

Investigation of Perceived External UAM Design Features as a New Transportation Method

Nathan Chun, Nate Jachim, GeeBeum Park, Sang-Hwan Kim

Department of Industrial and Manufacturing Systems Engineering,
University of Michigan – Dearborn, Dearborn, MI 48128, USA

Urban air mobility (UAM) has been suggested as a new method of transportation to solve issues of rising populations and traffic congestion in metropolitan areas. UAM is mostly conceptual, as there is no standardization for the external aesthetic features of a UAM. This study aims to understand how people would perceive and describe the external design of UAM and how specific features of UAM design associate with the descriptor terms and preference by adopting the methods of Kansei Engineering or Measure of Perception. Participants were asked to rate different sample UAM designs using 30 semantic pairs selected to best describe UAM. The factor results on the semantic pairs revealed five descriptor terms including safety, comfort, novelty, simplicity, and its level of advancement. The results also found that participants prefer the sample designs that generate feelings of safety, comfort, and simplicity, with a few advancements. Even though the study is preliminary, the study can be extended to understand users' mental models and apply them to the effective design of UAM in various ways.

INTRODUCTION

Urban air mobility (UAM) is an emerging concept for a new transport system, especially in metropolitan areas (Cohen & Shaheen, 2021). The 2011 Urban Mobility Report found that traffic congestion in metropolitan areas resulted in 1.9 billion gallons of wasted fuel, 4.8 billion hours of wasted time sitting in traffic, and the yearly delay during peak periods for the average consumer was 34 hours, suggesting that there needs to be improvements as well as other methods of travel to improve traffic congestion (Schrang et al., 2011). Rising populations and increased traffic congestion have resulted in UAM technology being suggested for many services like parcel delivery, emergency services, surveillance, and passenger transportation (Straubinger et al., 2020).

UAMs are currently mostly conceptual, as there are many obstacles that stand between the concept and its creation. The most notable of these limitations on the technical end include adequate noise level management, battery size, material, rotor size (Cokorilo, 2020), as well as compliance with any legal restrictions in respective countries (Gillis et al., 2021). UAM's also face many barriers to becoming mainstream on the user end. Some of the most prominent issues UAMs face when getting public acceptance include price, noise pollution, increased aircraft activity over residential areas, piloting (Cohen, 2021), and concerns for overall safety (Yedavalli & Mooberry, 2019).

Human Factors Challenges to UAM Integration

With the integration of UAM's into society, there are multiple facets that are directly related to human factors issues. Vehicle concepts, airspace integration, and ground infrastructure all have various aspects relating to human factors issues, and many of these issues serve as the initial barriers to integration (Chauhan & Carroll, 2021). Other

human factors issues include the designs and development of a new sector of aircraft vehicles, new cockpit designs for pilots and/or passengers, new procedures for operation of the UAM and the air traffic control of multiple UAM in operation, overall infrastructure, maintaining high situation awareness while riding, managing pilot or controller stress and workload, and the passenger experience of riding in a UAM (Chauhan & Carroll, 2021).

In addition, due to the nature of UAM being mostly conceptual, the preferred external design features of a UAM for potential passengers is unknown, whereas other transportation methods have typical shapes such as ground vehicles, trains, and ships. It is important to find the preferred external, aesthetic features as research has found the success of new products in the market are a result of physical, visible design features (Yadav et al., 2013).

Kansei Engineering

Kansei Engineering, or sometimes referred to as emotional or affective engineering, is a term that was created by Mitsuