embedded within an extremely streamlined body. These changes enhance visibility from the cockpit and support the bot's real-world operability in complex airport environments.



Form factor evaluation

In the transition from Stage 2 to 3, the final form was assessed for its effectiveness in signal communication and cockpit visibility. Based on the Airbus A320 cockpit height (~5 meters) and a typical following distance of 10–20 meters, the optimal pilot viewing angle was determined to be 15–20 degrees. This supports a rooftop geometry that curves gently upward, enhancing visibility from the cockpit.

To refine the screen curvature, two configurations were compared: "stick-out" (convex) versus "stick-in" (concave). Considering factors such as sunlight reflection, screen glare, and visibility from both pilot seats, the concave "stick-in" form proved more effective, offering a broader field of view while reducing visual distortion under varying lighting conditions.

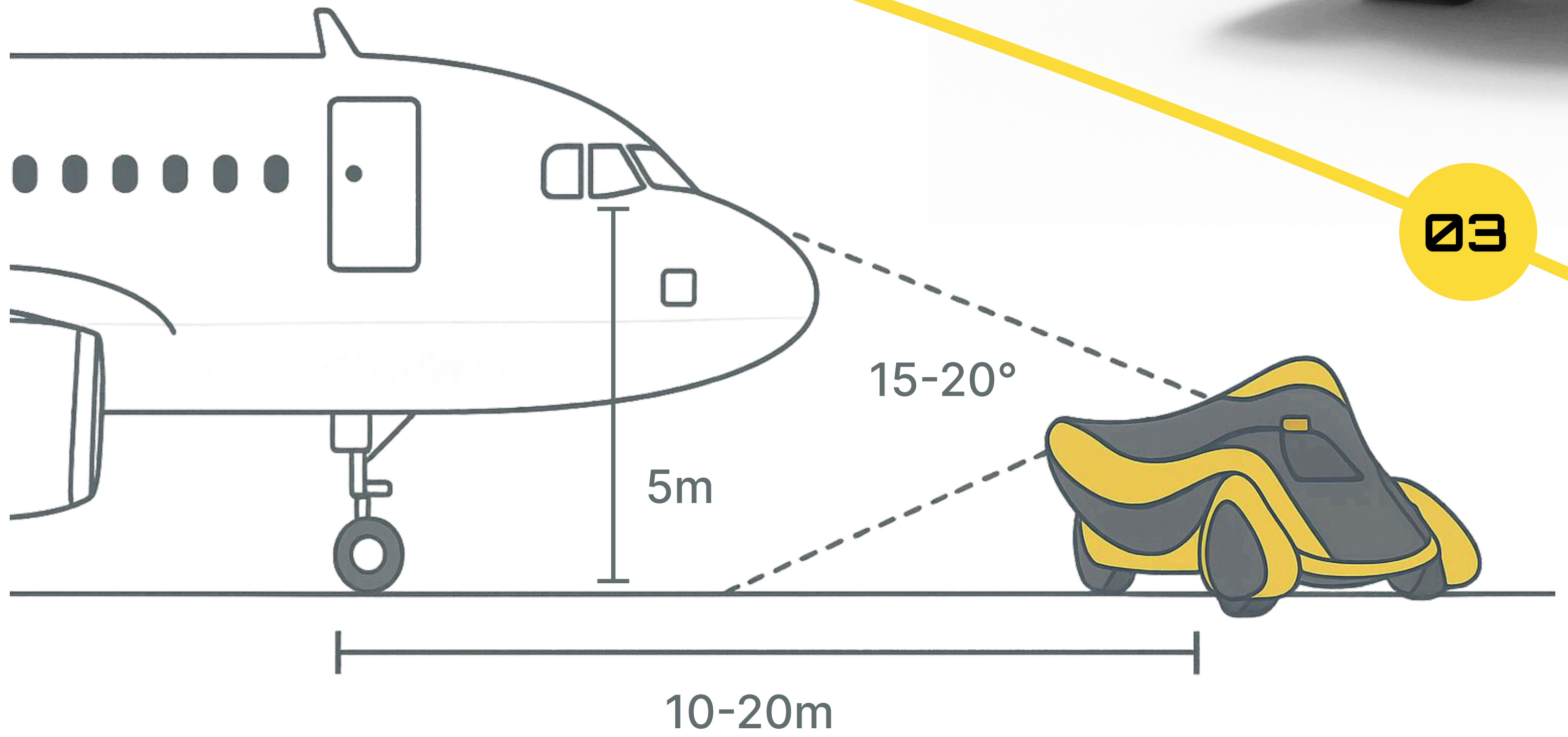


Figure 10 shows the calculation and ideal angle from a cockpit view

Design Qualities Summary

To summarize, the final concept of Stingray Floating embodies three defining traits:

- Fluid Curvature: Enhances aerodynamic expression and screen orientation.
- Instinctive Use Cues: Communicates position and behavior clearly without textual or verbal reliance.
- Extended Interaction Surface: Provides ample digital space while maintaining a compact, readable profile.

Function Definition

In this chapter, the internal architecture of the UsherBot is defined, detailing its core components, functional layout, and interaction logic. It outlines how the system integrates sensing, projection, and mobility modules, and introduces the motion cues and signal patterns that form the basis for clear and intuitive pilot communication.

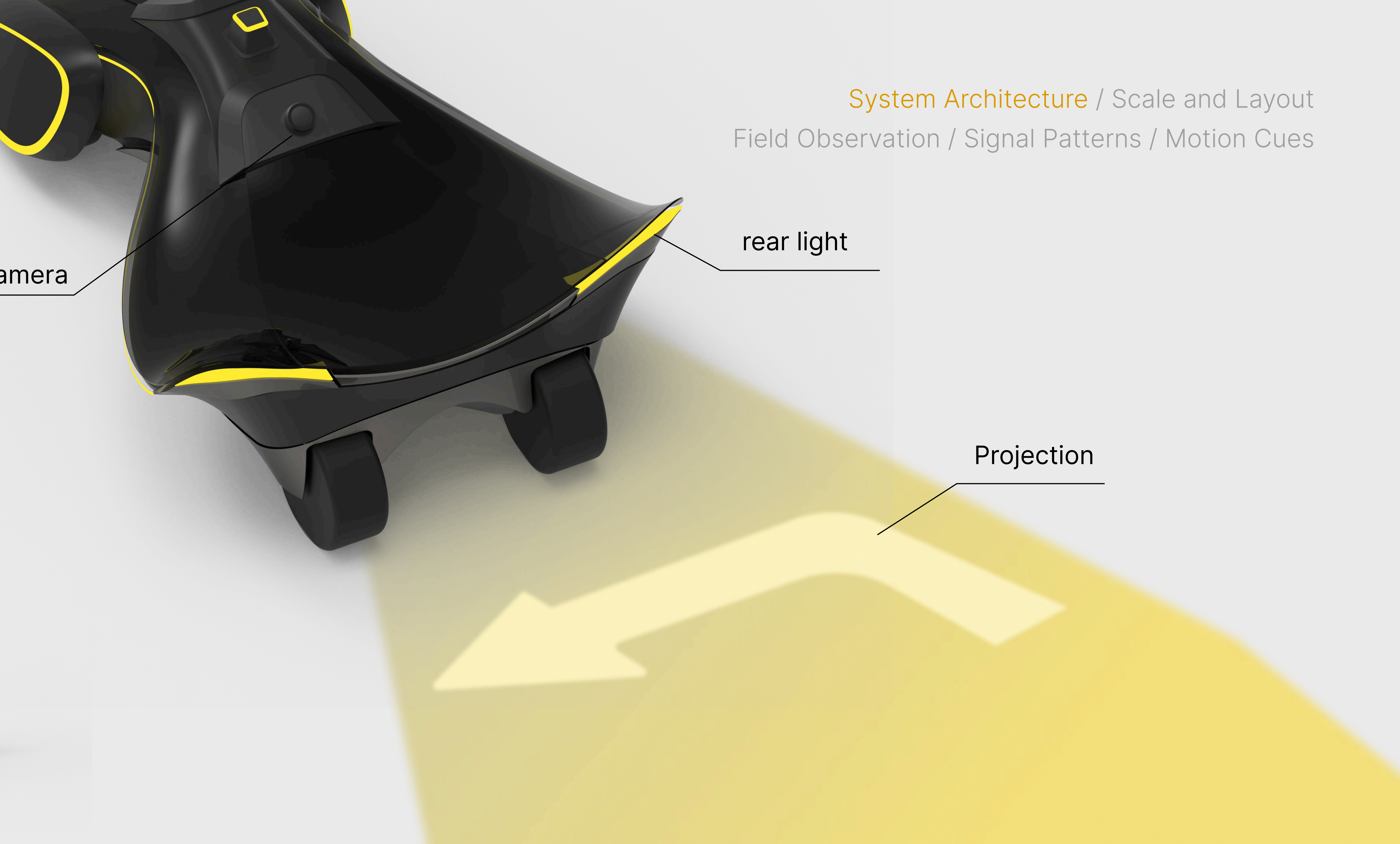
4

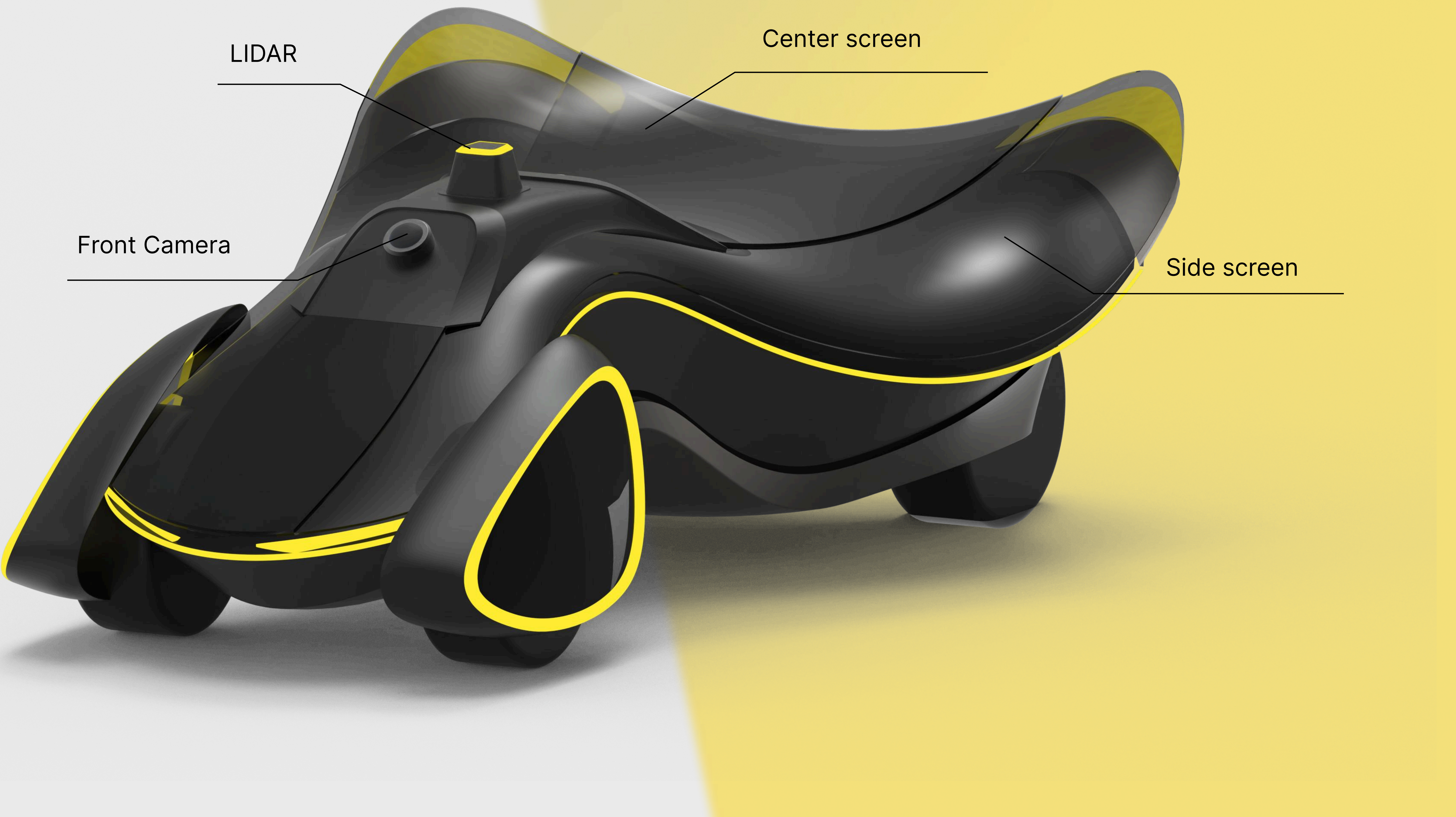
4-1 System Architecture

x1 x2 x3 x4

Following the development of the 3D form, this section defines the UsherBot's internal system architecture and component layout. The vehicle integrates key elements necessary for autonomous operation and pilot communication, including:

- A single LIDAR unit positioned at the top point of the vehicle to continuously scan and measure spatial data from the surrounding environment.
- Two cameras placed at the front and rear to enable environmental scanning and situational awareness from both directions.
- Three curved digital display panels positioned strategically to deliver real-time instructions and visual signals to the pilot.
- Four external lights including two headlights and two tail lights are used to communicate directional intentions such as turning, slowing down, or stopping via dynamic light cues.





4.2 Scale and Layout

To ensure both functionality and environmental fit, the internal layout and external dimensions of the UsherBot were carefully defined. The final design prioritizes component integration, visual positioning, and operational feasibility in the airport context.

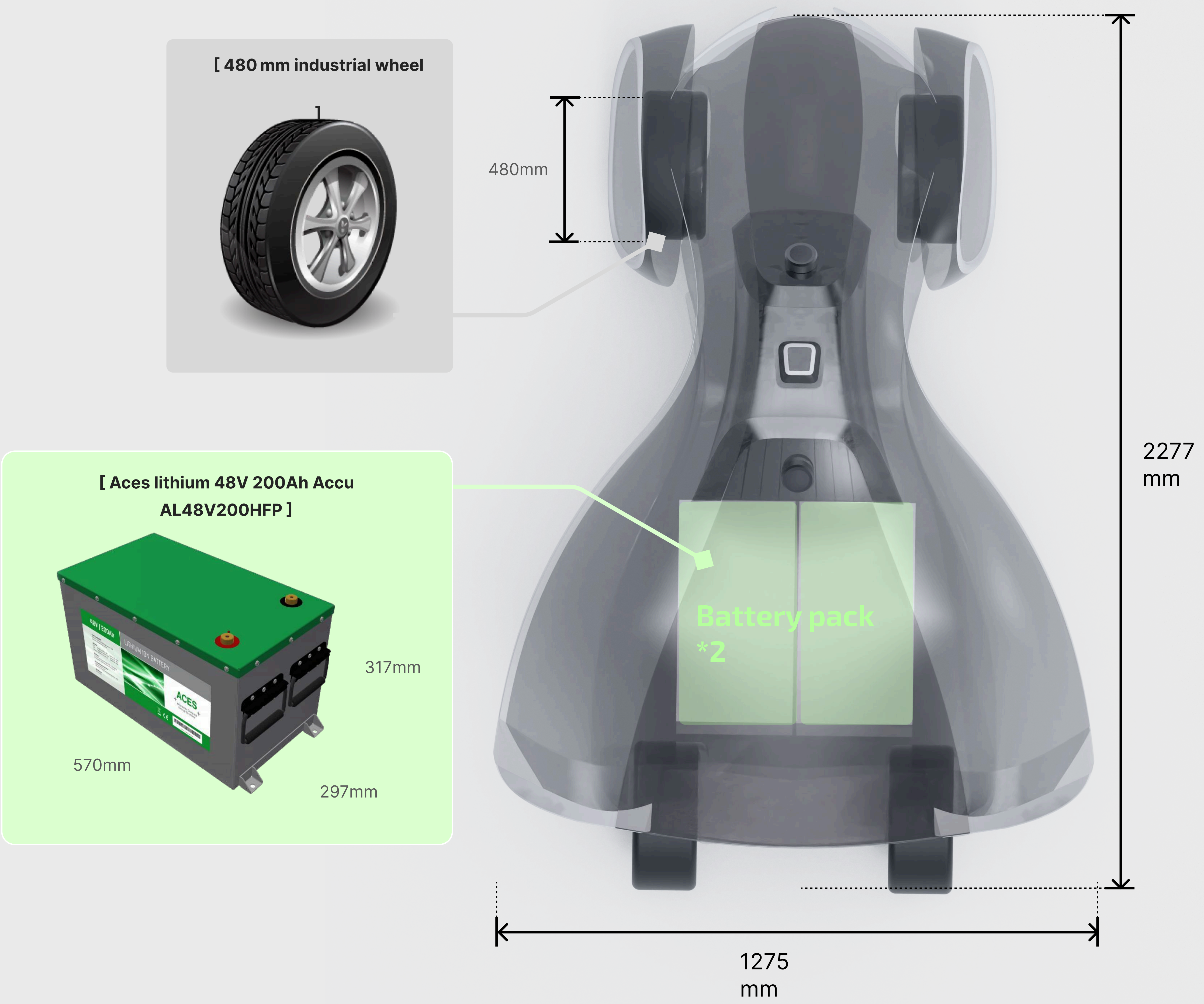
Scale & Dimension

The final measures of the vehicle is Length: 2277 mm, Width: 1275 mm, Height: 800mm based on the idea of minimum the space taken over from the airport while maintaining ample space for putting two standard battery pack and 4 wheels in the organic and visually positioning shape.

Data Sheet Reference

In terms of the component specifications, it was informed by the Spijkstaal Elektro BV performance sheet (see appendix x for the full data). While the UsherBot design exceeds the listed vehicle size (1600 mm length x 900 mm width) from the reference EV platform, its battery setup follows the same technical base:

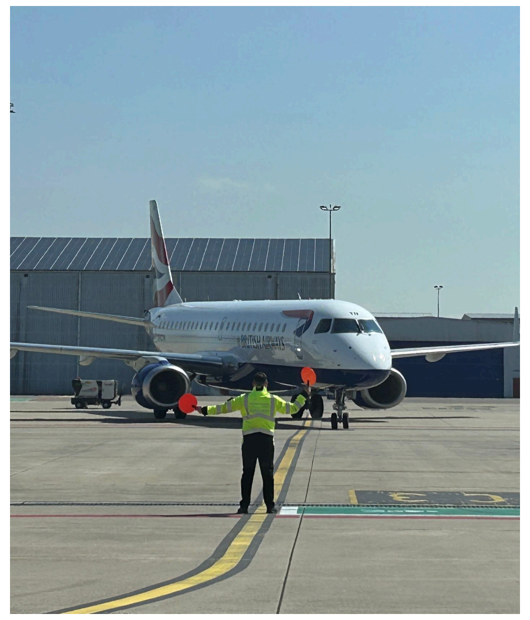
- Battery voltage: 48 V
- Capacity: 200 Ah per pack (2 total),
  Yielding ~15.36 kWh usable energy
- Calculated range (reference vehicle): ~136 km
- Motor performance: 22 kW at 750 RPM
- Top speed potential: ~70 km/h



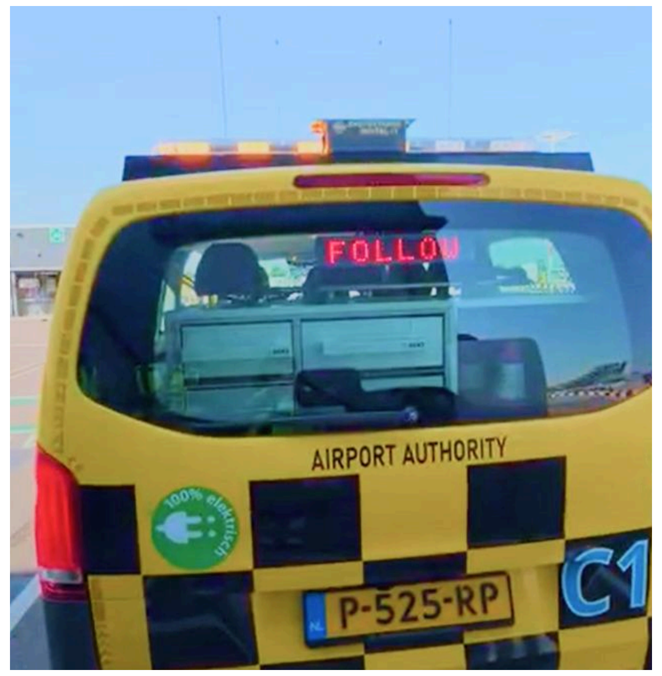
Although the UsherBot prioritizes visibility and interaction over high-speed travel or towing capacity, the selected hardware supports reliable autonomous performance with sufficient runtime for extended airport operations.

4.3 Field Observation

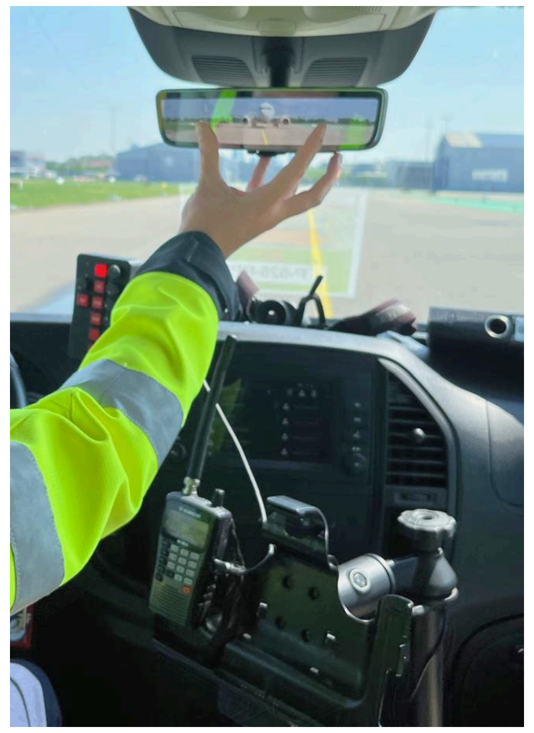
To support the communication system design of the UsherBot, a mid-stage field observation was conducted at Rotterdam Airport. While earlier design phases were informed by literature and expert input, this visit provided real-world validation for visibility, signal clarity, and motion cues—offering critical input for refining the interaction strategy. Three key insights emerged:



Marshaller doing the taxiing to the parking lot



The “ FOLLOW ME” sign is too small to be visible from a distance



Distance managing by staff experience

Limited Sign Visibility

The “FOLLOW ME” signage on current operational vehicles is too small and difficult to recognize from a distance, especially from the pilot’s view. This highlights the need for larger, more legible communication formats.

Manual Distance Estimation

Current procedures rely on mirror checks and operator experience to estimate safe distances between the taxiing vehicle and aircraft. While ground staff are typically well-trained, this method lacks systematic accuracy, posing potential risks under varying conditions or for less experienced personnel..

Potential for Docking Signal Integration

Hand gestures used by marshallers can be adapted into digital signaling systems, offering clear and familiar cues for the pilot.

These findings directly informed the design of UsherBot’s motion and light communication system, which seeks to offer higher clarity, consistency, and automation.

4.4 Signal patterns

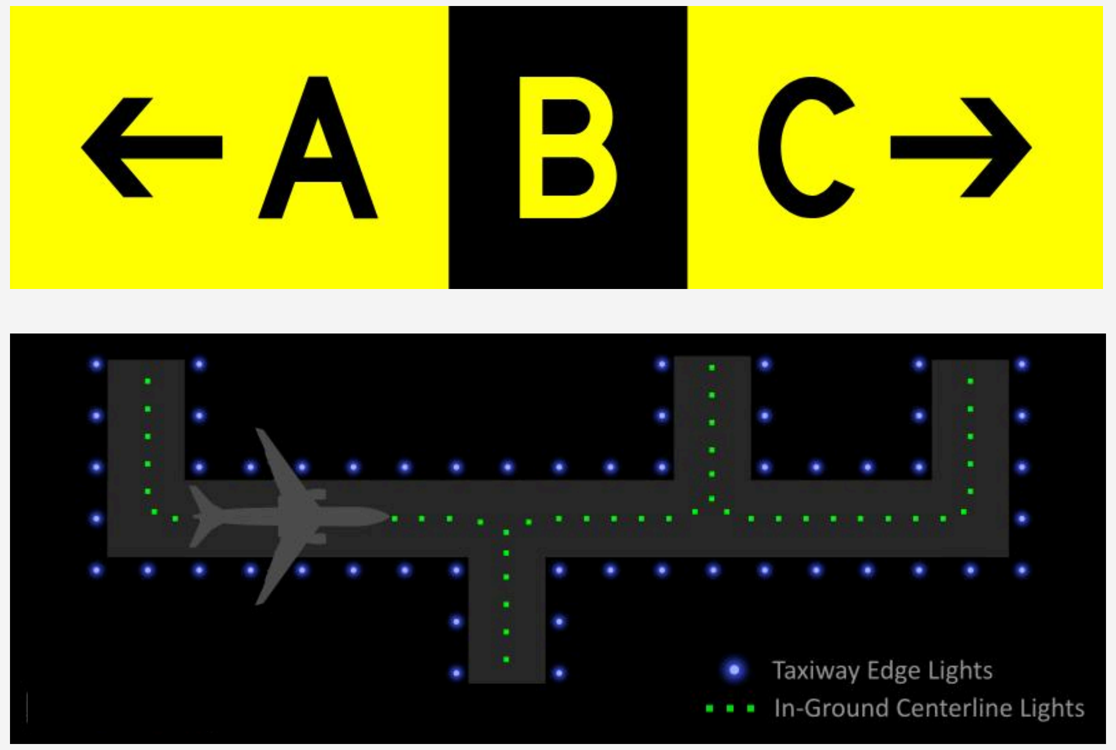


Figure X shows the taxiway sign and in ground center taxiing green light

Signal alignment

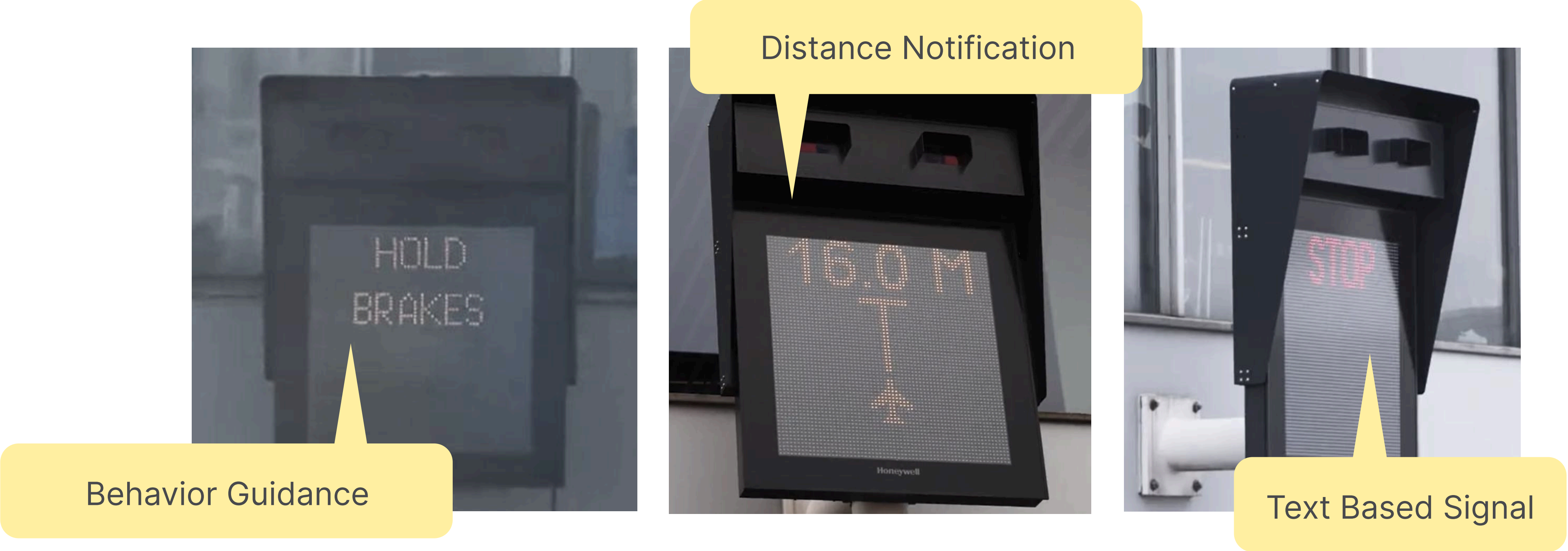
To ensure familiarity and intuitive recognition for pilots, the signal system of the UsherBot aligns closely with existing taxiway signage and color coding standards used in airport ground navigation.

As illustrated in Figure X, the current taxiway signage system uses black backgrounds to indicate the aircraft's current location, while yellow letters such as "A" or "C" represent upcoming taxiways based on directional turns. For example, a sign showing "← A " communicates that turning left leads to Taxiway A .

By referencing this established system, the UsherBot facilitates quick interpretation while minimizing pilot confusion.

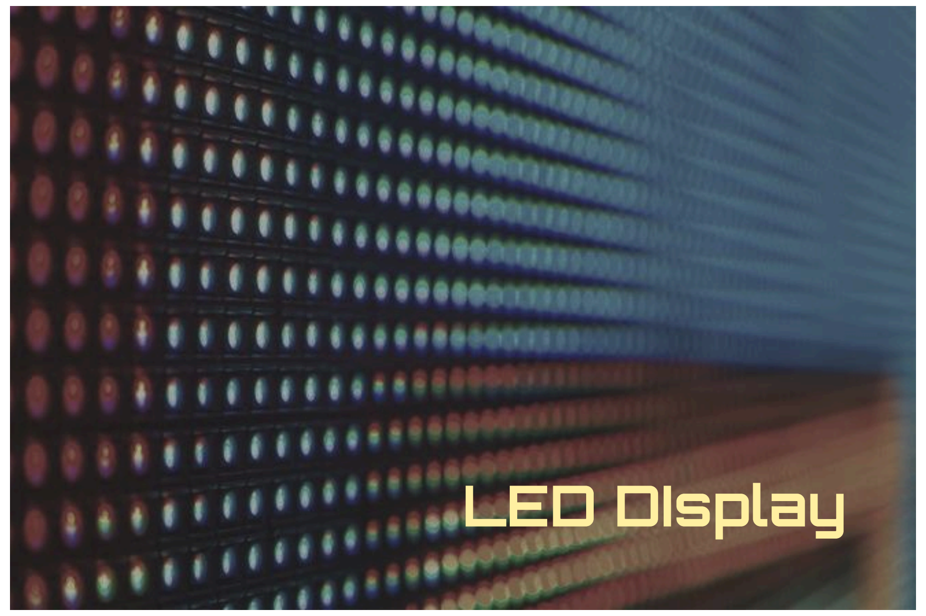
Signal system in airport

Within current airport infrastructure, the electrical screen display for docking showcase the distance and motion guidance for pilots, serving as good reference on how to communicate behavior through text and dynamic screen.



Solution for Usherbot

Based on the current infrastructure, I incorperate exisiting screen display together with the projection technology to create the signal patterns for usherbot.



Digital Projection

Building upon those existing logic, the UsherBot uses projection-based signaling and screen display to guide pilots in a similarly structured way.
At the start of the “FOLLOW ME” process, the projection system displays the aircraft's current position and the available route options after the next turn, mirroring the established signage convention. To maintain visibility during daylight conditions, this visual signal is reinforced by a digital display on the UsherBot’s rooftop, which mirrors the projected guidance.

Accelerate

Turnings

Warning

Stop

4.5 Motion cues

Figure 11 shows the motion cues of usherbot in various color and light animation

Motion alignment

The motion design of the UsherBot builds upon conventional car lighting system, together with subtle, organic animation inspired by a stingray. This combination allows the UsherBot to behave not just as a machine, but as an active, expressive tour guide, one that communicates direction, speed, and intention through both light and movement.

Motion design

As shown in Figure 11, the UsherBot uses animated rear lighting to communicate its motion state in a clear and expressive manner.

- Straight Movement: When accelerating forward, the rear light glows blue with a smooth, wing-like animation that flows from the center outward. This motion mimics the rhythmic propulsion of a stingray, establishing a sense of continuity and calm progression.
- Turning: When preparing to turn, the system activates a blinking yellow light on the corresponding side, following standard automotive conventions. This directional cue aligns with pilots' existing expectations and supports instinctive interpretation.
- Stopping: Upon deceleration and full stop, the rear light shifts to red with a subtle dimming effect to indicate braking. The transition remains smooth, preserving the bot's composed and non-aggressive visual language.

By integrating both **behavioral animation** and **familiar light cues**, the UsherBot enhances pilot understanding and reinforces trust through expressive, readable motion.

VR Evaluation

In this chapter, the UsherBot's interaction concept is evaluated through an immersive Virtual Reality (VR) simulation. By placing participants in a first-person cockpit perspective within a realistic taxiing scenario, the study investigates how pilots perceive and respond to the bot's motion and light-based signals, gathering insights through behavioral feedback and think-aloud protocols.

5.1 VR Application Research Plan

Purpose of the Research

The aim of the study is to **evaluate pilot comprehension and trust** in the motion and light-based communication signals of the UsherBot in a simulated taxiing scenario. By utilizing a first-person perspective within a **Virtual Reality (VR)** environment built in Unreal Engine, the research will examine whether the designed cues are effectively perceived and interpreted by pilots.

Research Objectives

- To assess pilots' **understanding** of the UsherBot's light and motion signals used during autonomous taxi guidance.
- To evaluate **levels of trust** in the UsherBot system from the pilot's point of view.
- To identify which signal types and motion patterns are most intuitively understood in dynamic taxiing situations.

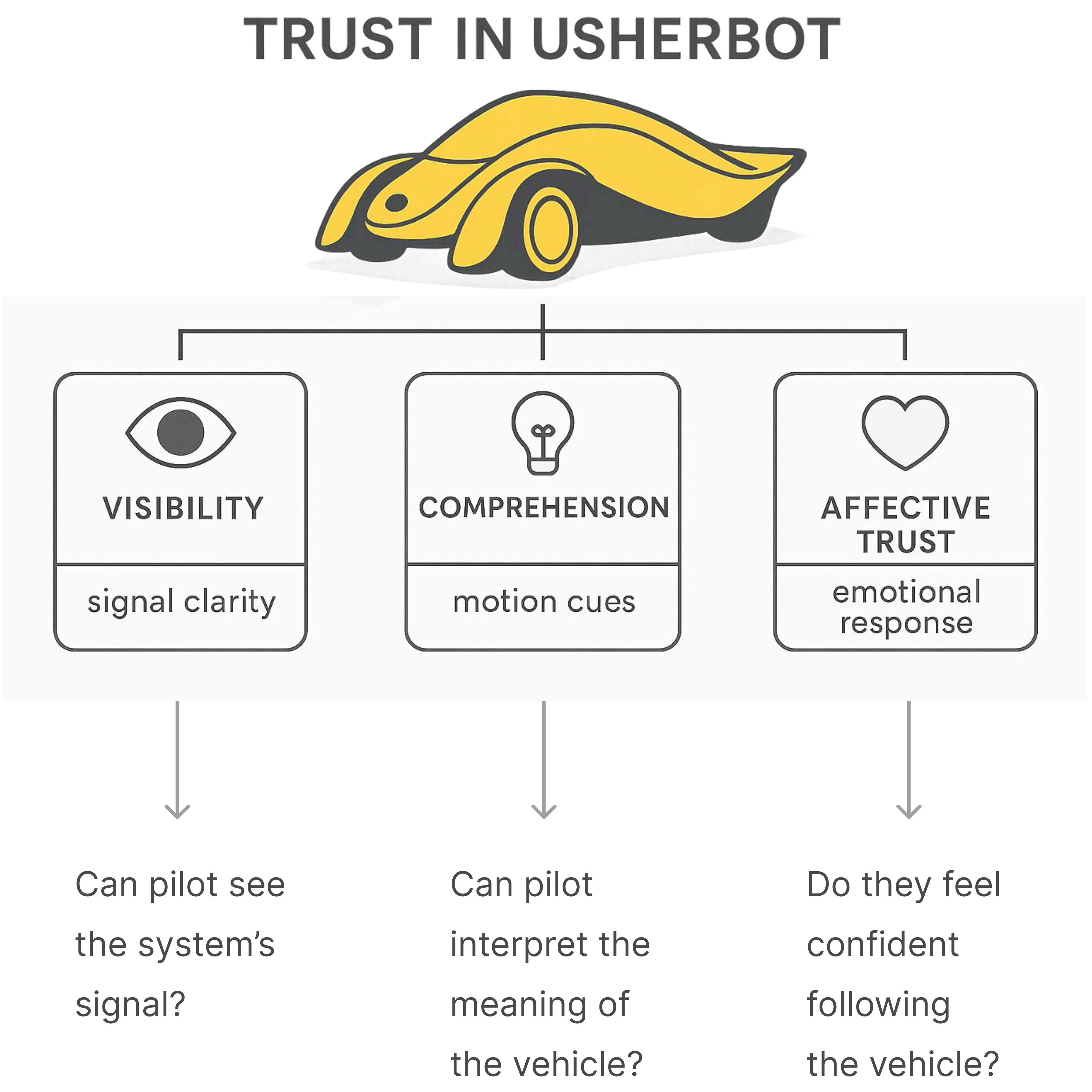
Research Framework Reference

As introduced in Chapter 2.1, trust is understood as a **multi-dimensional** construct. The design of the UsherBot's light and motion communication draws on these insights to ensure **legibility, consistency, and confidence** for the pilot.

Therefore, I break down the VR testing research into three measurable dimensions:

- Visibility: Can pilots easily see and detect the UsherBot's signals?
- Comprehension: Can they interpret the meaning of those signals accurately?
- Emotional Trust: Do they feel confident and safe following the vehicle?

These dimensions directly inform the VR-based evaluation, which assesses how effectively the UsherBot communicates through projected lights, motion cues, and spatial positioning.



TRUST IN USHERBOT

VISIBILITY
signal clarity

COMPREHENSION
motion cues

AFFECTIVE TRUST
emotional response

Can pilot see the system's signal?

Can pilot interpret the meaning of the vehicle?

Do they feel confident following the vehicle?

Figure 12 shows the research framework for the VR evaluation

5.2 VR Context Set up

To prepare a proper testing context that represent the taxiing scenario. The interaction will proceed as follows, gradually transit the pilots from “greeting of usherbot” that indicate the destination, and process to “Confirm follow” as a confirm response, and in the end move on to the “Follow me taxiing process.”

VR experience flow

1. Scene Introduction:
The scenario opens with a static cockpit view. The UsherBot enters the pilot’s field of vision and positions itself on the taxiway.

2. Initiation of Guidance
The UsherBot activates its yellow light to signal guidance and wait for confirmed response from pilot.

3. Pilot Aknowledgement
Notified by usherbot’s communication, pilot trigger confirm by controller to follow and start of the follow me process.

4. Accelerate and Go Straight Guidance
To start driving, the usherbot show blue accelerate and go straight projection ,with blue blinking rear light to indicate speed up and go straight

5. Turnings Instruction
Around the corner, the usherbot show the yellow arrow projection with yellow blinking for direction.

6. Warning and Stop Guidance
The UsherBot activates its red warning and stop projection with blinking in rear light, indicating its end of guidance.

5.3 Route and movement Planning

To showcase a proper route for usherbot's guidance in VR, I choose a taxiway from outside to the runway, and return back to the original location, further on, more routes that indicate the real world congestion context will be planned for proof of concept for further development. In terms of the speed and distance, we take reference from current taxi process, the usherbot will be 20 meters in front of the aircraft, with a straight speed 20–30 knots (≈ 37–55 km/h), Taxiway Turns, Apron Areas 5–10 knots (≈ 9–18 km/h)

Movement Control	Speed	Distance
Straight Taxiing	20–30 knots (≈ 37–55 km/h)	10–20 meters
Taxiway Turns, Apron Areas	5–10 knots (≈ 9–18 km/h)	10–20 meters

5.4 Data Collecting Methods

For the VR test, 2 methods are applied to get the feedback data from pilots:

Think-Aloud + In-Scenario Questions
During the VR experience, I will ask quick questions on visibility of the component to get intuitive reaction for the interaction.

Post-Test Interview Questions
Within this section, in depth interview together with questionnaire (see appendix c for details) is applied to get feedback based on the model of "Visibility, Comprehensive, and Trust" for understanding.

The questions are on the right:

1. Visibility Evaluation

- On a scale of 1–5, how would you rate the visibility of the usherbot vehicle?
- Please elaborate more on the visibility of the vehicle
- On a scale of 1–5, how would you rate the visibility of the projection?
- Please elaborate more on the visibility of the projection
- On a scale of 1–5, how would you rate the visibility of the lightening patterns (rear light and light strip)?
- Please elaborate more on the visibility of the lightening patterns (rear light and light strip)
- On a scale of 1–5, how would you rate the visibility of the colors (blue, yellow, red light) ?
- Please elaborate more on the visibility of the colors (blue, orange, red light)

2. Comprehension & Signal Design

- On a scale of 1–5, did you find the guidance of the usherbot familiar enough for you to follow?
- Please elaborate more on the familarity of the guidance process from the usherbot
- On a scale of 1–5, did the projection help you feel aware of what was happening and what to expect next?
- Please elaborate more on the reason of its predictability
- Regarding the light patterns on the vehicle(rear light and blinking patterns): Were they easy to understand?
- Please elaborate more on the light patterns of the vehicle
- Were there any moments where you felt unsure about what action to take?

3. Trust & Confidence Evaluation

- How does this experience feel compare to the traditional ATC-guided taxiing process?
- Did the Usherbot feel reliable in guiding you through the taxiing process?
- Please elaborate more on the reliability of the vehicle
- On a scale of 1–5, how much did you trust the usherbot's guidance on taxiing preocess
- Please elaborate more on the trust of the vehicle
- Do you have any suggestions for improving the interaction or communication, based on your professional experience?

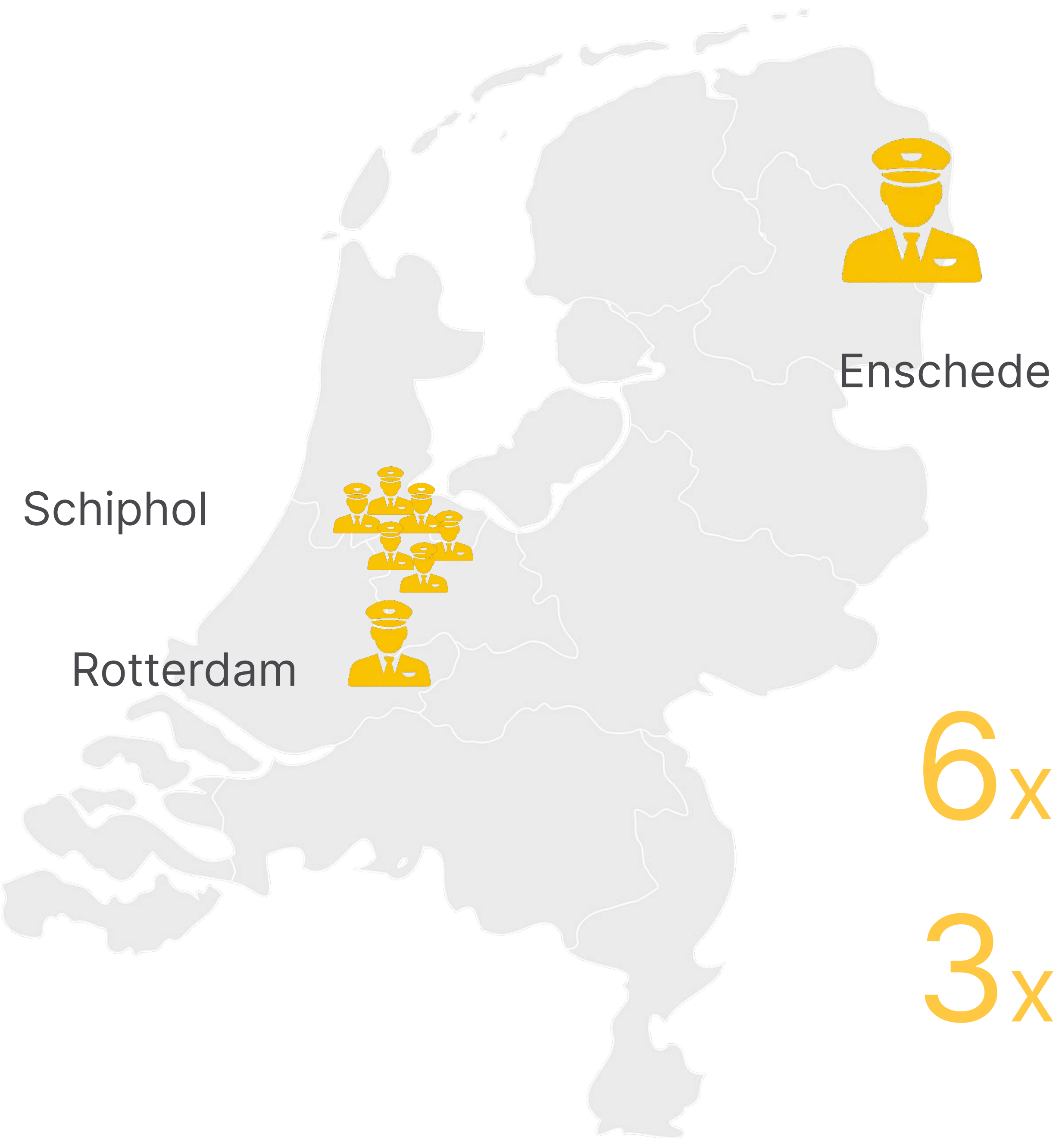
5.5 Result

In the result, both quantity data and qualitative data from interview of the visibility, comprehension, and trust will be shown, and will be conclude as several design recommendation that shape the future development of the usherbot interaction.

5.5.1 Overview of the result

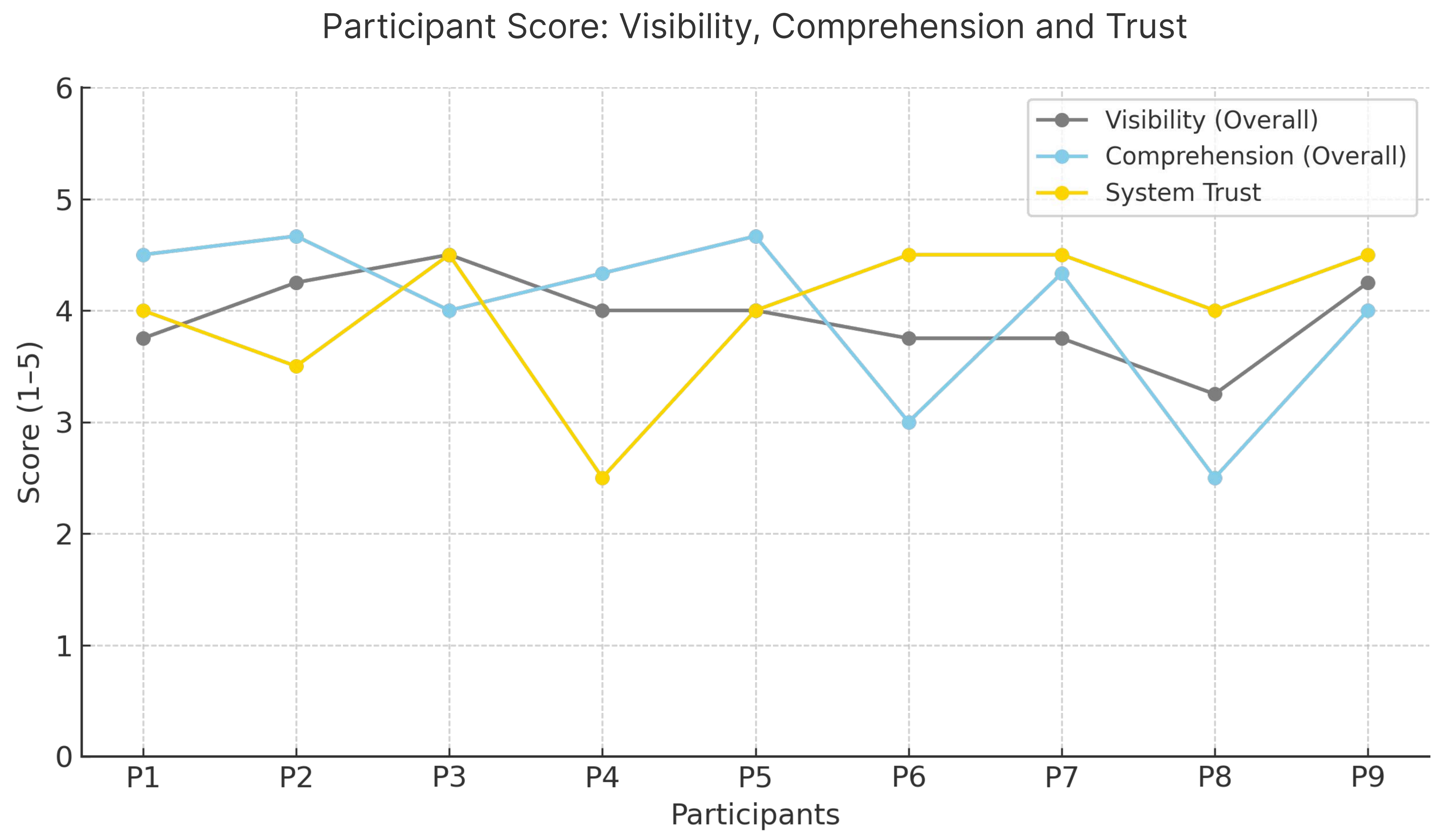
Background of participants

A total of nine pilots participated in the evaluation session, including six commercial pilots and three private pilots. All participants were based in the Netherlands and were invited through Usher AI's professional aviation network. The goal of this session was to assess the visibility and comprehension of the UsherBot's signaling system, as well as the participants' trust and confidence in the vehicle.



6x Commercial pilot

3x Private pilot



Data summary

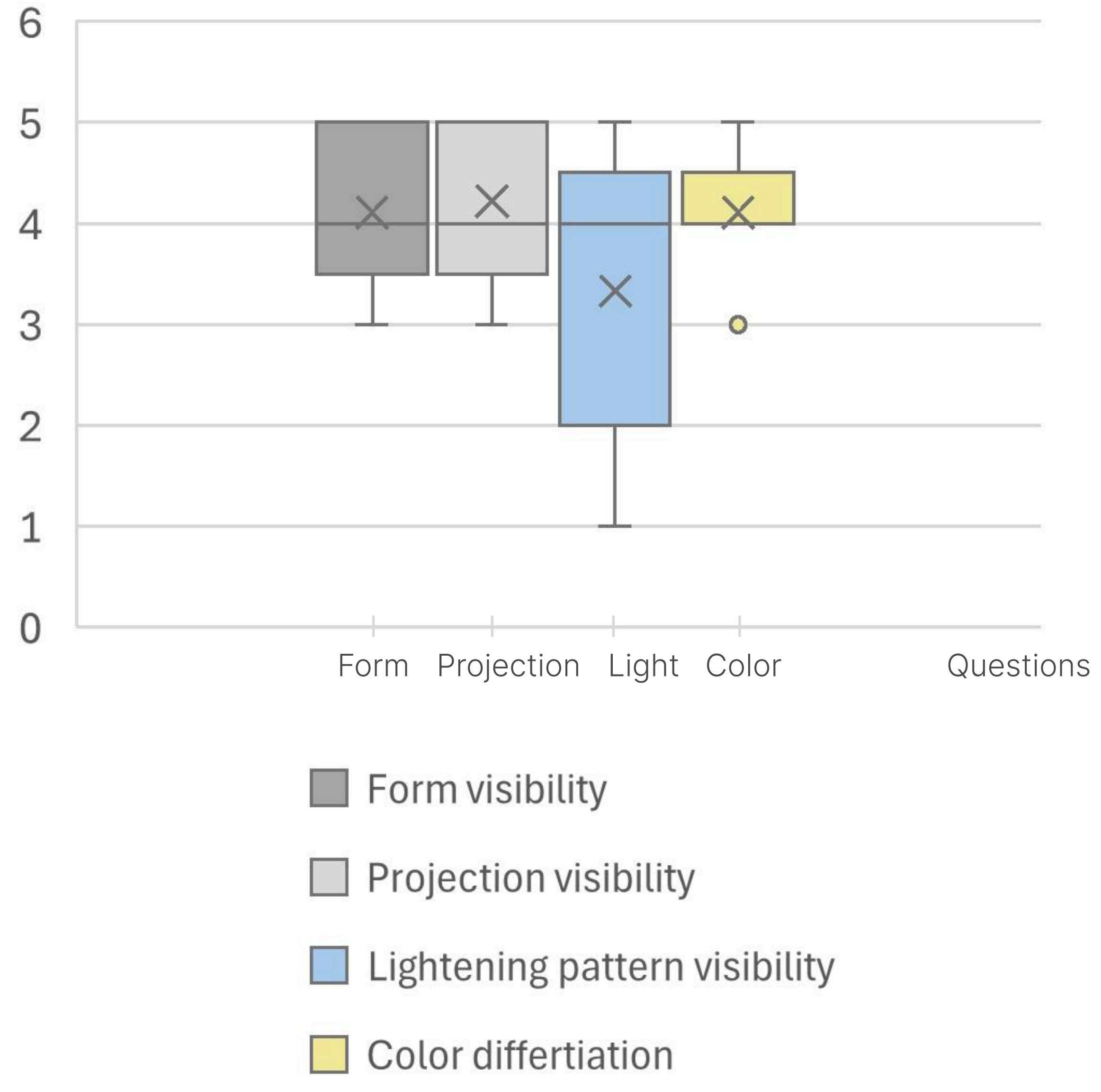
As shown in the line chart, each participant's average scores were calculated for three key dimensions: visibility, comprehension, and trust & confidence. The overall averages across all nine participants were: Visibility: 3.94, Comprehension: 4.11, Trust & Confidence: 4.11.

The results indicate a generally positive reception toward the system, with consistent performance in both signal clarity and trust-building. To explore the relationships between these variables, Chapter 5.5.2 will introduce a hybrid view combining both qualitative insights and a Spearman's rank correlation analysis.

5.5.2 Hybrid View

This section integrates both quantitative metrics (including score-based rankings and Spearman's correlation, see appendix e.-g. for raw data) and qualitative interview insights to build a holistic understanding of how participants evaluated the UsherBot's performance across three key dimensions: Visibility, Comprehension, and Trust & Confidence. The following findings highlight areas of consensus, identify divergent viewpoints, and offer deeper interpretations of the factors that contribute to trustworthy human-automation interaction within airport.

Visbility



Overall, the visibility of form, projection, and color differentiation each received average scores above 4, indicating that most participants found these elements clear and effective. In contrast, light pattern visibility received a slightly lower average score of 3.33, suggesting participants generally found it acceptable, though it posed more challenges in salience and attention capture compared to other visual elements.

Consensus - Yellow

Participants showed strong alignment in their evaluation of the color-coded signals, with color differentiation receiving a consistently high average score (e.g., 4.44/5, as shown in the boxplot). Multiple participants confirmed the signals were clearly distinguishable, particularly appreciating the contrast between blue, yellow, and red.

- However, despite its visual clarity, 4 participants raised a design-related concern regarding the use of shiny blue for “go straight” and “accelerate” instructions. Three of them noted that while blue was visually prominent, it lacks a universally intuitive association with forward motion or acceleration. In contrast, green was suggested as a more semantically appropriate alternative, aligning with existing airport guidance systems (such as green centerline taxiway lights) and common traffic light conventions.

> "Totally distinguishable, but blue doesn’t intuitively mean ‘accelerate’ to me—maybe green?"
> "For the accelerate and go straight signal, green would be better. It matches the center taxi light."

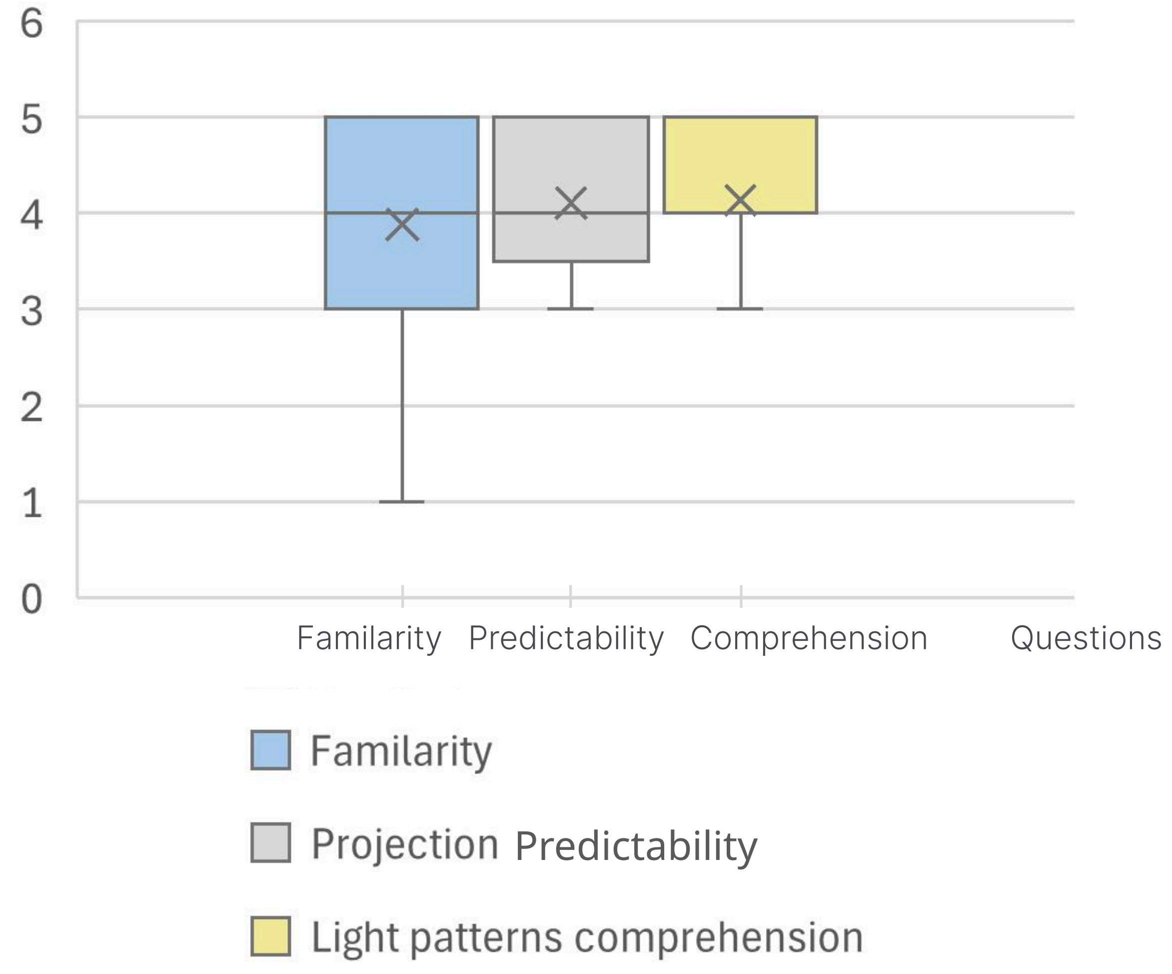
Divergent opinions - Blue

The evaluation of the light pattern signal revealed a broad range of responses, with ratings spanning from 1 to 5. While several participants appreciated the brightness and contrast of the light pattern, noting it was sufficiently visible even from a distance, others found it less noticeable due to their primary attention being directed toward the projection. This variability was reflected in the wider spread of the boxplot and further supported by interview feedback:

> "Just clear, I can see it properly." — P4
> "I was too focused on the projection, so I didn't notice there's blinking light there." — P8
> "A larger and brighter light area might help grab attention better." — P7

These responses suggest that while projection and color-based signals are consistently effective, supplementary lighting features like the rear light strip may require enhanced contrast or size adjustments to ensure equal perceptual salience in complex environments.

Comprehention



Overall, participants responded positively to the comprehension of UsherBot's instructions. The average score for projection predictability and lighting comprehension both exceeded 4, indicating high levels of clarity.

However, familiarity was scored slightly lower (avg. 3.7), reflecting the novelty of the autonomous follow-me interaction.

Consensus Area – Intuitive Comprehension

- Participants widely described the system as "intuitive," especially in reference to the use of dynamic projection and motion-based signaling.
- All participants agreed that the lighting patterns were easy to comprehend, drawing parallels with familiar conventions from automotive signaling.

> "It's quite intuitive to follow, so I find it totally familiar." — P2
> "Im not familiar with it because it's different from the tradiational guidance, but the usherbot behave intuitively and it's better than the traditional follow me car, they didn't show anything." — P3

These responses align with the high average scores and tight distribution in the boxplots, reinforcing that participants found the visual language easy to understand once experienced.

Uncertainty & Discussion

- 2 participants were unsure about the warning sign, noting that it signals an issue but does not provide clear instruction on what action should follow.

- 2 participants mentioned that the “double arrow” signal for acceleration was not immediately understandable. One suggested animating the arrow forward to clarify intent:

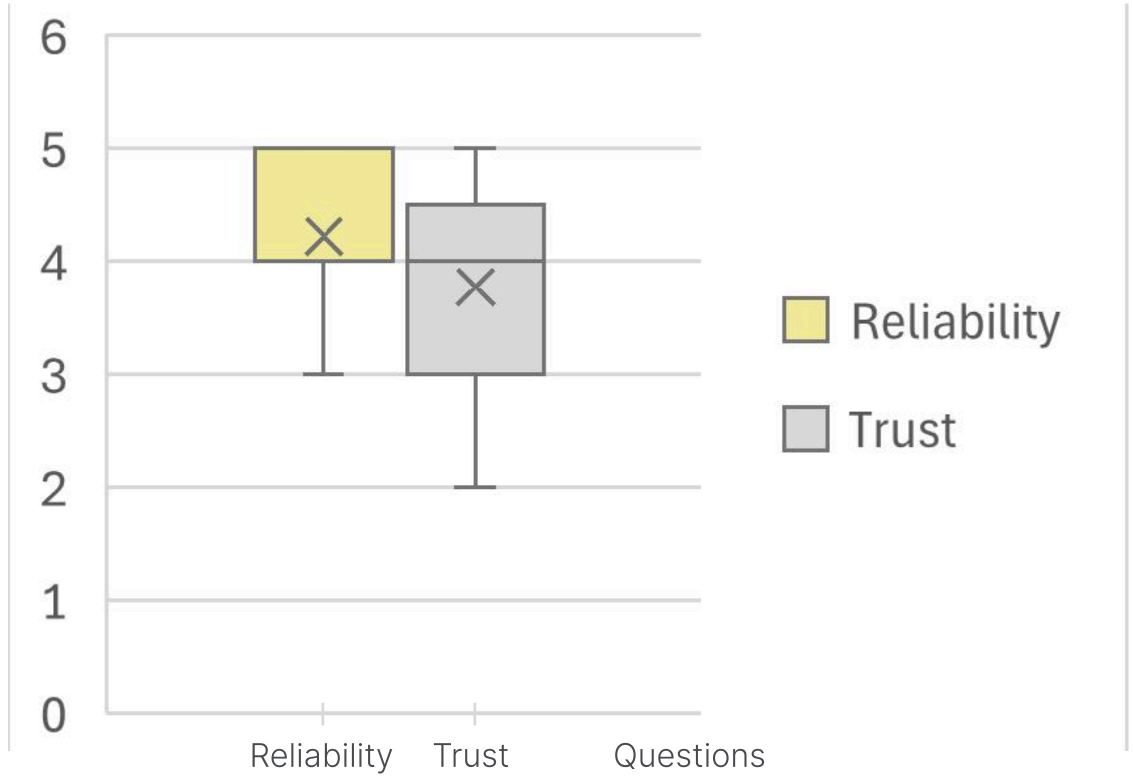
> “ Accelerate with double arrow is a bit unsure, since it's not existing yet, I think it will be great if it's moving forward on the ground then I know”

- 3 other participant expressed the need for more route transparency, mentioning that the “call message” and “end-of-guidance” signals were helpful additions, as they clearly indicate when to start and stop following the UsherBot.

> “ As a pilot I would like to know the overview of the route and understand when I will dis attach from the usherbot, so that I know Im following the right car, and leave at the right moment.”

These feedback suggest that while most comprehension cues were effective, few newly introduced signals require further refinement to reduce ambiguity in operational contexts.

Trust



Consensus Area

Participants generally responded positively when asked about the system’s reliability, with many describing the experience as more relaxed and cognitively effortless compared to conventional ATC-based taxiing.

- 2 participants highlighted that not having to memorize instructions or perform radio-based readbacks enhanced their sense of ease and confidence.

> “I think the experience is more relaxed. I don’t need to memorize all the routes at once. For ATC guidance, I need to read back from the radio. This innovation makes it easier and feels safer to me.” — P2

- The overall reliability score averaged 4.2/5, with a compact interquartile range in the boxplot, indicating a shared perception of stable and trustworthy system behavior.

Divergence & Discussion

Despite strong scores for reliability, the overall trust score showed more variation, showing that deeper confidence in the system depends on other factors beyond system performance.

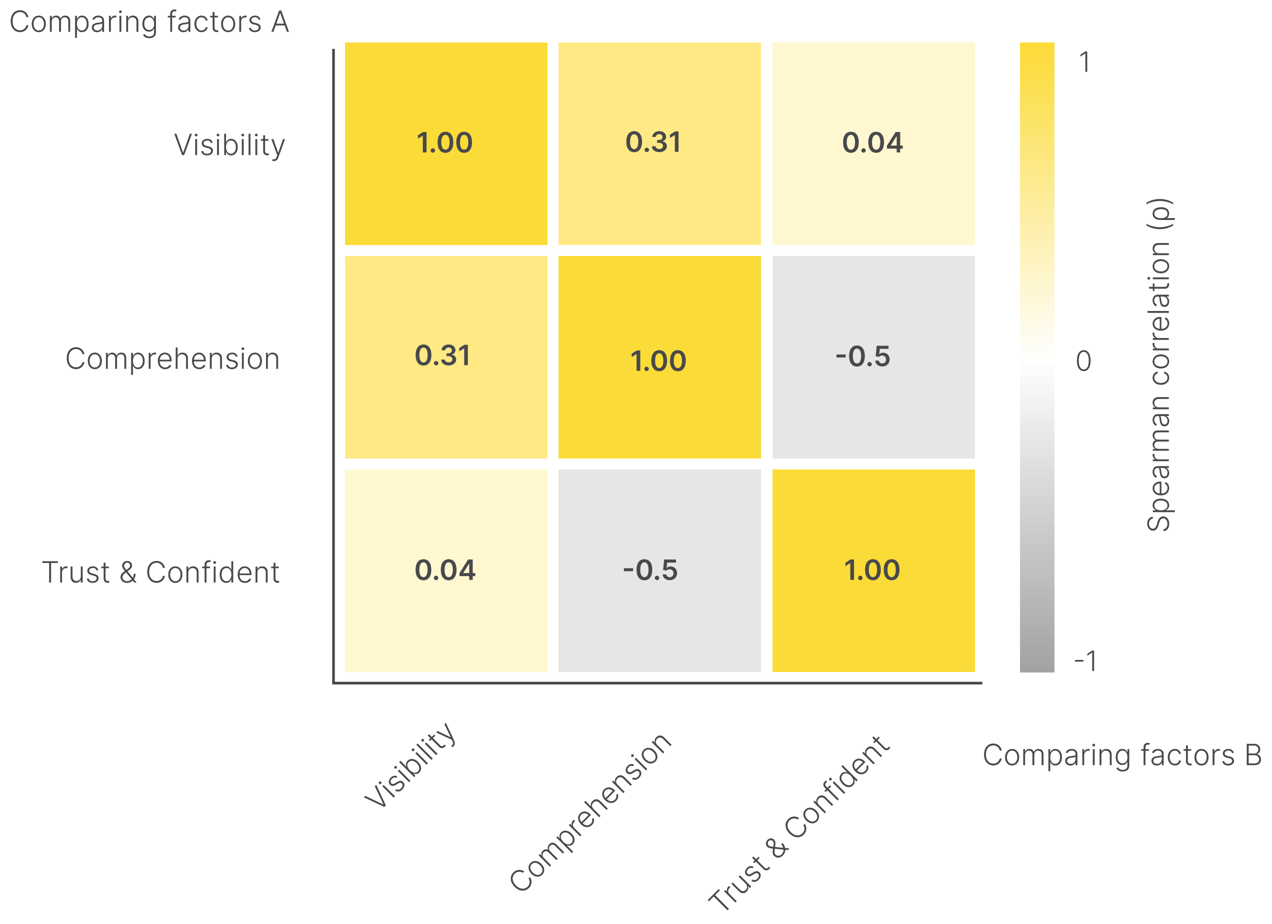
> “As a pilot I would like to know the overview of the route and understand when I will detach from the UsherBot, so that I know I'm following the right car, and leave at the right moment.”

- Participants also emphasized that trust is not instant. It is something that develops with continued, successful interactions and consistent, predictable signals:

> “The signal cues are quite easy to predict. But for runway crossing, I hope the info will pass to the pilot as well, otherwise it's a bit scary to follow.”
>
> “Depends on the experience, probably after 3 or 4 times, I can start trusting it. Trust comes gradually if things work well.”

These insights align with the broader understanding that trust in automation is context-sensitive, accumulative, and reinforced by transparency and system predictability.

5.5.3 Spearman’s rank correlation



	Visibility	Comprehension	Trust & Confident
Visibility	1.00	0.31	0.04
Comprehension	0.31	1.00	-0.5
Trust & Confident	0.04	-0.5	1.00

To deepen the understanding of how the core elements of visibility, comprehension, and trust & confident contribute to designing a clear and trustworthy external Human-Machine Interface (eHMI), a Spearman rank-order correlation analysis was conducted.

This non-parametric method measures the strength and direction of association between two ranked variables, helping to determine whether improvements in one area might influence another.

Positive Correlation:
Visibility and Comprehension

The analysis revealed a weak positive correlation between Visibility and Comprehension (ρ = 0.31), showing that when participants perceived the UsherBot's signals and projections as more visible, they also tended to find them easier to understand.

This correlation aligns with the design intention that clarity of visual cues(including shape and signal interaction) enhances intuitive interpretation.The result also supports the assumption that enhancing visibility facilitates better comprehension, particularly when signals are well-integrated with expected conventions and environmental constraints.

No Positive Correlation:
Visibility/Comprehension and Trust

In contrast, no positive correlation was found between Visibility and Trust & Confidence (ρ = 0.04) or Comprehension and Trust & Confidence (ρ = -0.5). These values indicate that better visibility or comprehension alone does not directly foster trust.

While this may challenge initial assumptions, it aligns with qualitative insights: trust depends less on visual clarity and more on factors like system transparency, perceived control, and repeated positive experiences. It is accumulative and contextual, built over time as users grow confident in the system’s consistency.

These findings underscore that while visibility and comprehension are essential, trust must be reinforced through design strategies such as route previews, timely feedback, and clear communication. Trust, ultimately, extends beyond interface clarity into experiential and psychological reassurance.

5.5.4 Conclusion of testing result

Building on the mixed-method findings from 5.5.1 and 5.5.2, this section synthesizes insights from both quantitative data (boxplots, Spearman correlation) and qualitative feedback (interviews) across the three core themes: visibility, comprehension, and trust. These results reveal how participants interpreted and responded to the UsherBot's interaction design in a simulated airport context.

Visibility
Competing for Attention

A recurring theme among participants was the need for the UsherBot to visually stand out within the visually saturated context of an airport. Participants evaluated the vehicle's shape, projection behavior, light patterns, and color contrast in terms of how easily it could be spotted, especially at a distance.

One participant summarized this clearly:
"Within the airport context, every element is fighting for attention, so how to make things stand out is the essential point." — P7

The Stingray-inspired form and its surrounding light stripe were perceived positively, as they enhanced visibility and recognition. However, concerns were also raised regarding the dark body color of the bot in certain lighting conditions, which could potentially reduce contrast and clarity, suggesting the need for visual optimization in real-world applications.

Comprehention
Representing Intent Clearly

Participants emphasized the importance of understanding what the bot was about to do, especially in moments of upcoming turns or stops. While the overall communication experience was rated positively (averaging above 4.1 on clarity and comfort), several participants requested more context-aware signaling.

Suggestions included:
- Differentiating turning angles visually (e.g., sharp vs. slight turns)
- Showing countdowns or progress cues before movement
- Indicating suggested pace (e.g., how quickly the aircraft should follow)

These insights support the potential of projection-based signals to go beyond static direction cues, by offering dynamic, anticipatory guidance that mirrors real-world decision-making in motion.

Trust: Feeling in Control Through Transparency

Although reliability received a solid score (avg. 4.22) with a tight boxplot, overall trust varied more widely (range: 2–5), suggesting that trust was most associated with feeling of being informed and in control. Participants expressed greater confidence when they get the route previews, ATC confirmation, and multiple exposures to build trust.

“I’d feel more certain if I knew which route and gates it’s going, like a preview or message before it moves.” — P4
“Trust comes gradually—probably after 3 or 4 times.” — P6

This finding aligns with existing literature (e.g., Hoff & Bashir, 2015), which highlights that trust in autonomous systems is built over time through repeated, predictable interactions and transparent feedback.

Participants also noted that time and experience will influence on the trust of the system, suggesting that early onboarding experiences and consistent behavior could play a vital role in trust calibration over repeated use.

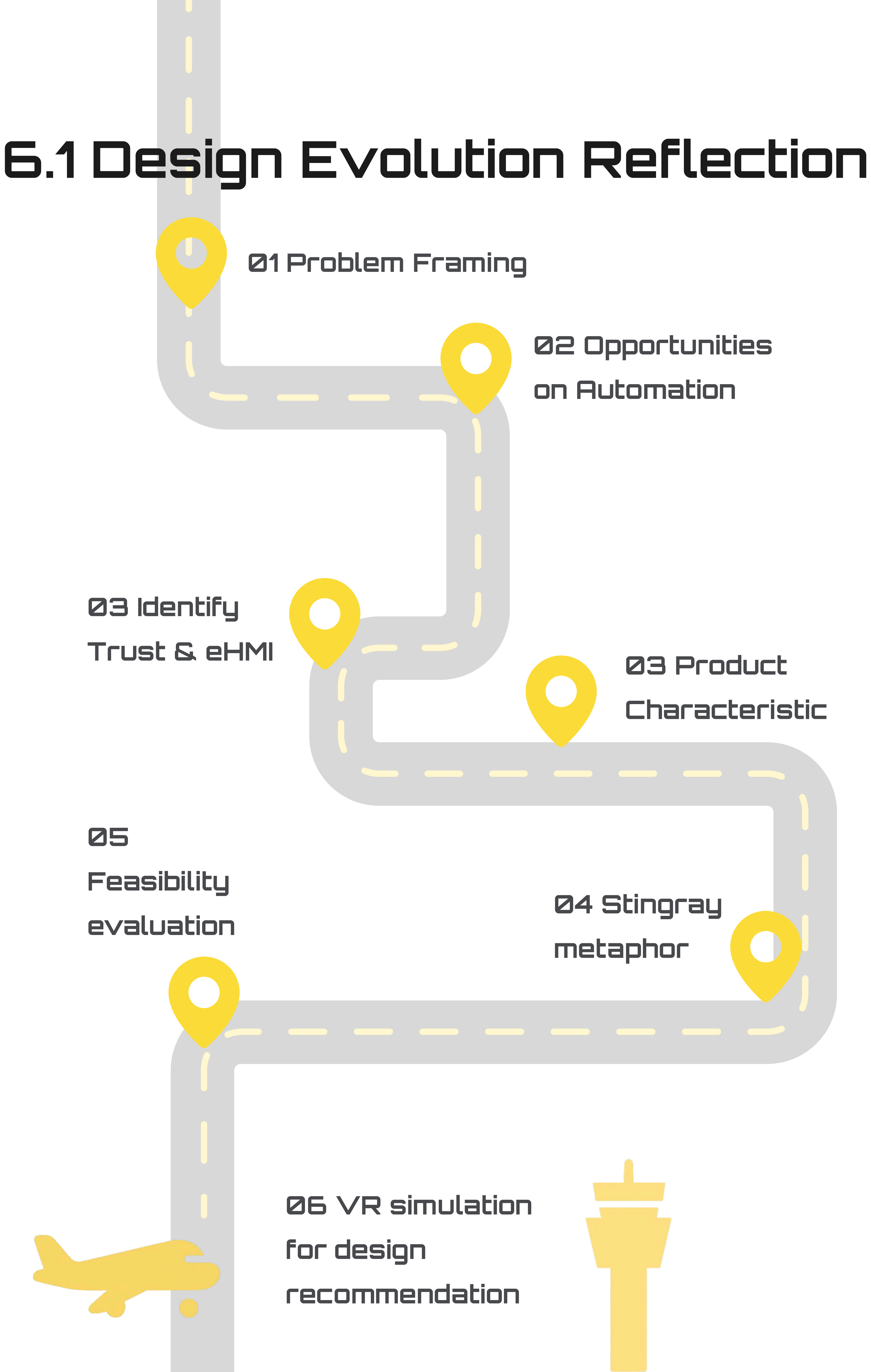
> These insights validate UsherBot’s foundational strategies in visual signaling and motion alignment, while also highlighting areas for refinement, particularly around attention capture, signal learning, and trust-building over time. These findings directly inform the design recommendations in Chapter 6, guiding how the UsherBot system can evolve into a reliable and intuitive partner for airport taxiing.

Discussion & Recommendation

This chapter reflects on the research and design process, showing how the UsherBot addresses the research question and delivers value to the aviation industry. The discussion examines its contribution from both design and systems perspective, highlighting how the proposed solution addresses operational challenges, enhances human–vehicle interaction, and supports the future vision of autonomous ground movement.

6

6.1 Design Evolution Reflection



01 Problem Framing

02 Opportunities on Automation

03 Identify Trust & eHMI

03 Product Characteristic

04 Stingray metaphor

05 Feasibility evaluation

06 VR simulation for design recommendation

Reflecting on the design evolution, the design of the UsherBot was shaped through an iterative process that responded directly to three key challenges identified in the early phases of this project:
(1) safety risks arising from verbal communication,
(2) inefficiencies from fragmented coordination, and
(3) sustainability concerns due to excessive fuel burn during taxiing.

These challenges framed the opportunity space:

> **Designing an autonomous system capable of delivering seamless, intuitive taxiing guidance through non-verbal communication.**

To inform the interaction approach, a targeted literature review was conducted focusing on trust in human–autonomous interaction (HAI) and external human–machine interfaces (eHMI). These frameworks highlighted the importance of predictability, transparency, and multimodal communication for fostering trust in high-stakes environments such as aviation.

Drawing from these insights, the project established a set of guiding design values: authority and futurism, to define the vehicle's intended character and aesthetic. These values were translated into early ideation using biological metaphors, particularly aquatic forms such as the stingray, to communicate both directional clarity and non-threatening guidance. The stingray metaphor helped inspire a low, wide form that glides fluidly through space, reinforcing visual trust without relying on verbal instructions.

As the concept matured, specific interaction components were developed around this form:

- The curved rooftop screen emerged as a primary communication surface, offering both visibility from cockpit angles and the flexibility for dynamic, icon-based display.
- The streamlined body shape provided a clear front–rear orientation while supporting the system's identity as a confident, intelligent guide.
- Light patterns and projection-based signals were layered into the design to extend its communicative reach making it easier to interpret across distances, weather conditions, and linguistic barriers.

Parallel to the aesthetic and interaction development, technical feasibility was continuously addressed. Key aspects such as sensor positioning, screen curvature, and battery housing were refined through 3D iterations to ensure the design remained operationally viable without compromising form.

Finally, the design was validated through a VR-based evaluation session, which simulated cockpit perspectives and allowed participants to interact with the system under controlled conditions. Feedback and data analyzation confirmed that the motion cues, directional light patterns, and spatial projections improved clarity, supported intuitive interpretation, and enhanced user trust in the vehicle's behavior.

This design evolution reflects the balance between aesthetic vision and technical grounding, resulting in a concept that is not only expressive and future-oriented but also feasible, readable, and system-aware in the complex environment of airport ground movement.

6.2 Contributions to the Field

The UsherBot introduces two key design innovations that contribute to safer, clearer, and more sustainable taxiing guidance.

Biological Form for Visual Recognition & Trust

By adopting a bio-inspired, fluid form with integrated light contours, the UsherBot becomes instantly recognizable and readable from a distance, improving pilot confidence and followability without verbal instructions. Its physical presence communicates authority and movement intent more effectively than traditional follow-me vehicles.

"The shape of usherbot is unique and clear, making it easy to spot." — P5

Less Cognitive Load & All weather fit

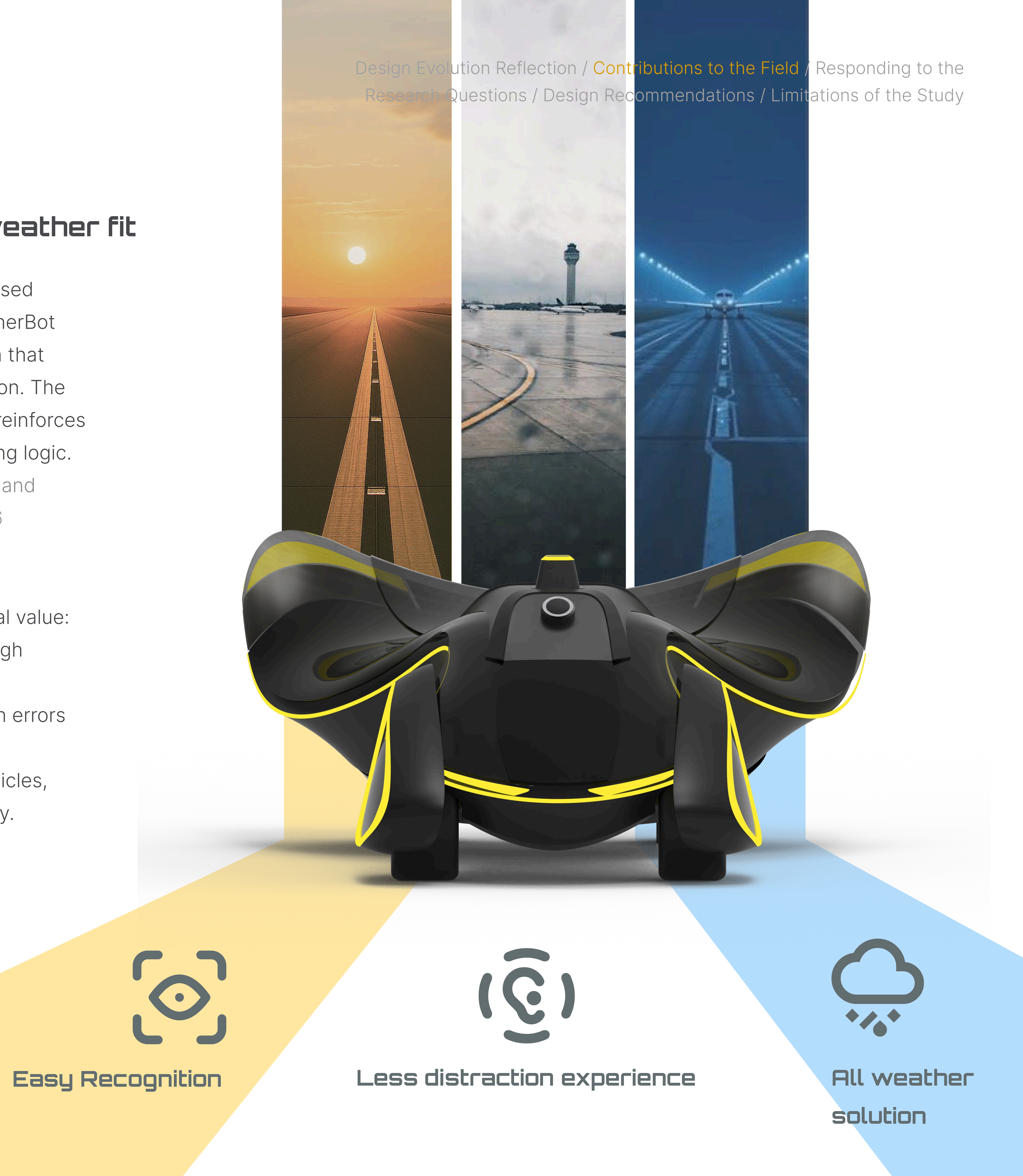
Through a combination of projection, icon-based rooftop signals, and dynamic lighting, the UsherBot offers layered, context-aware communication that reduces radio dependency and pilot distraction. The system supports all-weather readability and reinforces intuitive comprehension using familiar signaling logic.

"With UsherBot's guidance, there's less noise and distraction. This really improves safety." — P6

These contributions turns into clear operational value:

- Enhanced pilot situational awareness through expressive yet minimal interaction.
- Reduced cognitive load and communication errors in high-pressure taxiing environments.
- Potential to replace combustion-based vehicles, supporting greener, smarter ground mobility.

> Ultimately, UsherBot demonstrates how tangible design, signaling clarity, and smart system can work together to transform human–machine collaboration in aviation.



6.3 Responding to the Research Questions

Outline

The central research question guiding this thesis was: **"How can an autonomous follow-me vehicle provide clear and trustworthy motion- and signal-based instructions to pilots during taxiing?"**

To address this challenge holistically, the question was broken into two interrelated sub-questions:

RQ1: What design strategies can foster trust between pilots and an autonomous follow-me vehicle during taxiing?

RQ2: How do specific visual and motion-based cues contribute to clearer and trustworthy guidance?

Each sub-question is addressed below through a synthesis of theoretical insights, design development, and VR-based evaluation.

RQ1: What design strategies can foster trust between pilots and an autonomous follow-me vehicle during taxiing?

The first sub-question focuses on strategic design decisions that influence pilot trust in an autonomous system. Literature on Human–Autonomous Interaction (HAI) emphasizes the importance of transparency, predictability, and consistent behavior in trust-building (Lee & See, 2004; Hoff & Bashir, 2015). These insights were translated into three guiding strategies in the UsherBot design:

- A distinct and recognizable form language, inspired by biological metaphors (e.g., a stingray), was developed to convey calm authority and intentionality. This allows the bot to be easily spotted and visually interpreted without ambiguity.
- Minimal verbal dependency: All interactions were designed to be handled visually—reducing cognitive load and allowing pilots to stay focused on their environment.
- Behavioral alignment: Light and motion behaviors were timed and structured to match pilot expectations (e.g., blue for forward motion, yellow for turning), fostering interpretability and emotional neutrality.

These strategic choices were validated through the VR evaluation, where participants noted:
"The shape of the usherbot is unique and clear, making it easy to spot."
"With UsherBot's guidance, there's less noise and distraction—this really improves safety."

Conclusion: Trust can be fostered through a combination of clear form expression, behaviorally aligned signaling, and non-verbal consistency, reducing ambiguity and supporting a calm, intuitive interaction model.

RQ2: How do specific visual and motion-based cues contribute to clearer, trustworthy guidance?

Based on literature and VR testing, three core interaction elements were identified as essential for enhancing clarity in autonomous taxiing communication:

Curved Rooftop Display

Optimized for cockpit viewing angle (~15–20°), the slightly concave, elevated screen ensures high visibility and minimizes glare—making visual cues easily readable from both pilot seats.

Ground Projection of Directional Cues

Projected arrows and turn indicators directly on the taxiway create a spatially intuitive guidance path, helping pilots follow the UsherBot instinctively without relying on radio instructions.

Color-Coded Motion Lighting

Projected arrows and turn indicators directly on the taxiway create a spatially intuitive guidance path, helping pilots follow the UsherBot instinctively without relying on radio instructions.

While these features improve visibility and comprehension, VR feedback and data analysis showed that trust depends on deeper factors:

- Transparency — Pilots trusted the system more when they understood why and when the bot made decisions.
- Feeling in control — Knowing the route or receiving pre-movement information reinforced confidence.
- Positive experience over time — Consistent, predictable behavior across interactions helped build long-term trust.

Conclusion

Effective visual and motion cues enhance clarity, but trust is not built on clarity alone. It grows from a sense of transparency, control, and consistency, elements that must be embedded into both the interaction design and system behavior. Together, these strategies form the foundation for trustworthy autonomous taxiing.

6.4 Design Recommendations

Drawing from both data analyzation and iterative design reflection, three key recommendations are proposed for further development of the UsherBot and similar autonomous airport guidance systems:

High-Contrast Signaling

- **Use High-Contrast, Shape-Led Signaling**

  Clear visibility remains a top priority, especially within visually complex airport environments. The design should maintain a distinct form factor and illuminated contours that make the vehicle easy to spot from the cockpit. Signal clarity can be further enhanced by using high-contrast color schemes and minimizing visual clutter or overload.

Adaptive Signal

- **Implement Adaptive Signals Based on Context**

  Pilots expressed interest in more dynamic, context-sensitive cues. This includes projections or light patterns that indicate not just direction, but also pacing (how fast to follow), timing (countdowns or transitions), and type of movement (e.g., wide vs. sharp turns). Adaptive signals can help align the system’s behavior with real-world operational flow.

Transparency & Consistent

- **Provide Transparent Route Previews and Approval**

  Trust and confidence improve when pilots are informed of the route and any ATC coordination before movement begins. Providing a ‘call message’ or route overview at the start creates a key trust-building moment, aligning with cockpit expectations for planning and confirmation.

- **Design for Familiarity and Long-Term Use**

  Trust develops over time. To support this, the system should use consistent signal logic, intuitive visual language, and non-aggressive animations that feel calm and reliable. Designing for long-term deployment also means minimizing novelty and favoring recognizable interaction patterns that support habit formation.

6.5 Limitations of the Study

1. Gap Between VR and Real-World Conditions

This study utilized virtual reality (VR) as a simulation tool to evaluate the communication between the UsherBot and pilots in a controlled airport environment. While VR enabled immersive feedback collection and spatial realism, several participants highlighted that the simulation did not fully replicate real-world variables, particularly those influencing visibility.

Specifically, 7 out of 9 participants mentioned that the UsherBot was clear and easy to spot in VR, but expressed concern about how signal visibility would be affected by real-world lighting, weather conditions, and taxiway surface textures. However, when it came to comprehension and trust, participants did not report any perceived differences between the VR simulation and expected real-world behavior.

Additionally, some participants expressed curiosity about how the UsherBot would perform in more complex operational scenarios, such as runway crossings, multi-aircraft environments, or congested traffic flows. Although these use cases were considered during the design phase, time constraints limited the simulation to a single taxiing route before takeoff.

Future work recommendation

- Incorporating multiple weather and lighting conditions in VR to better test signal reliability.
- Programming a wider range of dynamic airside scenarios (e.g., holding points, runway approvals) to evaluate how well pilots interpret the UsherBot’s instructions under more realistic operational complexity.

2. Technical Feasibility of Signaling Systems

The UsherBot concept proposes a dual signaling approach:
- A curved digital rooftop screen for visual instructions
- A ground-level projection system to extend communication to the taxiway surface

While these elements were designed with pilot visibility, eye-level angles, and weather variability in mind, the projection system in particular presents technical challenges in real-world conditions. Factors such as daylight brightness, surface reflectivity, and weather could significantly influence projection clarity.

Further research is required to test the projection in real-world airport conditions, determine optimal lumen intensity, projection size, and contrast settings, and assess how signals are perceived from different aircraft types and viewing angles.

3. Sample Size and Evaluation Scope

This study involved 9 pilot participants in total, with the VR-based user testing focusing primarily on qualitative interviews to gather feedback on visibility, comprehension, and trust.

A limited amount of quantitative data was collected as supportive evidence, primarily to reinforce subjective user impressions and clarify participant statements.

Due to the small sample size, the quantitative data of spearman’s rank correlation presented is not statistically significant and should not be interpreted as academically generalizable. Rather, the results serve to guide design reflection and future testing directions.

Conclusion

This chapter summarizes the thesis findings and contributions, documents personal reflections, and highlights how autonomous vehicles can shape the future of aviation through its advanced technology and human–machine interaction.

7.1 Thesis Summary

This thesis investigates how the interaction between an autonomous follow-me vehicle and pilots can be designed to foster intuitive and trustworthy communication during the taxiing phase of airport operations. The research began by exploring the concept of trust in human–autonomous interaction, drawing from literature in psychology, HMI, and autonomous systems to define how trust is built, particularly in high-stakes, non-verbal environments.

These insights were translated into design strategies for the UsherBot, focusing on three key areas:

1. Form language, including personality and recognizability
2. Visual signals, such as projection and rooftop displays
3. Motion cues, including light rhythm, directionality, and timing

Through an iterative process, multiple concept directions were explored and refined into a final design, evaluated via a VR-based simulation with pilot participants.

Results showed that a successful autonomous follow-me system should feature:

- A distinctive and readable form that conveys presence and intent
- Adaptive signals that appear at the right time and in the right format
- Familiar visual language, aligned with existing pilot expectations
- Smooth, predictable motion cues that enhance clarity and reduce cognitive load

These elements, when combined, contribute to a system that builds trust not instantly, but gradually, through repeated positive experiences and consistent, readable behavior.

7.2 Final Reflections

This thesis project has been both a deeply rewarding and intellectually challenging journey. Looking back, I would like to reflect on three key aspects of the process: design development, planning and time management, and team collaboration.

Design Process

Reflecting on the design process, I believe the integration of literature insights into a tangible concept was one of the project's greatest strengths. The theories around trust and human–autonomous interaction were not only informative but directly shaped the design outcomes, offering a new perspective on how an autonomous ground vehicle should behave and communicate with pilots.

While the final concept was iteratively developed with attention to feasibility, user behavior, and signaling logic, I also recognize that there is still room to further evaluate the form factor, especially through real-world pilot testing and more in-depth shape exploration. As a designer, I found the balance between concept vision and technical constraints to be a valuable and humbling learning experience.

Planning & Schedule

Overall, the project followed the original planning framework outlined in the Gantt chart. The phases of research, ideation, and concept development proceeded in a structured and timely manner. However, when it came to VR development, I underestimated the time needed for debugging, refining interactivity, and ensuring visual consistency.

Although the VR prototype successfully enabled pilot evaluation and helped answer the research question, additional time would have allowed the inclusion of more diverse scenarios—such as varying weather conditions and complex ground traffic situations. These enhancements could further strengthen the realism and credibility of the concept demonstration.

Team Dynamic

The collaboration throughout this thesis has been incredibly inspiring. The supervisory team offered a strong balance between mobility design expertise and VR research knowledge, which helped guide the project from both strategic and technical perspectives.

From the industry side, working with Usher AI brought valuable aviation insights, technical knowledge, and stakeholder feedback that helped bridge the gap between academic design and real-world application. The team dynamic was open, energetic, and intellectually honest—everyone contributed actively and shared ideas transparently, which was essential to shaping the final outcome.

Without this exceptional collaboration across disciplines and industries, the project would not have reached its current depth and clarity.

7.3 Future Outlook

While this thesis focused on designing the UsherBot as a trustworthy and intuitive autonomous guidance system for aircraft taxiing, its implementation opens up a wider range of possibilities in the evolution of airport automation. Looking ahead, three key areas represent promising directions for future exploration and development:

System for ATC monitoring

Given that air traffic controllers (ATC) are the central decision-makers in airport ground operations, future development should explore how the UsherBot system can be integrated into existing ATC interfaces. A real-time monitoring dashboard that allows ATC staff to track the position, signal status, and intent of UsherBots would improve coordination, oversight, and safety. Designing a system that aligns with ATC workflows and supports intuitive decision-making will be essential for scalable deployment.

Automation in systematic network

While this project focused on the taxiing phase, airport ground movement involves many other vehicle types and subsystems, such as towing tractors, docking systems, luggage transporters, and maintenance vehicles. A natural next step is to integrate the UsherBot into a system-wide autonomous network. Such integration would enable centralized route planning, collision avoidance, and energy-efficient scheduling, contributing to a more sustainable and intelligent airport infrastructure.

Transition Toward Smart Airports and Pilot-Free Operations

Looking further into the future, many airports envision a transition toward fully autonomous operations, potentially including pilotless aircraft. In this context, the need for machine-to-machine communication and autonomous ground coordination becomes even more critical. Systems like UsherBot could evolve into fully automated, decision-making agents capable of interacting with both aircraft systems and ATC in real time.

This shift also raises questions about how monitoring, route planning, and safety control will be handled in the absence of human pilots. The UsherBot, as a tangible and intelligent intermediary, offers a foundation for exploring these questions and prototyping systems that are prepared for a human-absent future.

Reference

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Appendix

a.   Original Project Brief / b.   Spijkstaal Elektro BV performance sheet / c.   Questionaaire & Result for Interview / d.   VR Test Invitation Poster / e.   Participant feedback by person / f.   Data Analyzation - Box plot & line chart / g.   Data Analyzation - Avg score & Rank / h. Data Analyzation - Spearman's rank correlation

Appendix a.
Original Project Brief from usherAI

DESIGN OF AN AUTOMATED FOLLOW-ME VEHICLE

CONTEXT: The future of aviation depends on achieving growth in a responsible and therefore sustainable way (ICAO). The current operational concepts of airports are stretched, with infrastructure and resources limitations impacting ground movements particularly. We need to work smarter, not build more of the same. This can be achieved through a so-called Advanced Surface Movement Guidance and Control Systems (A-SMGCS) **to guide airplanes around airports** (not unlike your car navigation), with Europe imposing a 2030 target for implementation at key airports.

USHER AI is a start-up aiming to conquer a conservative industry with this revolutionary concept, which focusses primarily on the guidance part of aircraft by means of automated follow-me vehicles, where the market was not able to deliver a feasible solution yet. Combining existing procedures at airports with automated vehicle technology, ensures flexibility while reducing implementation time and the associated costs. Ultimately Usher ensures fluent, deadlock-free routing of all ground movements to improve sustainability, capacity and safety. You will benefit from Usher AI's founders of over 40 years of experience in aviation and automation technology, and from their extensive network of partners.

THE ASSIGNMENT is to **design the automated Usherbot vehicle** which drives in front of an aircraft on the platform area of any airport during any weather circumstance or time of the day, the so-called regulated **follow-me** process. The vehicle is automated and designed to perform tasks that are given by the supervisory software (Usher) which interfaces with and receives instructions from an apron or ground controller to guide pilots. As the vehicle is going to be assisting air traffic controllers in guiding pilots to the appropriate destinations, they need to **meet requirements from the different user perspectives**. The vehicles operate in a complex, multi-stakeholder landscape, with many requirements.

To support the discussions with the industry, Usher AI is in need a vehicle design that indicates what the ultimate design should look like, as its form giving must unambiguously express its functionality to the various stakeholders. Your mission, should you choose to accept it[1], is to translate the existing requirements into possible design directions that meet the different user perspectives and provide insight into the functionality provided.

APPLICANTS are obviously among the most brilliant students in the history of this faculty. If this graduation assignment fits your experience, learning objectives, and most importantly your future ambition, contact Robbert Lohmann, Usher AI, robbert.lohmann@usher-ai.com or Elmer van Grondelle, e.d.vangrondelle@tudelft.nl

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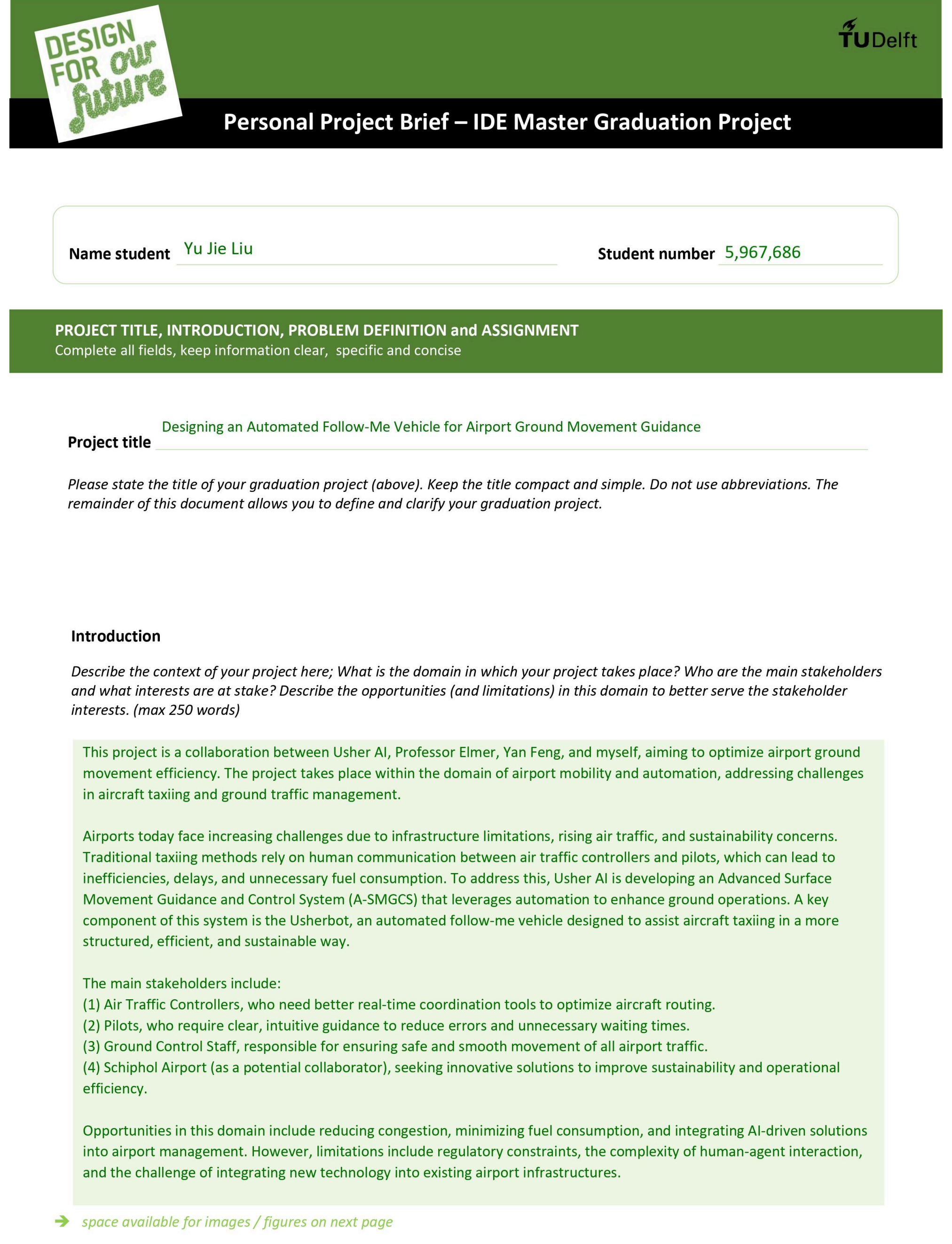
[1] Mission Impossible pun deliberately intended.



DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Name student Yu Jie Liu **Student number** 5,967,686

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT
Complete all fields, keep information clear, specific and concise

Project title Designing an Automated Follow-Me Vehicle for Airport Ground Movement Guidance

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

This project is a collaboration between Usher AI, Professor Elmer, Yan Feng, and myself, aiming to optimize airport ground movement efficiency. The project takes place within the domain of airport mobility and automation, addressing challenges in aircraft taxiing and ground traffic management.

Airports today face increasing challenges due to infrastructure limitations, rising air traffic, and sustainability concerns. Traditional taxiing methods rely on human communication between air traffic controllers and pilots, which can lead to inefficiencies, delays, and unnecessary fuel consumption. To address this, Usher AI is developing an Advanced Surface Movement Guidance and Control System (A-SMGCS) that leverages automation to enhance ground operations. A key component of this system is the Usherbot, an automated follow-me vehicle designed to assist aircraft taxiing in a more structured, efficient, and sustainable way.

The main stakeholders include:
(1) Air Traffic Controllers, who need better real-time coordination tools to optimize aircraft routing.
(2) Pilots, who require clear, intuitive guidance to reduce errors and unnecessary waiting times.
(3) Ground Control Staff, responsible for ensuring safe and smooth movement of all airport traffic.
(4) Schiphol Airport (as a potential collaborator), seeking innovative solutions to improve sustainability and operational efficiency.

Opportunities in this domain include reducing congestion, minimizing fuel consumption, and integrating AI-driven solutions into airport management. However, limitations include regulatory constraints, the complexity of human-agent interaction, and the challenge of integrating new technology into existing airport infrastructures.

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introduction (continued): space for images

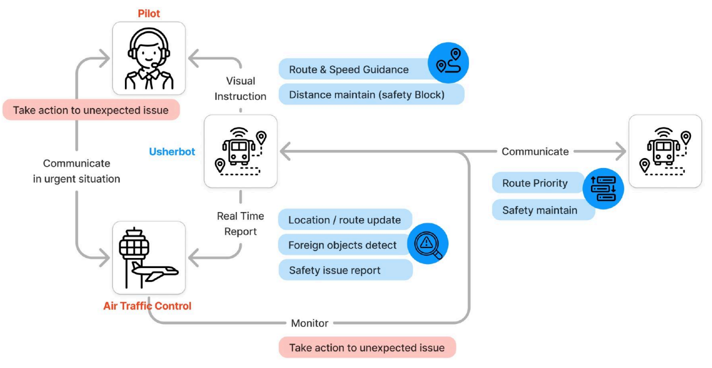

image / figure 1 shows the anticipated interactions in the Usherbot-guided taxiing process

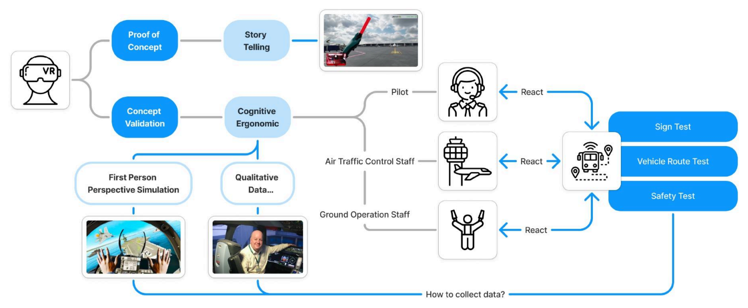

image / figure 2 shows the role of VR in optimizing user experience for Usherbot interaction and airport ground operations

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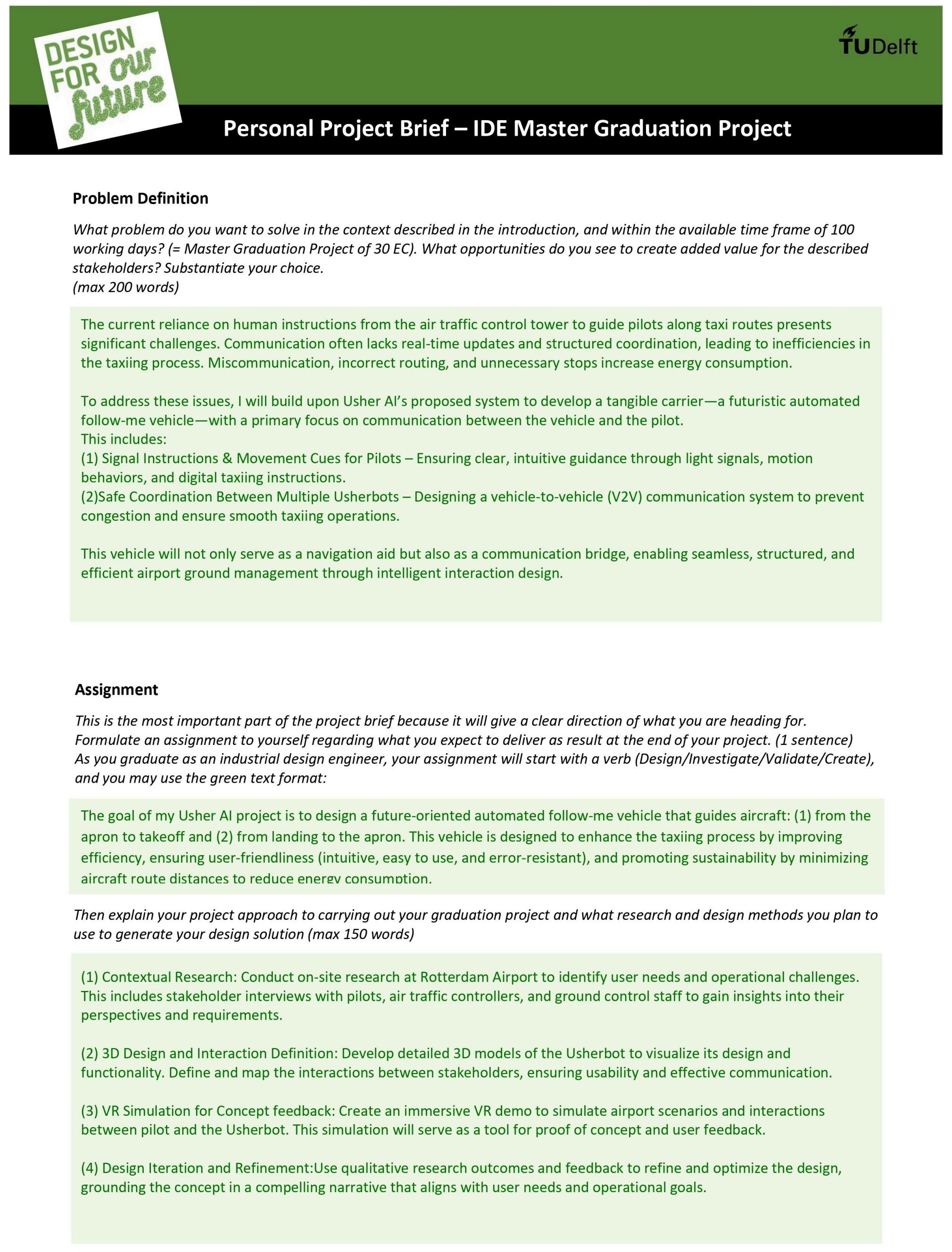


DESIGN FOR our future

TU Delft

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice.
(max 200 words)

The current reliance on human instructions from the air traffic control tower to guide pilots along taxi routes presents significant challenges. Communication often lacks real-time updates and structured coordination, leading to inefficiencies in the taxiing process. Miscommunication, incorrect routing, and unnecessary stops increase energy consumption.

To address these issues, I will build upon Usher AI's proposed system to develop a tangible carrier—a futuristic automated follow-me vehicle—with a primary focus on communication between the vehicle and the pilot.
This includes:
(1) Signal Instructions & Movement Cues for Pilots – Ensuring clear, intuitive guidance through light signals, motion behaviors, and digital taxiing instructions.
(2)Safe Coordination Between Multiple Usherbots – Designing a vehicle-to-vehicle (V2V) communication system to prevent congestion and ensure smooth taxiing operations.

This vehicle will not only serve as a navigation aid but also as a communication bridge, enabling seamless, structured, and efficient airport ground management through intelligent interaction design.

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for.
Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence)
As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the green text format:

The goal of my Usher AI project is to design a future-oriented automated follow-me vehicle that guides aircraft: (1) from the apron to takeoff and (2) from landing to the apron. This vehicle is designed to enhance the taxiing process by improving efficiency, ensuring user-friendliness (intuitive, easy to use, and error-resistant), and promoting sustainability by minimizing aircraft route distances to reduce energy consumption.

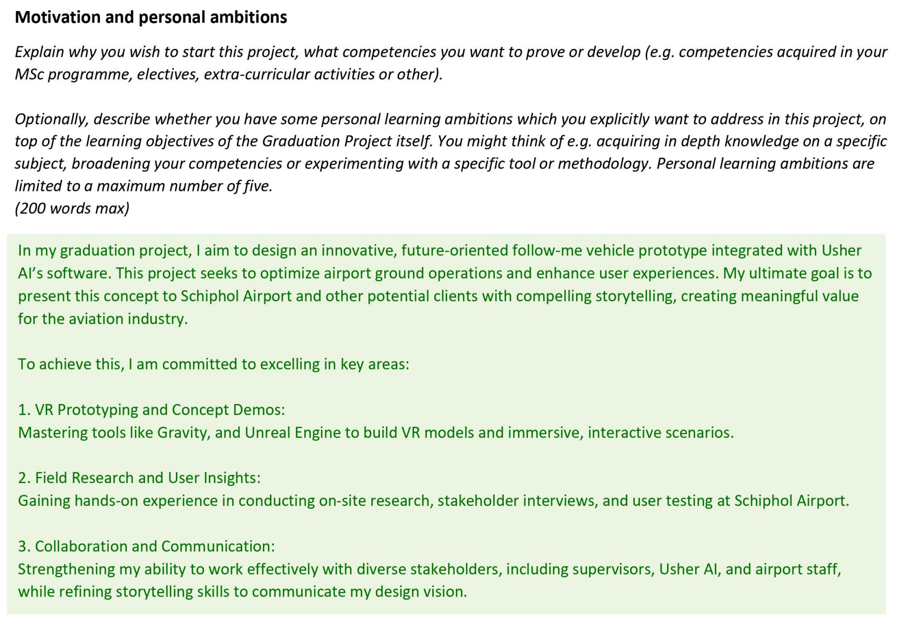
Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

(1) Contextual Research: Conduct on-site research at Rotterdam Airport to identify user needs and operational challenges. This includes stakeholder interviews with pilots, air traffic controllers, and ground control staff to gain insights into their perspectives and requirements.

(2) 3D Design and Interaction Definition: Develop detailed 3D models of the Usherbot to visualize its design and functionality. Define and map the interactions between stakeholders, ensuring usability and effective communication.

(3) VR Simulation for Concept feedback: Create an immersive VR demo to simulate airport scenarios and interactions between pilot and the Usherbot. This simulation will serve as a tool for proof of concept and user feedback.

(4) Design Iteration and Refinement:Use qualitative research outcomes and feedback to refine and optimize the design, grounding the concept in a compelling narrative that aligns with user needs and operational goals.



Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five.
(200 words max)

In my graduation project, I aim to design an innovative, future-oriented follow-me vehicle prototype integrated with Usher AI's software. This project seeks to optimize airport ground operations and enhance user experiences. My ultimate goal is to present this concept to Schiphol Airport and other potential clients with compelling storytelling, creating meaningful value for the aviation industry.

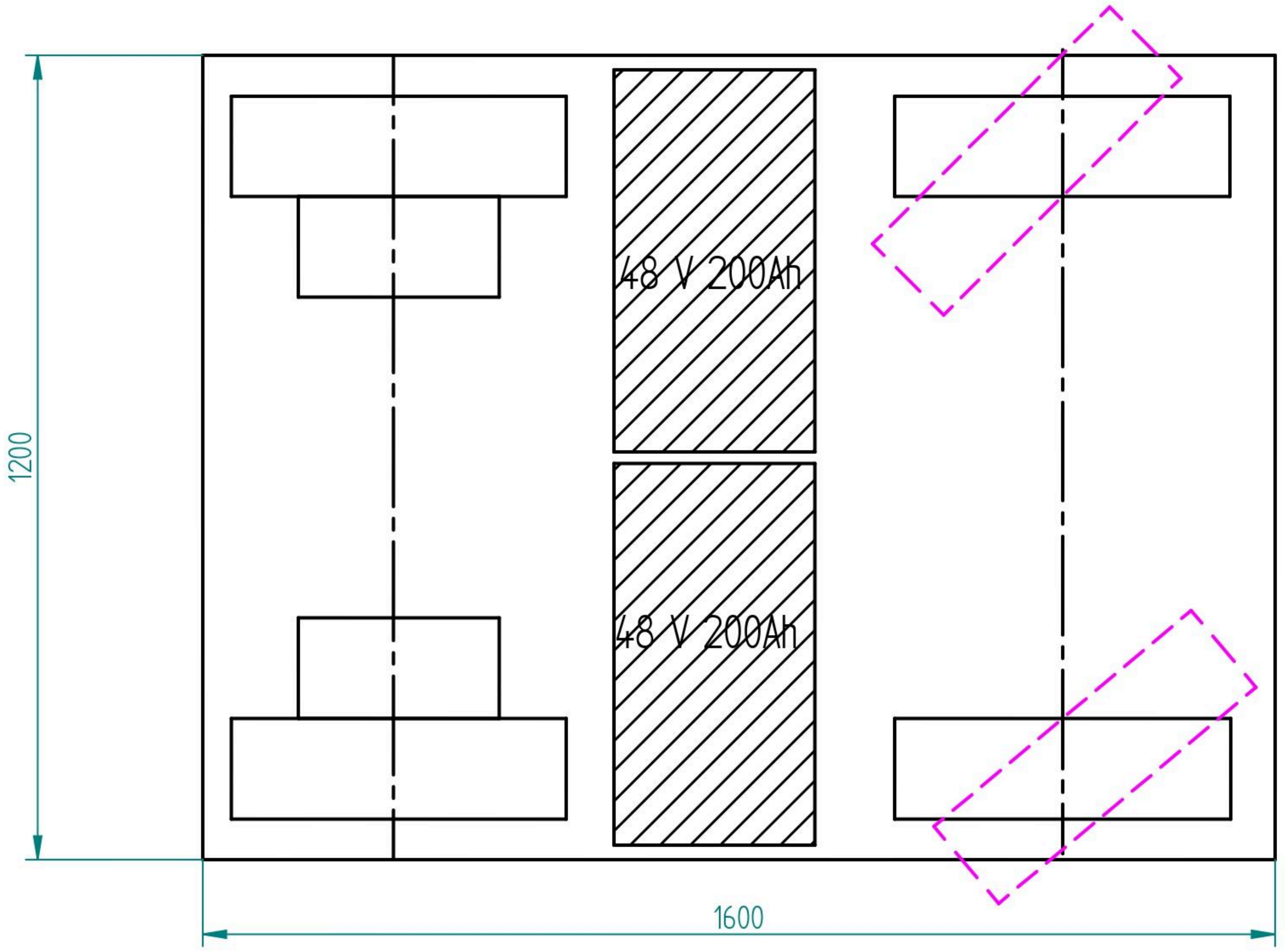
To achieve this, I am committed to excelling in key areas:

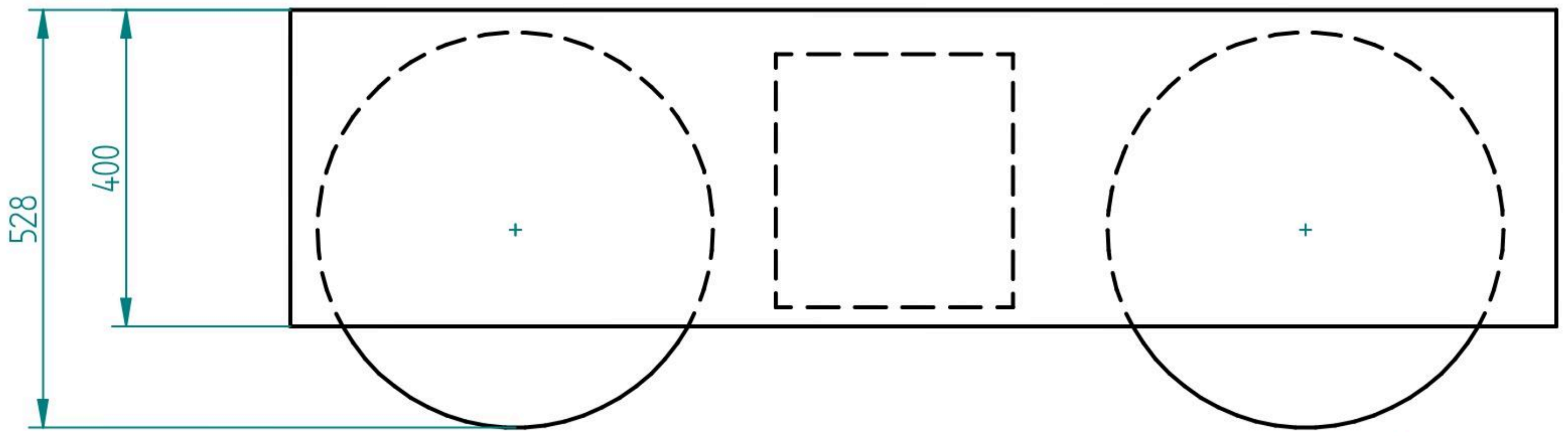
1. VR Prototyping and Concept Demos:
Mastering tools like Gravity, and Unreal Engine to build VR models and immersive, interactive scenarios.

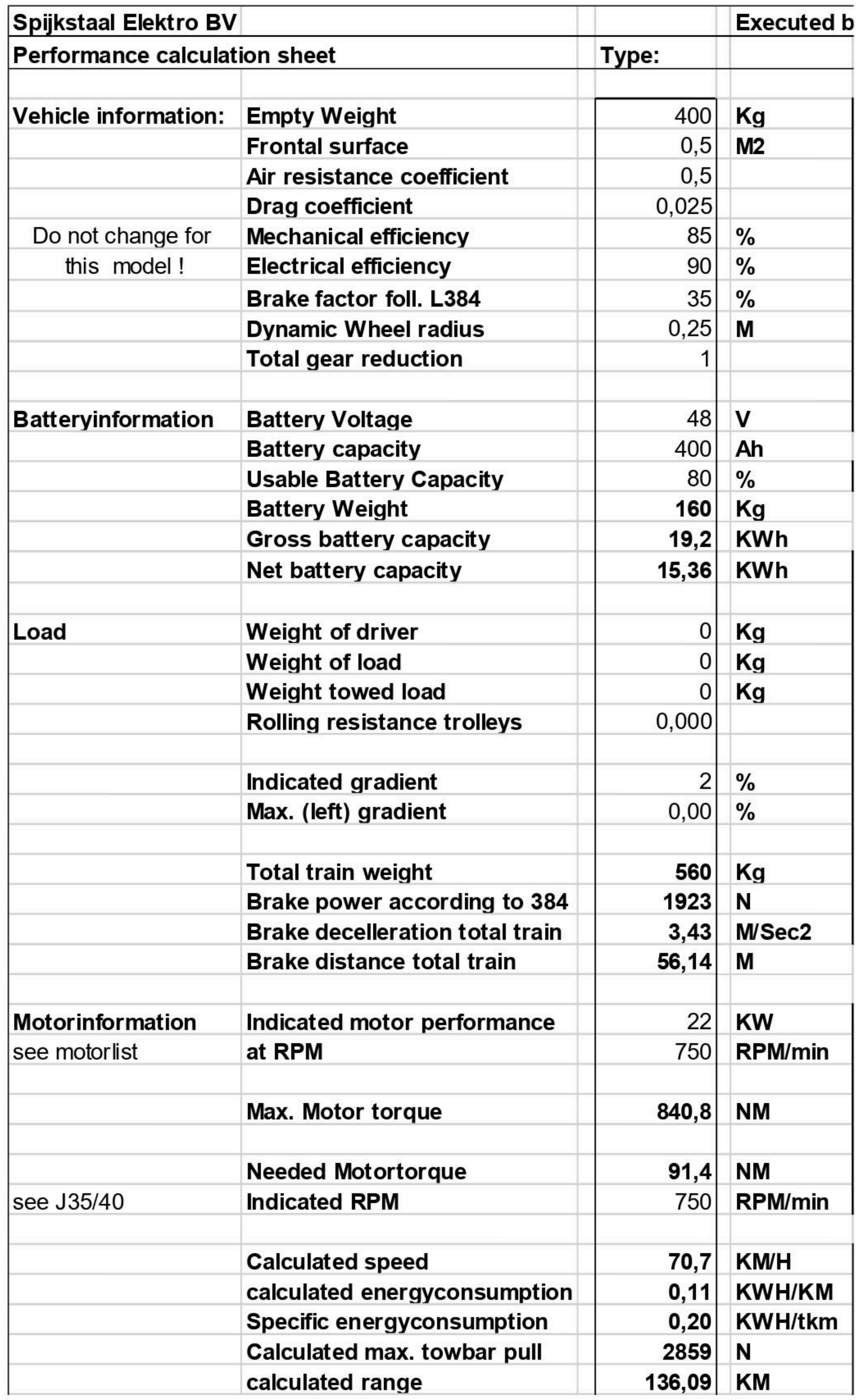
2. Field Research and User Insights:
Gaining hands-on experience in conducting on-site research, stakeholder interviews, and user testing at Schiphol Airport.

3. Collaboration and Communication:
Strengthening my ability to work effectively with diverse stakeholders, including supervisors, Usher AI, and airport staff, while refining storytelling skills to communicate my design vision.

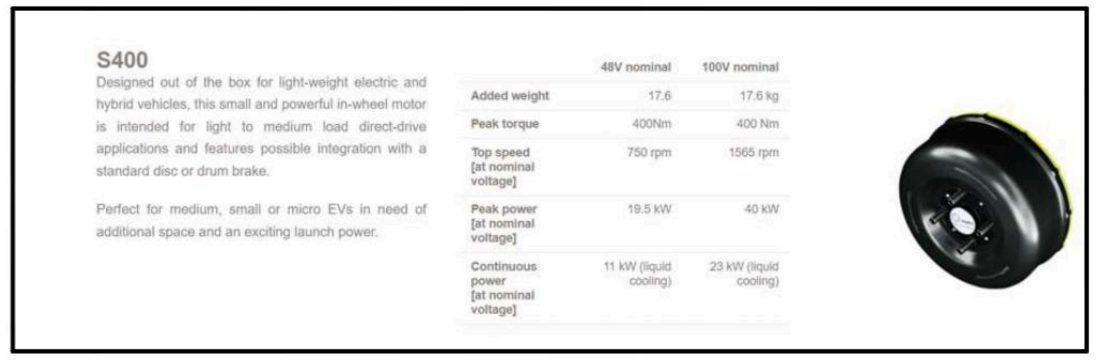
Appendix b.
Spijkstaal Elektro BV performance sheet







Spijkstaal Elektro BV			**Executed b**
Performance calculation sheet		**Type:**	
Vehicle information:	**Empty Weight**	400	**Kg**
	Frontal surface	0,5	**M2**
	Air resistance coefficient	0,5	
	Drag coefficient	0,025	
Do not change for	**Mechanical efficiency**	85	**%**
this model !	**Electrical efficiency**	90	**%**
	Brake factor foll. L384	35	**%**
	Dynamic Wheel radius	0,25	**M**
	Total gear reduction	1	
Batteryinformation	**Battery Voltage**	48	**V**
	Battery capacity	400	**Ah**
	Usable Battery Capacity	80	**%**
	Battery Weight	**160**	**Kg**
	Gross battery capacity	**19,2**	**KWh**
	Net battery capacity	**15,36**	**KWh**
Load	**Weight of driver**	0	**Kg**
	Weight of load	0	**Kg**
	Weight towed load	0	**Kg**
	Rolling resistance trolleys	0,000	
	Indicated gradient	2	**%**
	Max. (left) gradient	0,00	**%**
	Total train weight	**560**	**Kg**
	Brake power according to 384	**1923**	**N**
	Brake decelleration total train	**3,43**	**M/Sec2**
	Brake distance total train	**56,14**	**M**
Motorinformation	**Indicated motor performance**	22	**KW**
see motorlist	**at RPM**	750	**RPM/min**
	Max. Motor torque	**840,8**	**NM**
	Needed Motortorque	**91,4**	**NM**
see J35/40	**Indicated RPM**	750	**RPM/min**
	Calculated speed	**70,7**	**KM/H**
	calculated energyconsumption	**0,11**	**KWH/KM**
	Specific energyconsumption	**0,20**	**KWH/tkm**
	Calculated max. towbar pull	**2859**	**N**
	calculated range	**136,09**	**KM**



S400

Designed out of the box for light-weight electric and hybrid vehicles, this small and powerful in-wheel motor is intended for light to medium load direct-drive applications and features possible integration with a standard disc or drum brake.

Perfect for medium, small or micro EVs in need of additional space and an exciting launch power.

	48V nominal	100V nominal
Added weight	17.6	17.6 kg
Peak torque	400Nm	400 Nm
Top speed [at nominal voltage]	750 rpm	1565 rpm
Peak power [at nominal voltage]	19.5 kW	40 kW
Continuous power [at nominal voltage]	11 kW (liquid cooling)	23 kW (liquid cooling)

Beschrijving

Aces Lithium HF 48V 200Ah Accu AL48V200HFP

48V 200Ah model van Aces ui: de HF range. Met maar iets grotere af
compleet 48V systeem. Komt net Led indicatie. Onderstaand de spec

Energy 10240 Wh
Capacity 200 Ah
Voltage 51.2 V (range 42V - 57.6V)
Weight 81 kg
Charge cycles 3000
Dimensions 570×297×317 mm
Case Stainless Steel
Grips 4 handgrips
Connections 2 x M8 insert
Water resistance IP65
Indicators Led indicator Protection mode

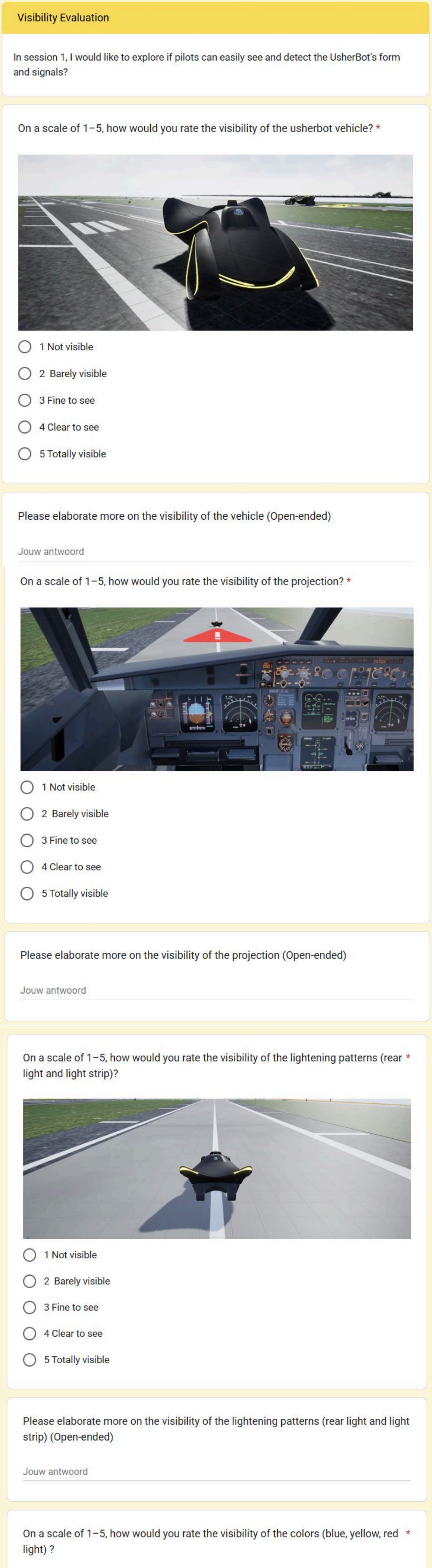
Appendix c. Questionaaire & Result for Interview

Link to the questionaaire

Usherbot VR Simulation Study

The aim of this study is to evaluate pilot comprehension and trust in the form factors and light-based communication signals of the UsherBot in a simulated taxiing scenario. By utilizing a first-person perspective within a Virtual Reality (VR) environment built in Unreal Engine, the research will examine whether the designed cues are effectively perceived and interpreted by pilots.

Log in bij Google om je voortgang op te slaan. Meer informatie



Visibility Evaluation

In session 1, I would like to explore if pilots can easily see and detect the UsherBot's form and signals?

On a scale of 1–5, how would you rate the visibility of the usherbot vehicle? *

○ 1 Not visible
○ 2 Barely visible
○ 3 Fine to see
○ 4 Clear to see
○ 5 Totally visible

Please elaborate more on the visibility of the vehicle (Open-ended)

Jouw antwoord

On a scale of 1–5, how would you rate the visibility of the projection? *

○ 1 Not visible
○ 2 Barely visible
○ 3 Fine to see
○ 4 Clear to see
○ 5 Totally visible

Please elaborate more on the visibility of the projection (Open-ended)

Jouw antwoord

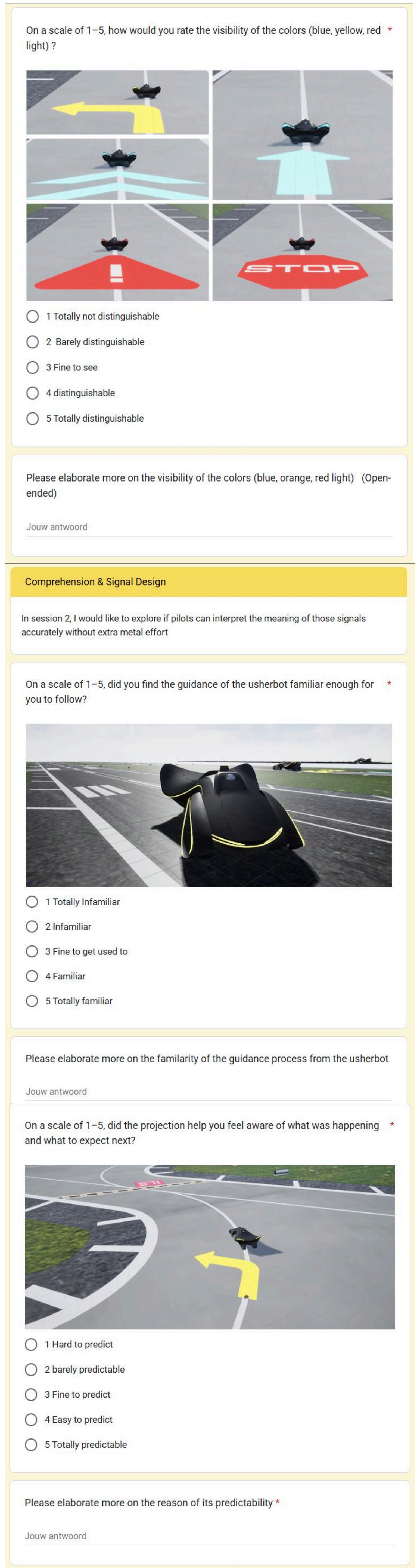
On a scale of 1–5, how would you rate the visibility of the lightening patterns (rear light and light strip)? *

○ 1 Not visible
○ 2 Barely visible
○ 3 Fine to see
○ 4 Clear to see
○ 5 Totally visible

Please elaborate more on the visibility of the lightening patterns (rear light and light strip) (Open-ended)

Jouw antwoord

On a scale of 1–5, how would you rate the visibility of the colors (blue, yellow, red light) ? *



On a scale of 1–5, how would you rate the visibility of the colors (blue, yellow, red light) ? *

○ 1 Totally not distinguishable
○ 2 Barely distinguishable
○ 3 Fine to see
○ 4 distinguishable
○ 5 Totally distinguishable

Please elaborate more on the visibility of the colors (blue, orange, red light) (Open-ended)

Jouw antwoord

Comprehension & Signal Design

In session 2, I would like to explore if pilots can interpret the meaning of those signals accurately without extra metal effort

On a scale of 1–5, did you find the guidance of the usherbot familiar enough for you to follow? *

○ 1 Totally Infamiliar
○ 2 Infamiliar
○ 3 Fine to get used to
○ 4 Familiar
○ 5 Totally familiar

Please elaborate more on the familarity of the guidance process from the usherbot

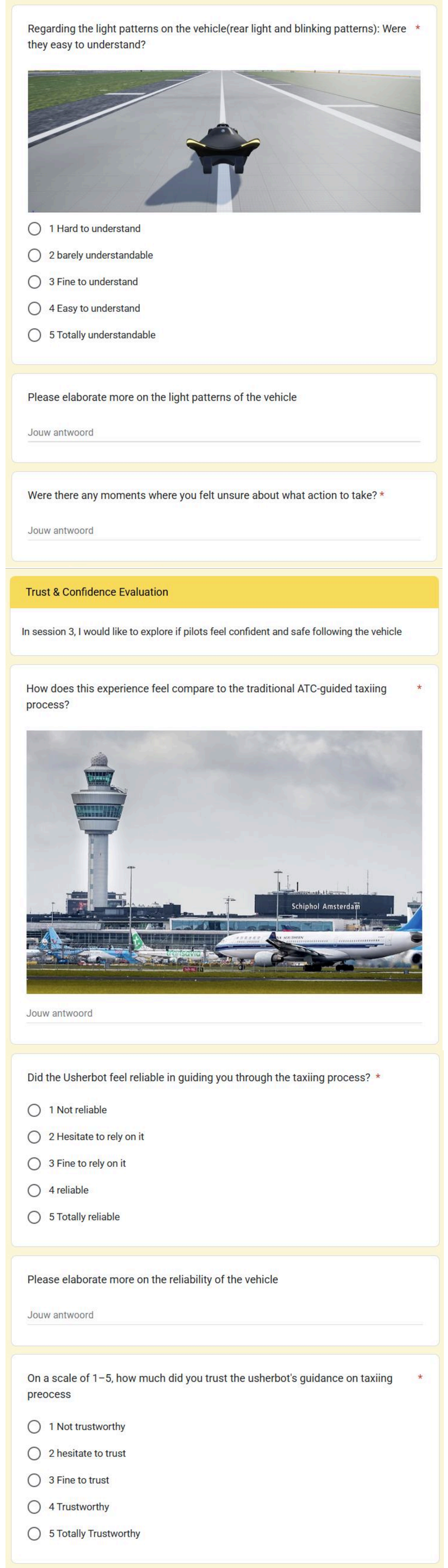
Jouw antwoord

On a scale of 1–5, did the projection help you feel aware of what was happening and what to expect next? *

○ 1 Hard to predict
○ 2 barely predictable
○ 3 Fine to predict
○ 4 Easy to predict
○ 5 Totally predictable

Please elaborate more on the reason of its predictability *

Jouw antwoord



Regarding the light patterns on the vehicle(rear light and blinking patterns): Were they easy to understand? *

○ 1 Hard to understand
○ 2 barely understandable
○ 3 Fine to understand
○ 4 Easy to understand
○ 5 Totally understandable

Please elaborate more on the light patterns of the vehicle

Jouw antwoord

Were there any moments where you felt unsure about what action to take? *

Jouw antwoord

Trust & Confidence Evaluation

In session 3, I would like to explore if pilots feel confident and safe following the vehicle

How does this experience feel compare to the traditional ATC-guided taxiing process? *

Jouw antwoord

Did the Usherbot feel reliable in guiding you through the taxiing process? *

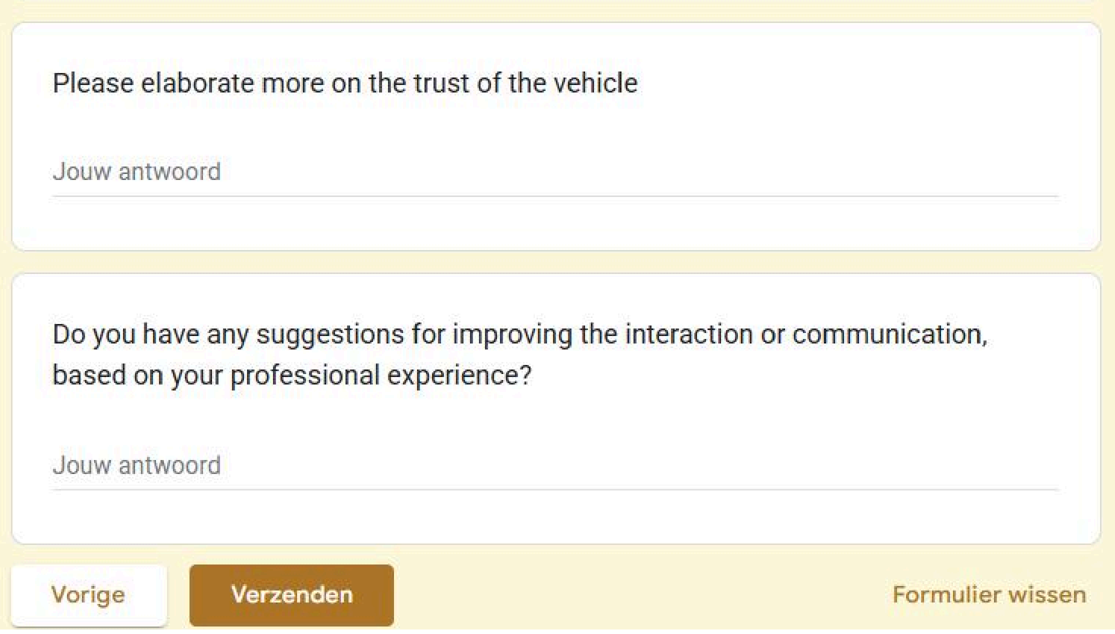
○ 1 Not reliable
○ 2 Hesitate to rely on it
○ 3 Fine to rely on it
○ 4 reliable
○ 5 Totally reliable

Please elaborate more on the reliability of the vehicle

Jouw antwoord

On a scale of 1–5, how much did you trust the usherbot's guidance on taxiing preocess *

○ 1 Not trustworthy
○ 2 hesitate to trust
○ 3 Fine to trust
○ 4 Trustworthy
○ 5 Totally Trustworthy



Please elaborate more on the trust of the vehicle

Jouw antwoord

Do you have any suggestions for improving the interaction or communication, based on your professional experience?

Jouw antwoord

Appendix d.VR Test Invitation Poster

Usherbot VR Study

Introduction

The Usherbot is an AI-based **autonomous follow-me vehicle** designed to guide aircraft during taxiing using **trustworthy light signals and motion cues.**

Goal of study

The aim of this study is to explore how pilots perceive and interpret these **form factors** and **visual signals** to evaluate the design clarity, trustworthiness, and usability of the current design.

Method: VR Simulation

The simulation will be created using Unreal Engine and experienced through a **Meta Quest 3 VR headset** from the pilot’s cockpit view. The VR experience is designed to replicate the aircraft taxiing process, guided by the UsherBot.

What to expect during the test

Date: June 9th - 20th / Time: 45 mins per test
Location and Timeslot depends on participants’ convenience

Testing process:

1. **Scene Introduction / VR introduction**
2. **Guidance Cues:**

Throughout the taxiing simulation, the UsherBot displays various motion and light signals corresponding to:

- Acceleration / Deceleration
- Braking / warning / Stopping
- Straight movement / Turnings

3. **Feedback session**

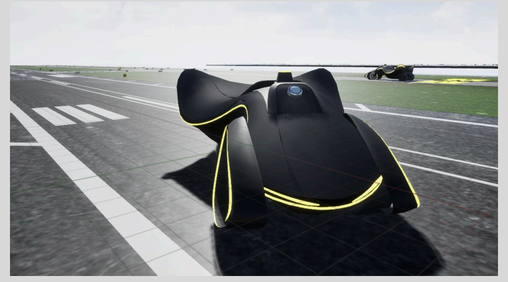
Questions for visibility(signal and design clarity, comprehension, and trust(emotional response) of the usherbot system

Appendix e. Participant feedback by person

pilot 1

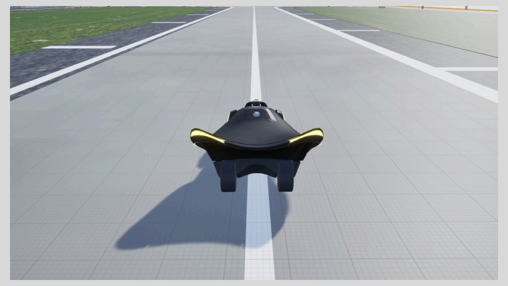
Private pilot
Schiphol

Form Design

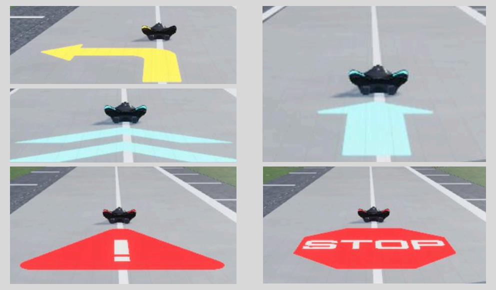


Projection

Blinking Motion



Colors



Visibility

Fine to see, but concern on the dark color of the body

Clear enough to get my attention

Not obvious due to video

Clear enough to tell the difference

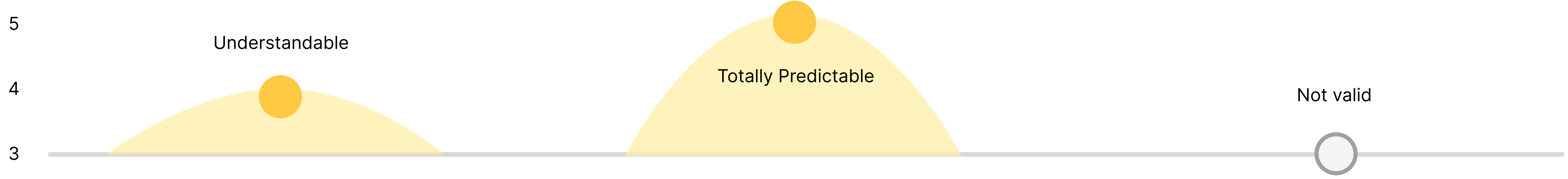
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



Depends on its behavior, find it familiar when it perform well and show its purpose clearly

Intuitive enough to show its purpose, just clear!

Not valid result, becuase I don't even find it visible

> The warning sign, it's not the standard signal, I think everyone has different interpretation on icons, so better use the text "SLOW DOWN"

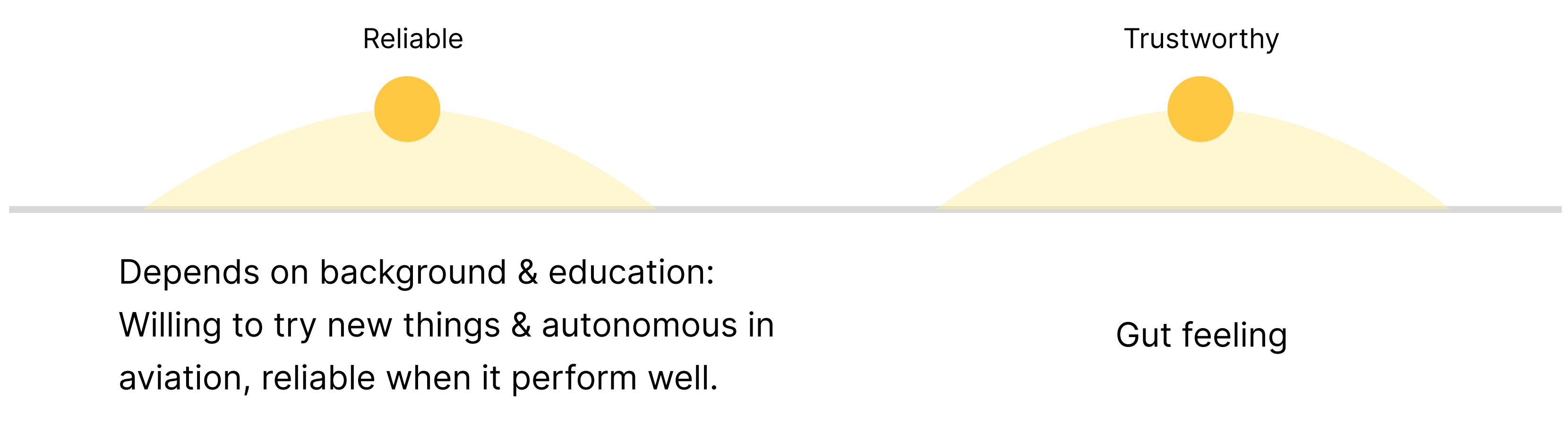
Trust & Confidence

Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing process?

> ATC message via radio: Focus on call message (lots of aircrafts share the same frequency) ; Usherbot: If it act like a Tesla that I know its movement then I think it's easy to follow the bot



Depends on background & education: Willing to try new things & autonomous in aviation, reliable when it perform well.

Gut feeling

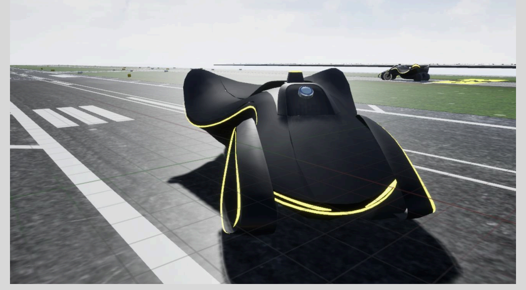
Recommendation / Insights

> 1. **Color** of the body should be more recognizable
> 2. Always **TEXT** for action and signal (turnings are fine) 3. **Call message** should be clear, I need to know it's the exact bot Im gonna follow.

pilot 2

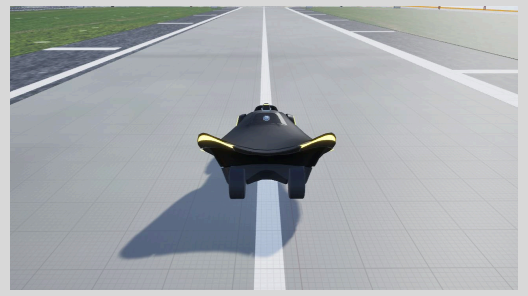
Commercial pilot, Boeing 737, Schiphol

Form Design

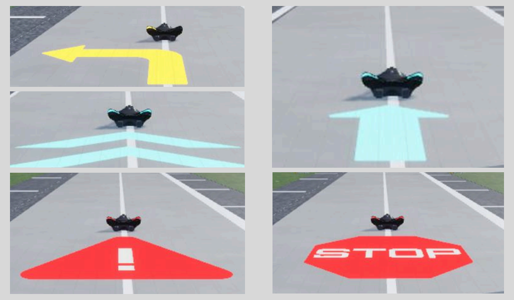


Projection

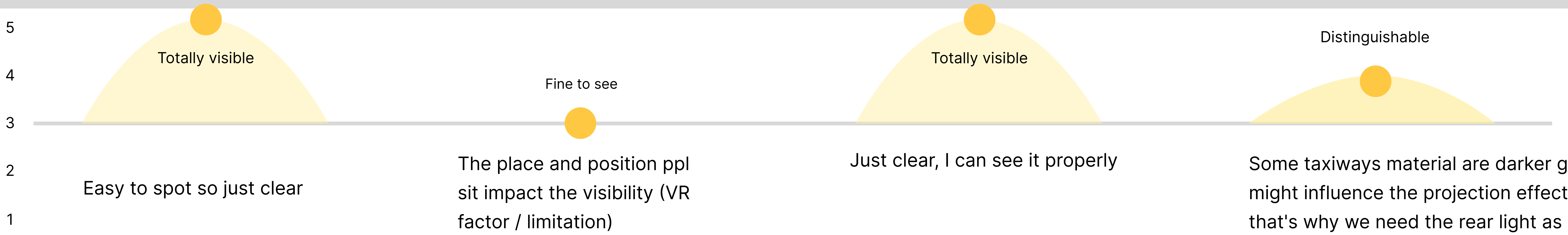
Blinking Motion



Colors



Visibility



Easy to spot so just clear

The place and position ppl sit impact the visibility (VR factor / limitation)

Just clear, I can see it properly

Some taxiways material are darker grey, might influence the projection effect so that's why we need the rear light as well

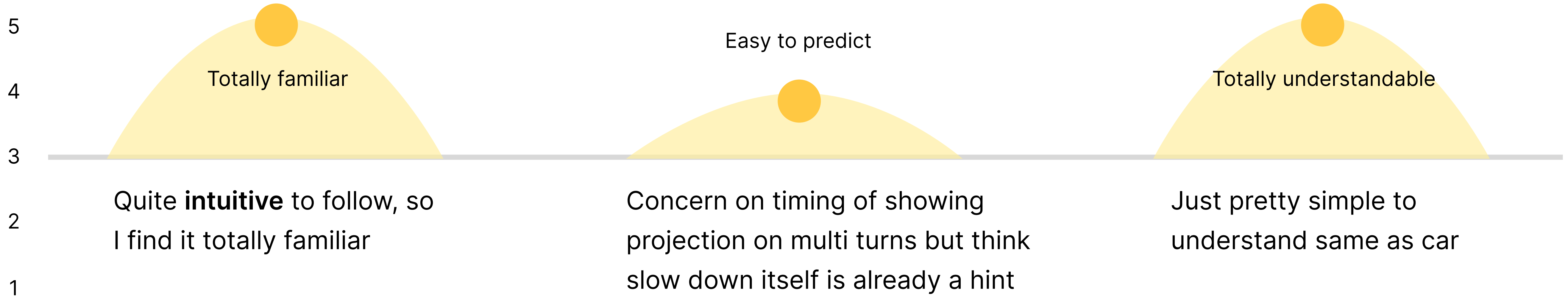
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



Quite **intuitive** to follow, so I find it totally familiar

Concern on timing of showing projection on multi turns but think slow down itself is already a hint for turnings and other movement.

Just pretty simple to understand same as car

> "Not really. For the warning sign, I think it's clear that I should slow down since something is happening."

Trust & Confidence

Experience compare to the traditional ATC-guidance?

> "Generally pilots concern on liable issue: who takes responsibility if things happen > **Safety** assessment to get approved, but I think it's **intuitive** to follow
>
> Hybrid network? current infrastructure not yet fully autonomous, so how to collaborate and detect those scenario in the hybrid system is also important."

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

Find it reliable but the speed of the movement need to be considered

Depends on the experience, 3-4 times I can starting trusting it, trust comes gradually if things work well, then I can rely on it

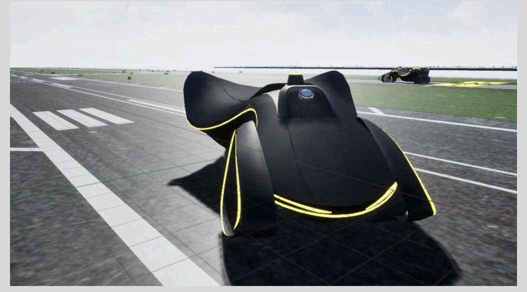
Recommendation

> 1. End of guidance signal
> 2. Should fit all weather conditions especially low visibility, slippery taxiways
> 3. The technology can scan all the ground movement, real time adjustment.

pilot 3

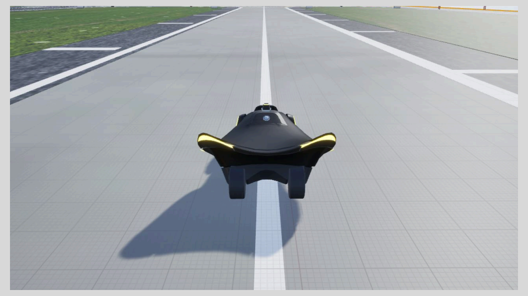
Private pilot
Enschede

Form Design

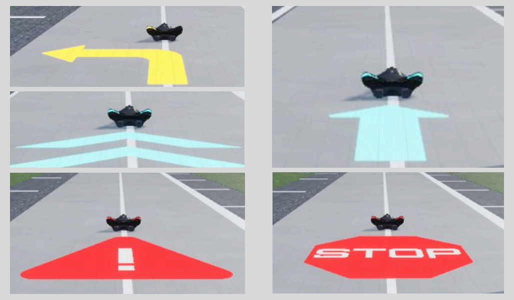


Projection

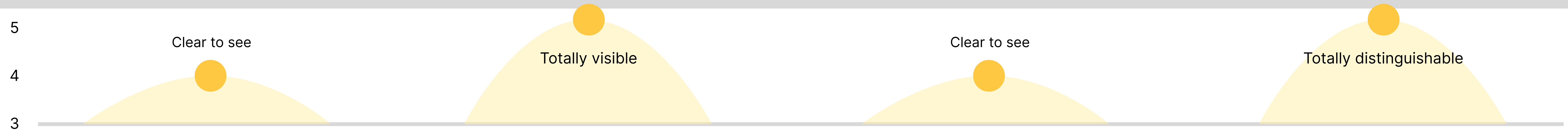
Blinking Motion



Colors



Visibility



It's clear to see in VR, dark body is not necessary bad, pilots can clearly distinguish the light / contour.

Totally obvious in VR but in daylight might not be visible. In terms of concept, It's better than the normal follow me car, because traditional one don't indicate anything.

Clearly visible rear light, for light stripe on the side, will be great to change as well to let other aircraft tell

Totally distinguishable, but blue immediately intuitive means accelerate for me, maybe green? means continue from traffic light.

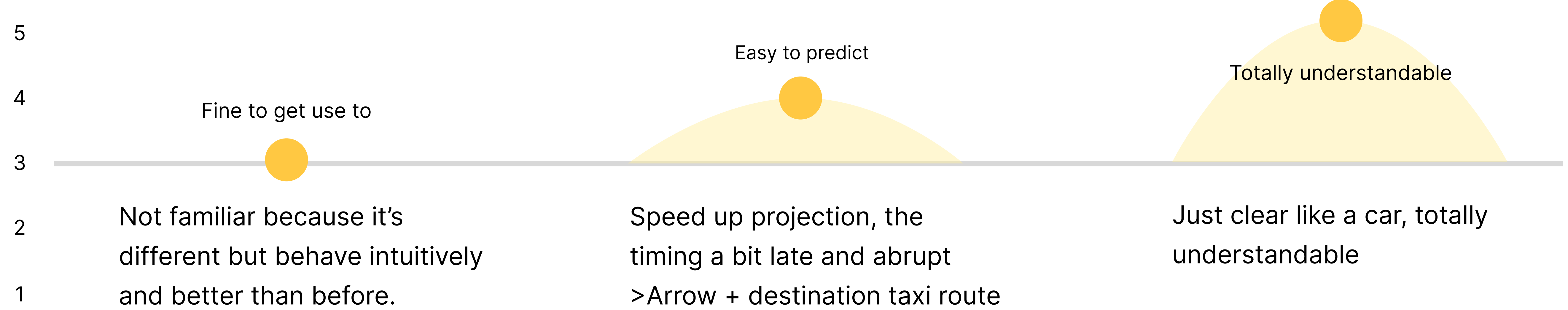
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



Not familiar because it's different but behave intuitively and better than before.

Speed up projection, the timing a bit late and abrupt
>Arrow + destination taxi route

Just clear like a car, totally understandable

> "Blinking blue light made me feel unsure, go straight ahead is clear but speed up is unsure. I even think of should I leave? because it's end of guidance"

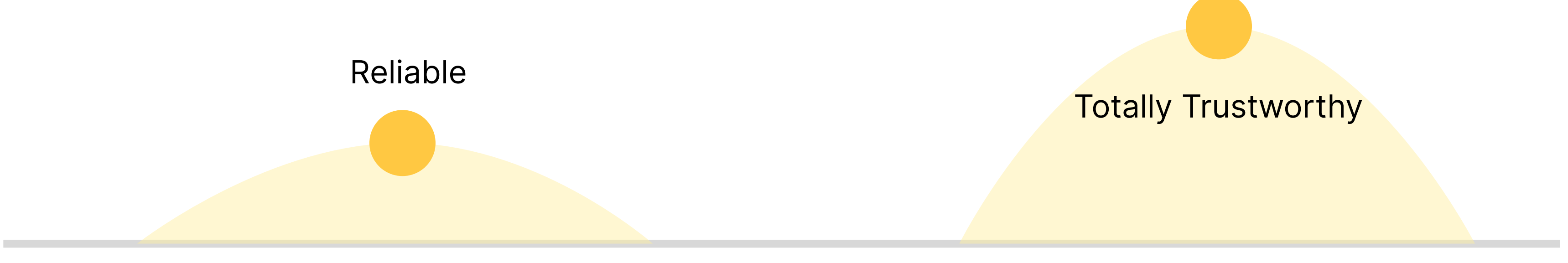
Trust & Confidence

Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

> "More relaxed, don't need to memorize all the route at once. For ATC guidance, need to remember and read back from radio, make it easier, feel safer to me."



Smoothly in VR, but would be great to show the decision making

More trustworthy than traditional way, human can make mistakes, so I trust machine more.

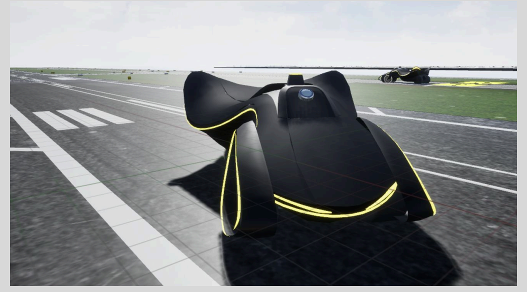
Recommendation / Insights

> "1. **Color** of the body should be more recognizable
> 2. Always **TEXT** for action and signal (turnings are fine)
> 3. **Call message** should be clear, I need to know it's the exact bot Im gonna follow."

pilot 4

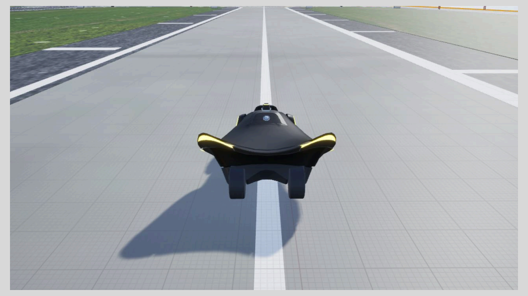
Private pilot
Enschede

Form Design

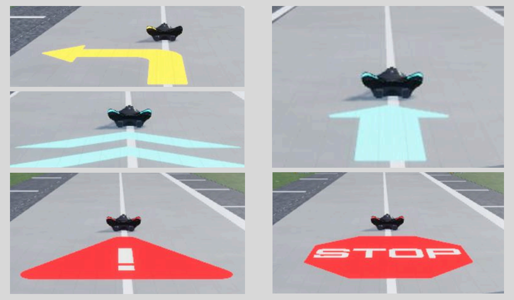


Projection

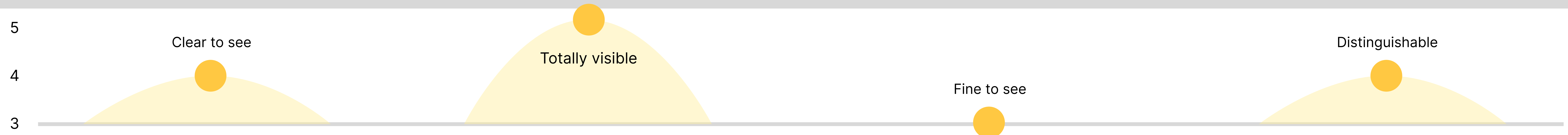
Blinking Motion



Colors



Visibility



At night might not that visible but there's light stripe, and also lightening is clear on dark body

This is really clear, I can spot it directly no problem

Changing of the color is not that clear, my focus is more on the projection (But second time I see them)

Warning sign is a bit unsure but I know sth happens. For accelerate, would be great if it’s moving

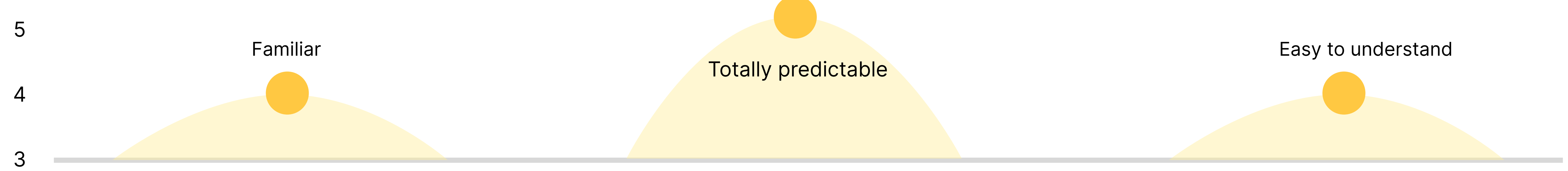
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



It's fine and familiar but the system need to know the requirement and restriction for each aircraft type

Easy to understand its purpose and what to expect, timing of projection is fine as well

Just clear like a car, easy to understand

> “Accelerate with double arrow is a bit unsure, since it's not existing yet, I think it will be great if it's moving forward then I know”

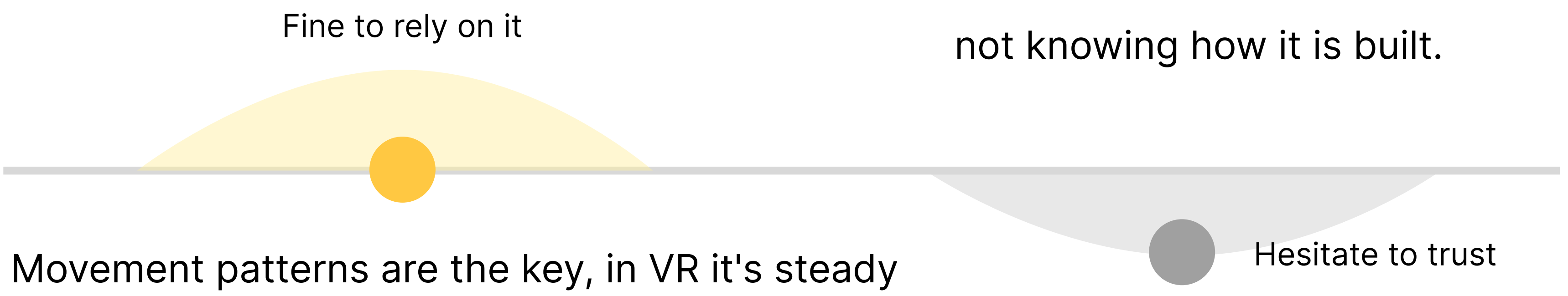
Trust & Confidence

Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

> “For traditional guidance, I will look around the scenario & map myself to check the situation, while for usherbot guidance, I will put my attention on the signal projection and lightening patterns and just follow it.”



Movement patterns are the key, in VR it's steady and smoothly so I can rely on it. However if it make me feel it's "unsure" then I will turn on my map and try to figure out the route myself.

Still feel hesitate to trust for not knowing how it is built.

But if pilots are informed before using that could definitely enhance trust

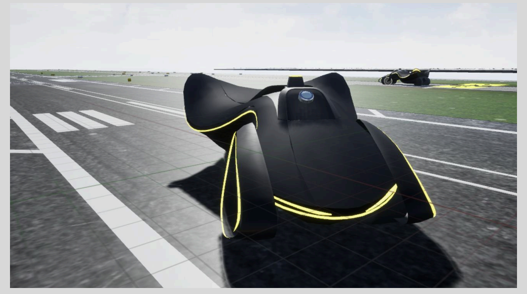
Recommendation / Insights

> “
> 1. Will be great if we can combine it with flight simulator so we can experience in a realistic environment (e.g. different weather condition)
> 2. Will be perfect If we can combine towing system and docking interface in one with the taxibot.
> 3. Great to let pilots and towers adjust details of the taxibot (e.g. light intensity when bad visibility)
> ”

pilot 5

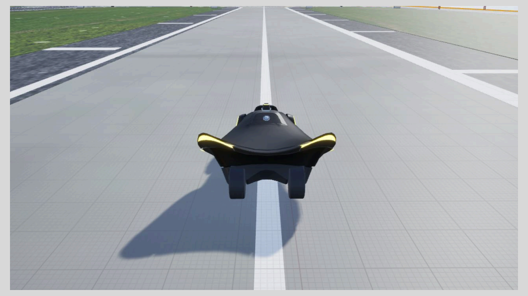
KLM-pilot on B777 and former A320 Schiphol

Form Design

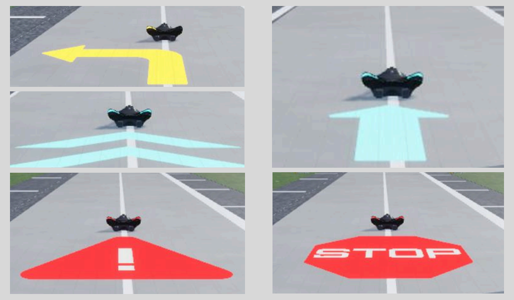


Projection

Blinking Motion



Colors



Visibility

Still prefer brighter body color especially at night.

This is really clear, but concern on if it works during daylight

Just clear

In terms of the accelerate and go straight signal, could be better with green. Follow the green?

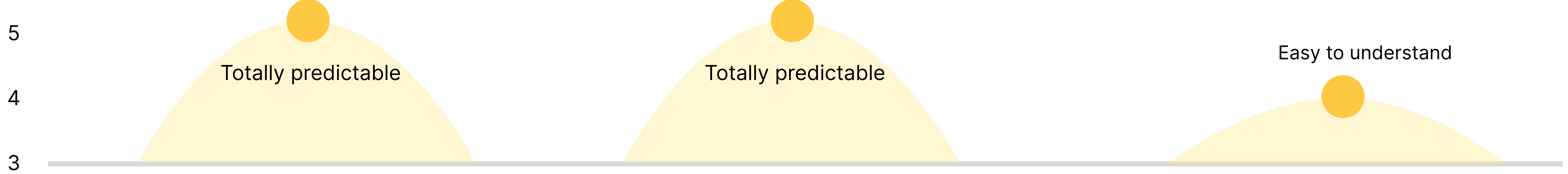
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



Totally familiar, but I need to know the flight number from the bot, so I know Im following the right car.

Quite easy to predict. But for runway crossing, I hope the info will pass to the pilot as well, otherwise it's a bit scary to follow.

Just clear like a car, easy to understand

> “No, I think every movement is clear”

Trust & Confidence

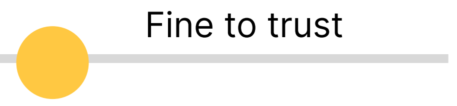
Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

> “Fine and familiar. But in low visibility context & runway crossing, what does it do? Does it trigger low visibility procedure?”

Same same level as trusting ATC, both ATC and autonmous system can be mistake.



If I can comfortably follow a normal follow me car, then I'm fine with this as well. But wonder what if sth wrong, if I don't follow it, what's the reaction & action of the bot?

As a pilot: Always keep in mind to ensure the safety of passengers, always be aware of what's actually happening.

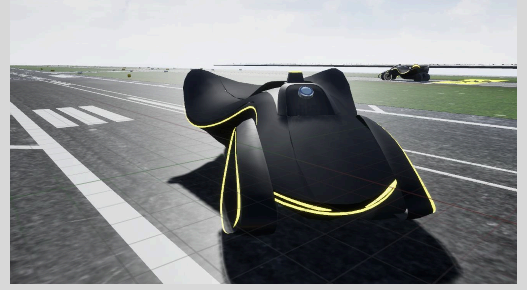
Recommendation / Insights

> “
> 1. Before I start following it, I would like a clear overview on the route
> 2. When it's runway crossing, I want to get the clearance(permission) so that Im confident enough to follow it.
> ”

pilot 6

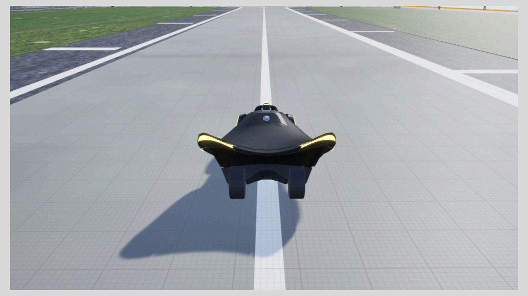
KLM-pilot on B777 and former A320 Schiphol

Form Design

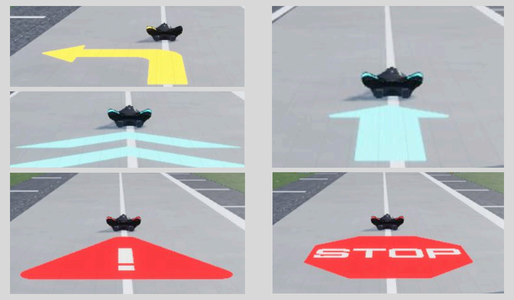


Projection

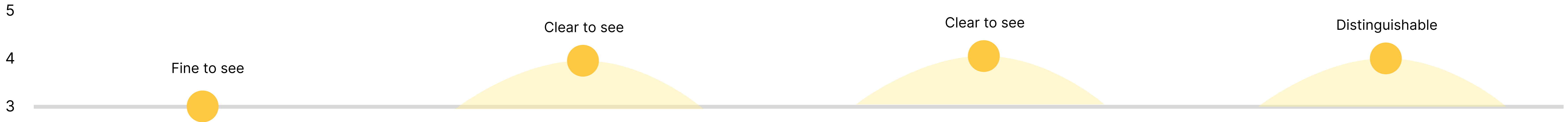
Blinking Motion



Colors



Visibility



Shape is unique and clear while dark color is similar to the taxi way.

Due to VR boundary,car is a bit too close , could be 5-10 meters further.

Just clear, but maybe bigger area for the rear light?

Easy to distinguish but why blue for accelerate and go straight signal, curious the reason behind.

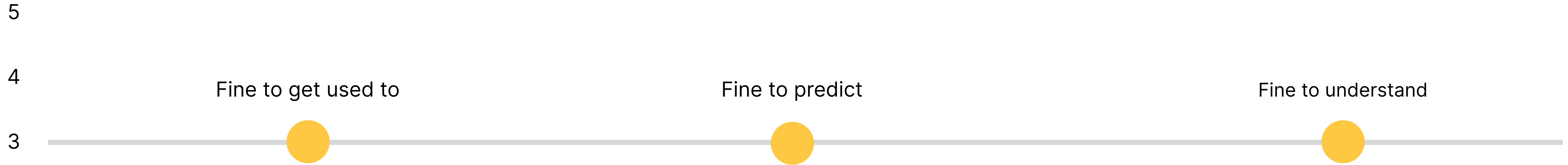
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



Straight forward and intuitive, but since it's different, people need time to get used to.

Arrow is understandable, while prefer it follow the center line and reflect actual bend to make it more predictable on what turnings it is.

It's good, but my attention were focus more on movement of the bot and the projection, looking beyond

> No, I think every movement is clear
> To extend, I think cues on speed would be great, for example: signal length will condense base on the distance

Trust & Confidence

Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

> By usherbot guidance, pilots have less noise and distraction, therefore more safety, and only communicate when necessary can get more attention, which is great.

Feel happy to see innovation. Airport context follow procedures, so autonomous in this case is safe, and if the safety assessment is passed, I find it reliable.

Any system can break down but as long as the system is monitored and have back up plan, it's not an issue for me.

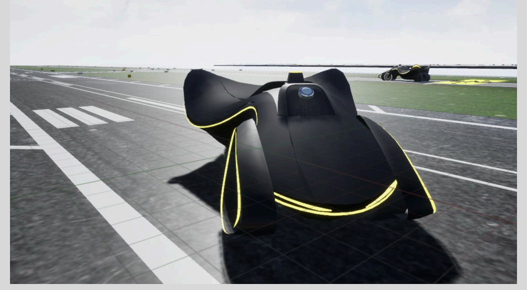
Recommendation / Insights

> 1. Turning arrows can follow real bend and the center line.
> 2. Condense the length of the sign to indicate the speed and how far pilots still have for that move.

pilot 7

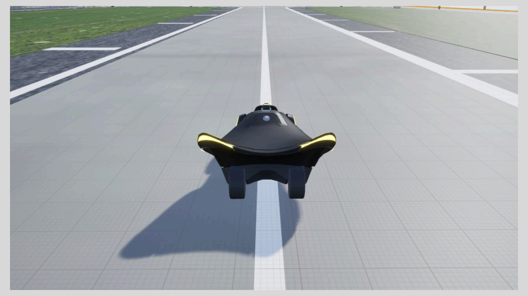
easyjet pilot
on A320
Schiphol

Form Design

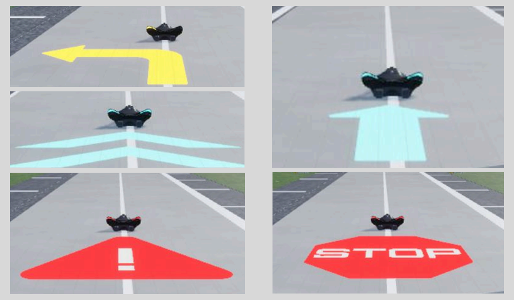


Projection

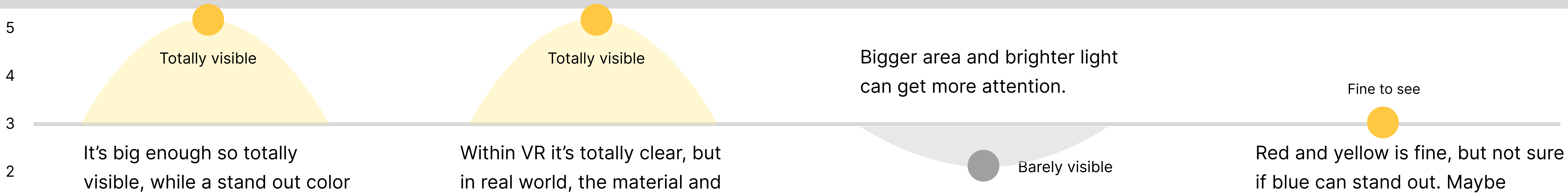
Blinking Motion



Colors



Visibility



It's big enough so totally visible, while a stand out color would be great to get notice

Within VR it's totally clear, but in real world, the material and weather could influence.

Bigger area and brighter light can get more attention.

Red and yellow is fine, but not sure if blue can stand out. Maybe strong green as alternative.

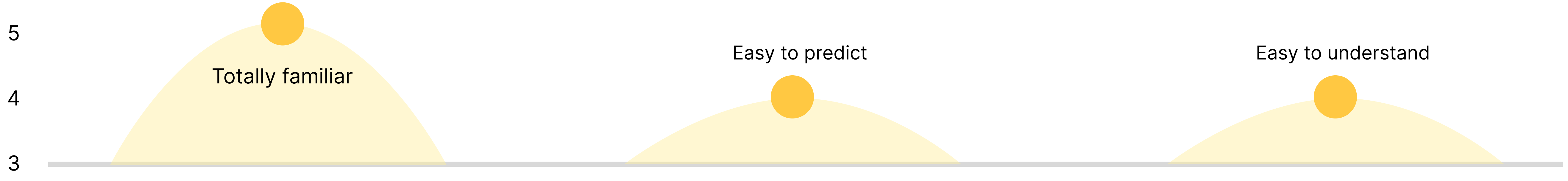
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



For me it's still similar process, no problem on this system.

Arrow is understandable, while if it's complex turn, hope to be informed at once for preparing the movement.

It's easy to understand, but my attention were focus more on movement of the bot.

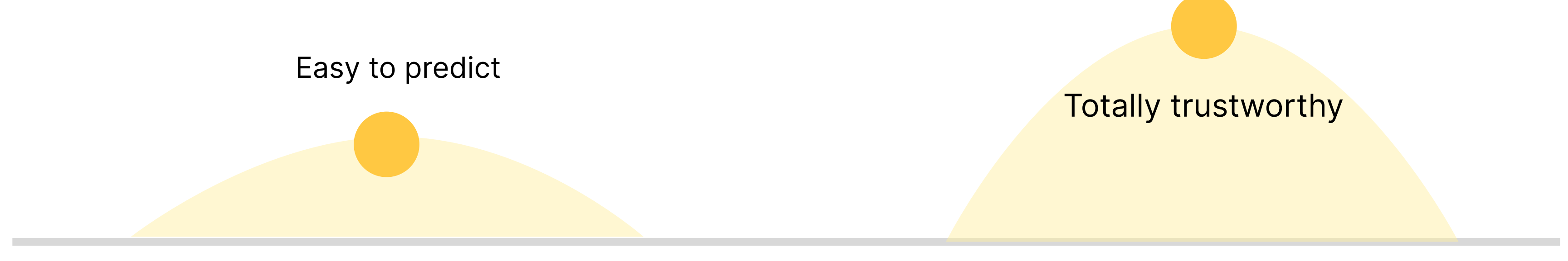
> "No, I think every movement is clear within VR. But in real world context, like complex turns and if conflict happened between ATC and the bot, I will be unsure, and probably stop to see what happened."

Trust & Confidence

Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?



> "It's absolutely fine with the new way, but route changing happens on the bot, pilots might find it less trustworthy to follow the bot compare to human."

It's reliable but always chance that something has changed

I assume the bot being brought to the airport is well developed, and airport is relatively safe context, so I think it's totally trustworthy.

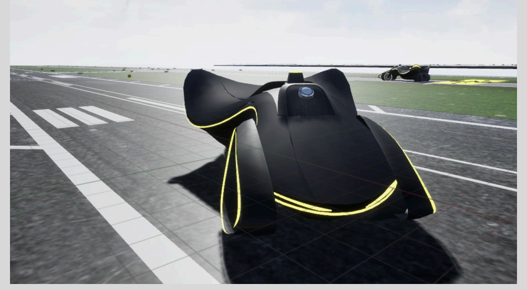
Recommendation / Insights

> "
> 1. Arrow projected behind the bot will become a bit confusing at the corner, since it's also turn together with the bot.
> 2. In VR, the bot can slow down a bit.
> 3. Bad visibility condition can be programmed for proofing visibility.
> "

pilot 8

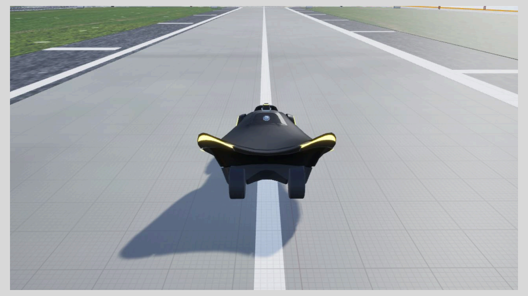
private pilot
Schiphol

Form Design



Projection

Blinking Motion



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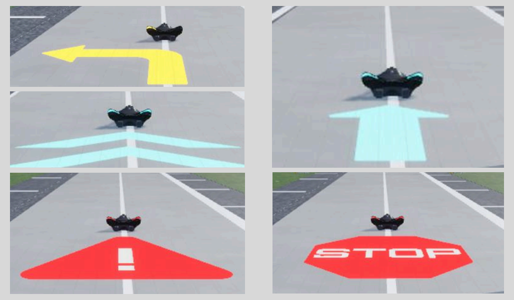


Visibility

5
4
3
2
1

Clear to see

Considering the foggy weather, would prefer yellow as main body color.

Clear to see

Under bad weather situation, we can see it properly if in the real world .

Didn't notice it, mainly focus on the projection.

Not visible

Distinguishable

In the VR it's clear, but I think blue will not be that visible in the real world context, I will make the speed up and go straight yellow as well.

Comprehemsion

5
4
3
2
1

Familiar enough for you to follow?

It's totally infamiliar because I first use it. If I use it more, I can gradually get used to it, but it take times.

Totally Infamiliar

Aware of what was happening and what to expect next?

Easy to predict

It's predictable, but I prefer the icon together with text as well so it can prevent people from guessing what the icon means.

Blinking light patterns easy to understand?

Not valid

Didn't notice the light patterns, only focusing on the projection.

Any moments where you felt unsure about what action to take?

" Speed up text is unsure to me, I think it would be great to also put it together with text. "

Trust & Confidence

5
4
3
2
1

Experience compare to the traditional ATC-guidance?

" With a new innovation they need time to get used to it. I think the interaction between the bot and the ATC is great, but the confirmation make them more assertive on action. "

Reliable in guiding you via the taxiing process?

Reliable

Still want to keep the ATC communication on confirm > instruction > read back before the vehicle starts driving

Trust the usherbot's guidance on taxiing preocess?

Trustworthy

Trust comes from confirmation. I want to be sure on if every movements are safe and correct.

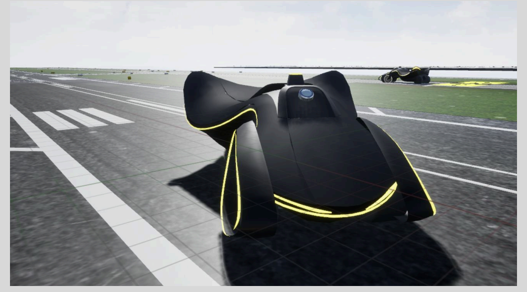
Recommendation / Insights

"
1. Signal with text, so people don't need to guess what it means
2. Overview of the route before start.
3. End of guidance > new command from ATC
"

pilot 9

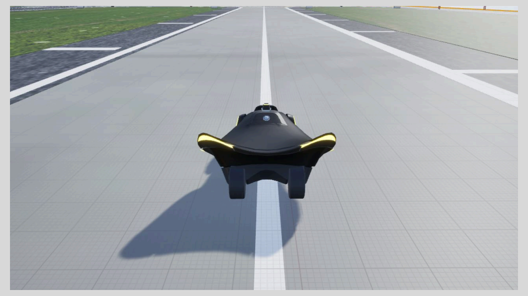
Commercial pilot, KLM 747 Schiphol

Form Design

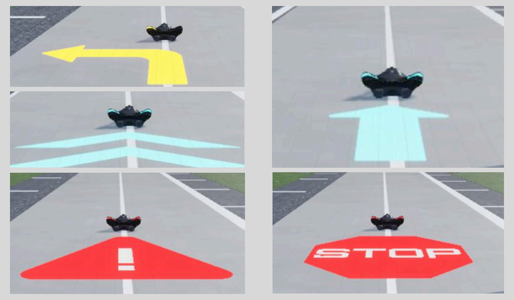


Projection

Blinking Motion



Colors



Visibility

2
1

It's visible in this context, but dark color at night is a bit concern, yellow and orange will be great.

Fine to see in this case but concern on bad weather situation & different ground material.

Totally Visible, I can see the blinking patterns.

It's distinguishable but blue could be more strong like the taxi light.

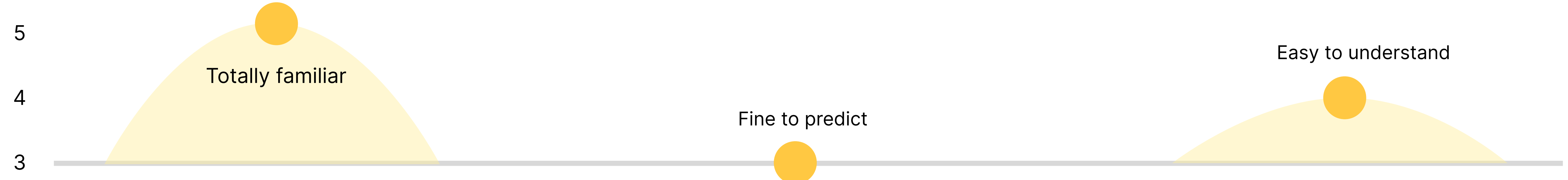
Comprehemsion

Familiar enough for you to follow?

Aware of what was happening and what to expect next?

Blinking light patterns easy to understand?

Any moments where you felt unsure about what action to take?



2
1

Totally familiar, although it's different, the procedure doesn't change too much, it's easy to handle.

It's predictable, but for accelerate might need to calculate the distance, short turning can show few steps at once.

Just same as car, easy to understand.

> No, I think it's straight forward. Blue light is new, but no problem on getting used to it.

Trust & Confidence

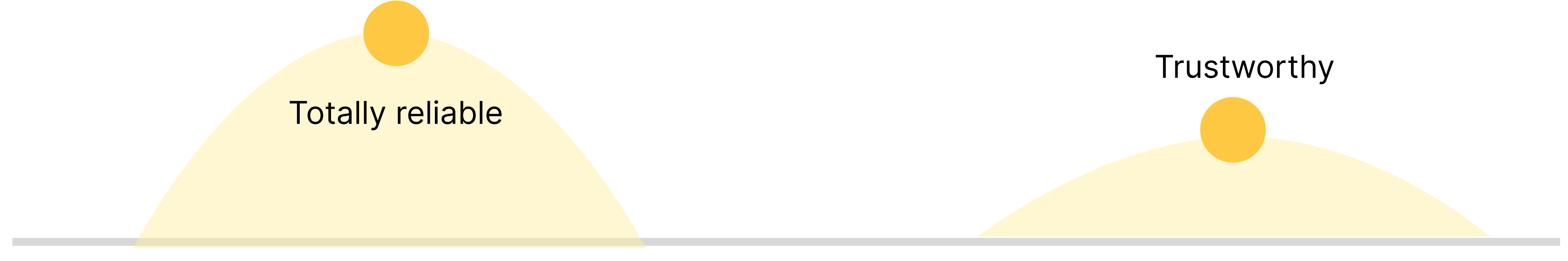
Experience compare to the traditional ATC-guidance?

Reliable in guiding you via the taxiing process?

Trust the usherbot's guidance on taxiing preocess?

5
4
3
2
1

> Similar, not too much difference, but just need to incorporate into the procedure, then it's just following the car.



Shouldn't be a problem if the ATC assign me to follow, but usherbot need to be programmed for checking if size of aircraft fits the taxiway.

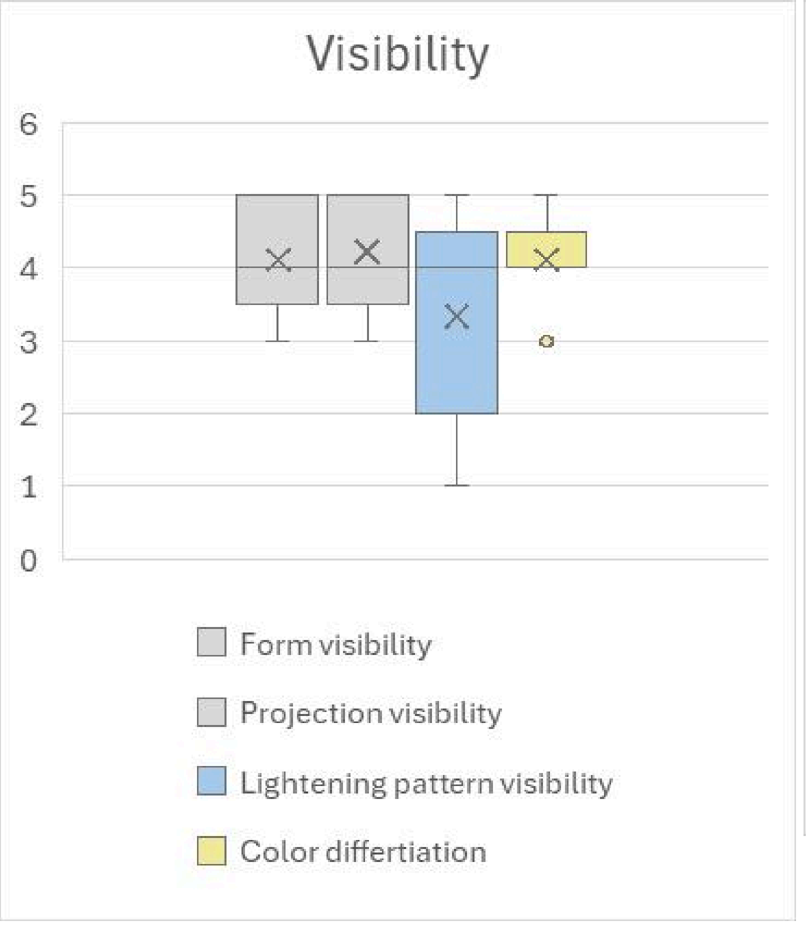
It's certified already by the airport so I trust it. If any doubt happens I just stop.

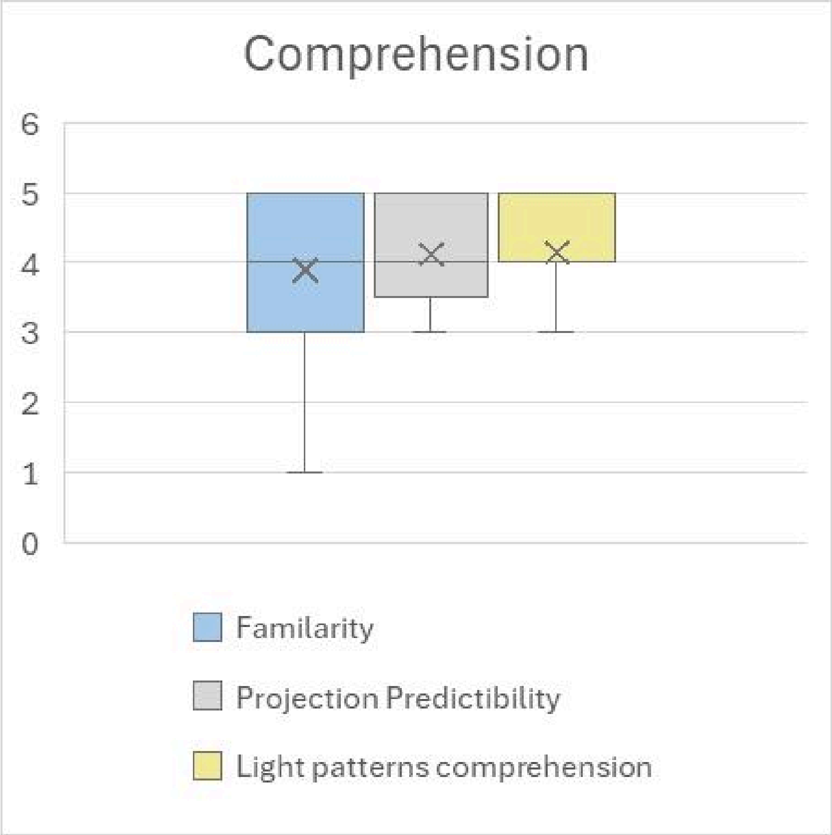
Recommendation / Insights

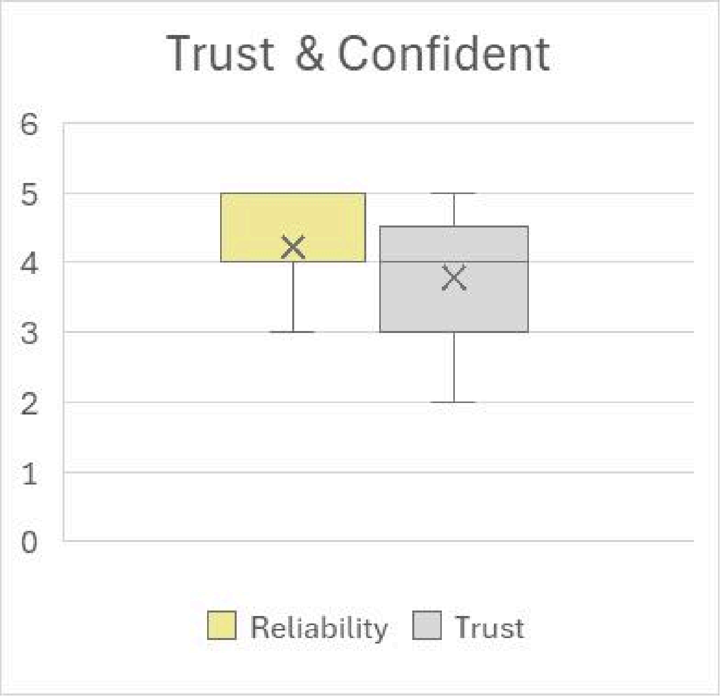
> 1. Ground control also need to get the input on what's going on.
> 2. The interface for ATC should be updated on schedule & delays of other aircrafts as well.

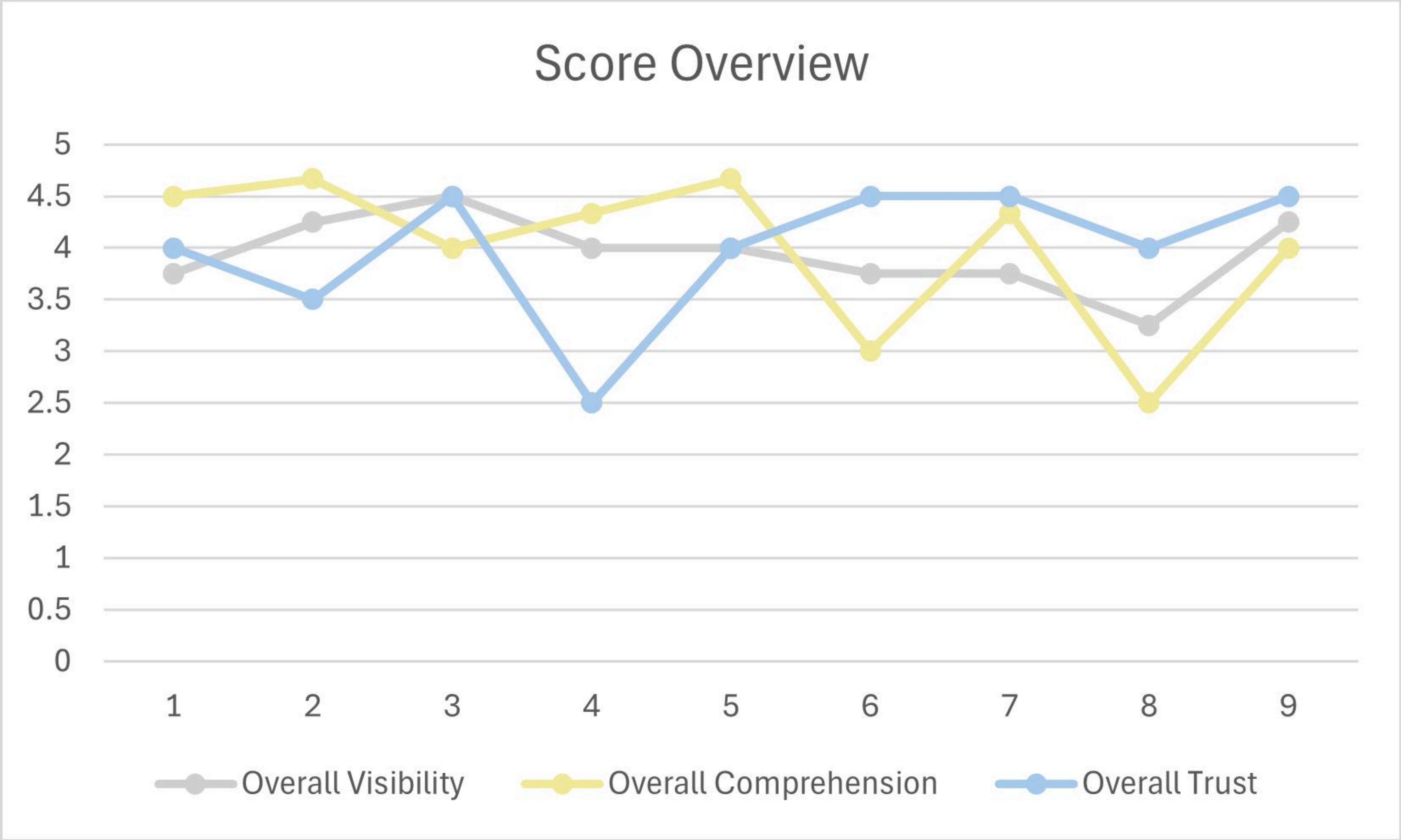
Appendix f.
Data Analyzation - Box plot & line chart

Original Data Overview

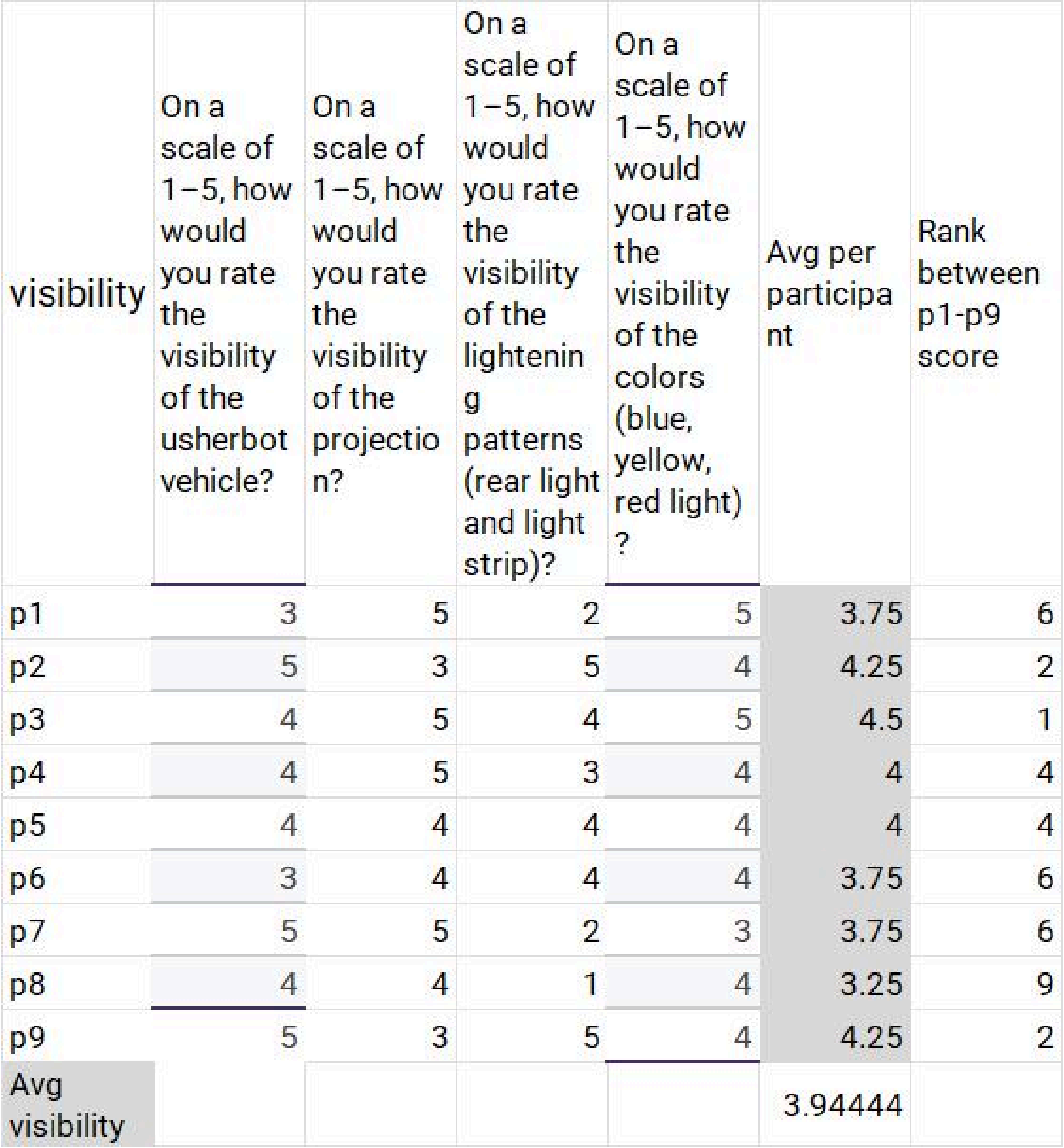




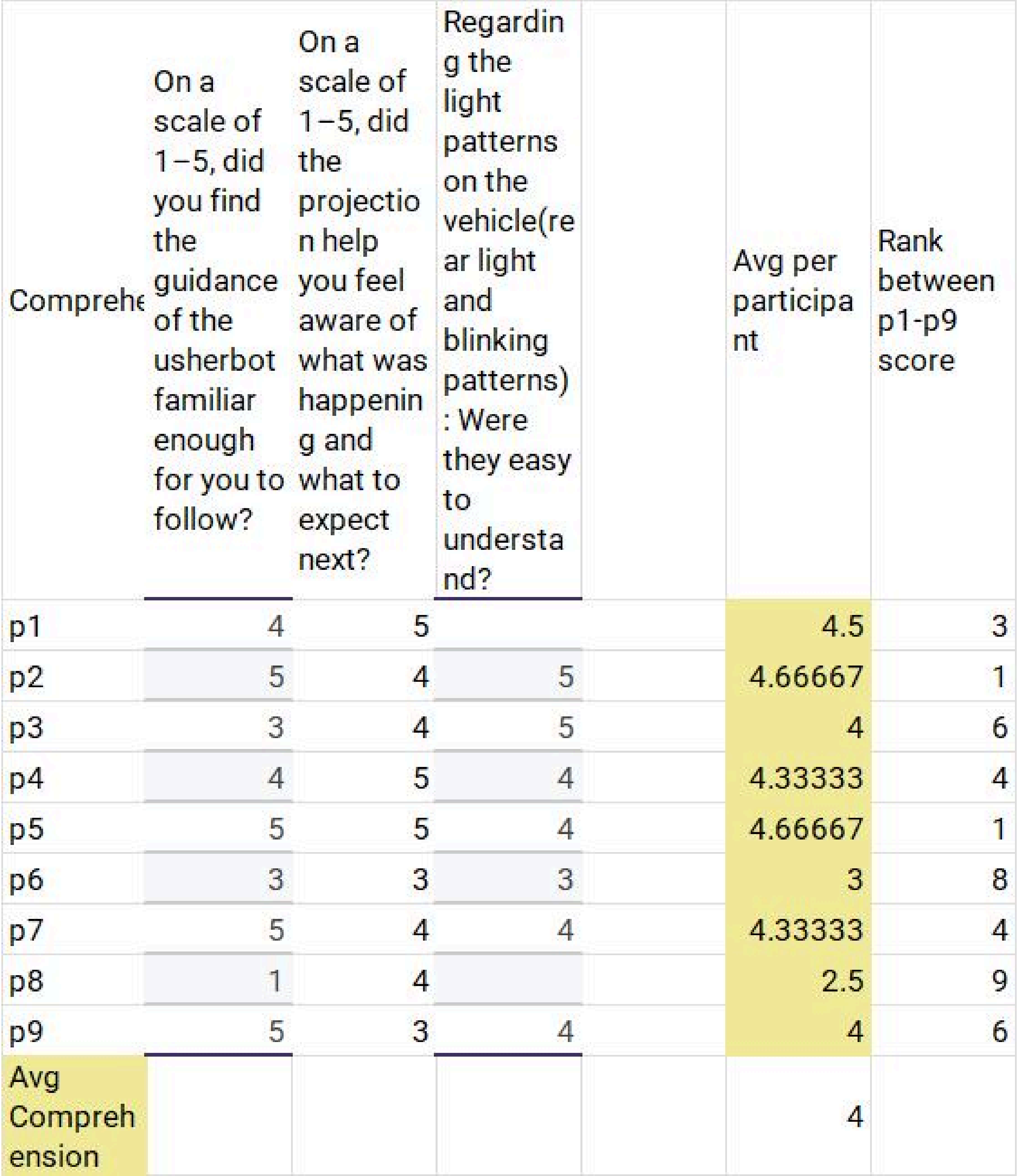




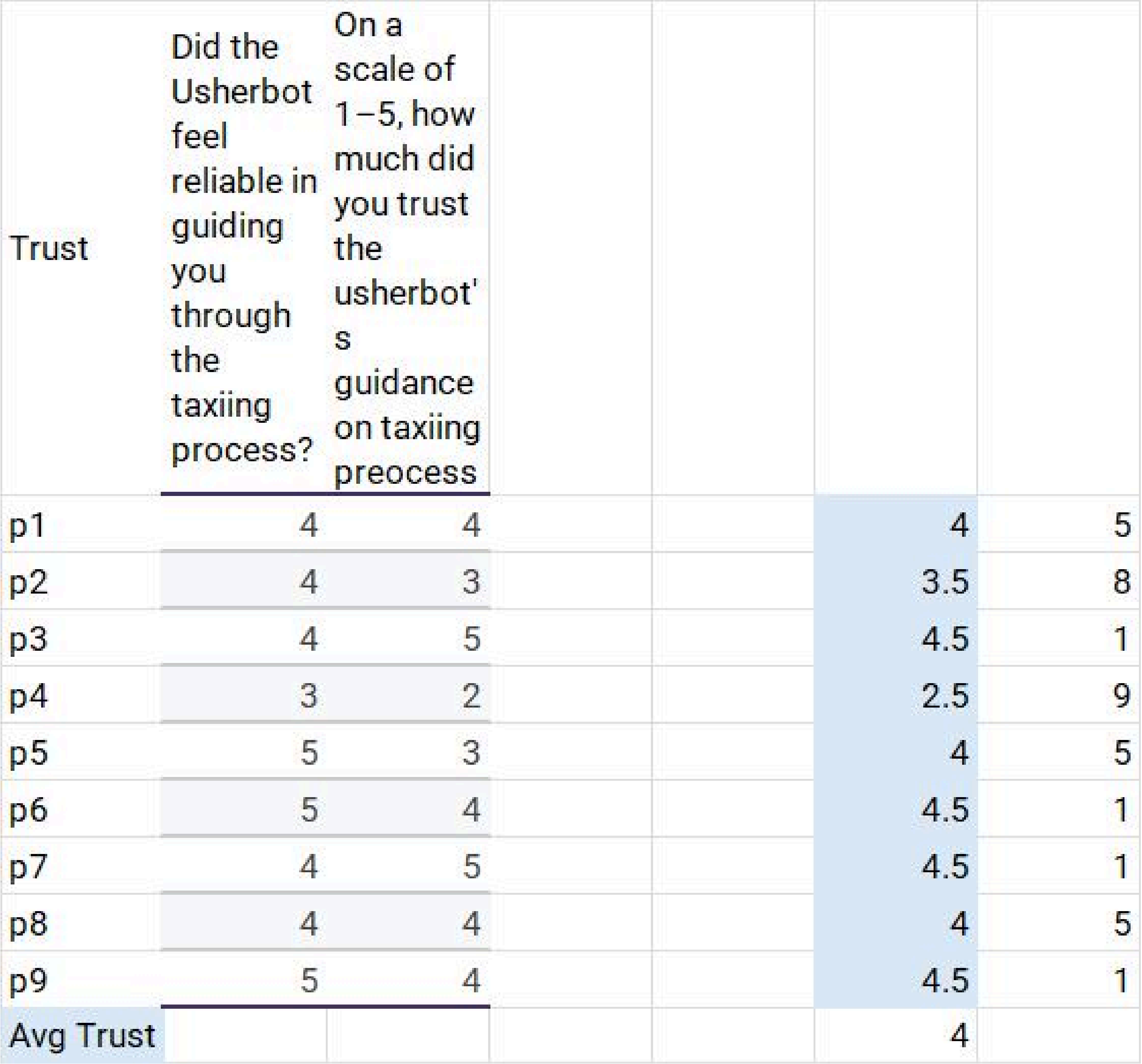
Appendix g.
Data Analyzation - Avg score & Rank



visibility	On a scale of 1–5, how would you rate the visibility of the usherbot vehicle?	On a scale of 1–5, how would you rate the visibility of the projection?	On a scale of 1–5, how would you rate the visibility of the lightening patterns (rear light and light strip)?	On a scale of 1–5, how would you rate the visibility of the colors (blue, yellow, red light)?	Avg per participant	Rank between p1-p9 score
p1	3	5	2	5	3.75	6
p2	5	3	5	4	4.25	2
p3	4	5	4	5	4.5	1
p4	4	5	3	4	4	4
p5	4	4	4	4	4	4
p6	3	4	4	4	3.75	6
p7	5	5	2	3	3.75	6
p8	4	4	1	4	3.25	9
p9	5	3	5	4	4.25	2
Avg visibility					3.94444	



Comprehe	On a scale of 1–5, did you find the guidance of the usherbot familiar enough for you to follow?	On a scale of 1–5, did the projection help you feel aware of what was happening and what to expect next?	Regarding the light patterns on the vehicle(rear light and blinking patterns): Were they easy to understand?		Avg per participant	Rank between p1-p9 score
p1	4	5			4.5	3
p2	5	4	5		4.66667	1
p3	3	4	5		4	6
p4	4	5	4		4.33333	4
p5	5	5	4		4.66667	1
p6	3	3	3		3	8
p7	5	4	4		4.33333	4
p8	1	4			2.5	9
p9	5	3	4		4	6
Avg Comprehension					4	



Trust	Did the Usherbot feel reliable in guiding you through the taxiing process?	On a scale of 1–5, how much did you trust the usherbot's guidance on taxiing preocess				
p1	4	4			4	5
p2	4	3			3.5	8
p3	4	5			4.5	1
p4	3	2			2.5	9
p5	5	3			4	5
p6	5	4			4.5	1
p7	4	5			4.5	1
p8	4	4			4	5
p9	5	4			4.5	1
Avg Trust					4	

Appendix h.
Data Analyzation - Spearman's rank correlation

Participant	Visibility Rank	Comprehension Rank	di	di²			Participant	Visibility Rank	Trust & Confidence Rank	di	di²		Participant	Comprehension Rank	Trust & Confidence Rank	di	di²
P1	3	7	-4	16			P1	3	4	-1	1		P1	7	4	3	9
P2	7.5	8.5	-1	1			P2	7.5	2	5.5	30.25		P2	8.5	2	6.5	42.25
P3	9	3.5	5.5	30.25			P3	9	7.5	1.5	2.25		P3	3.5	7.5	-4	16
P4	5.5	5.5	0	0			P4	5.5	1	4.5	20.25		P4	5.5	1	4.5	20.25
P5	5.5	8.5	-3	9			P5	5.5	4	1.5	2.25		P5	8.5	4	4.5	20.25
P6	3	2	1	1			P6	3	7.5	-4.5	20.25		P6	2	7.5	-5.5	30.25
P7	3	5.5	-2.5	6.25			P7	3	7.5	-4.5	20.25		P7	5.5	7.5	-2	4
P8	1	1	0	0			P8	1	4	-3	9		P8	1	4	-3	9
P9	7.5	3.5	4	16			P9	7.5	7.5	0	0		P9	3.5	7.5	-4	16
Spearman's Rank Correlation					ρ Visibility,Comprehension≈0.31\rho_{Visibility,Comprehension}\approx 0.31 ρ Visibility,Comprehension≈0.31						ρ Visibility,Trust&Confidence≈0.04\rho_{Visibility,Trust\&Confidence}\approx 0.04 ρ Visibility,Trust&Confidence≈0.04						ρ Comprehension,Trust&Confidence≈−0.50\rho_{Comprehension,Trust\&Confidence}\approx -0.50 ρ Comprehension,Trust&Confidence≈−0.50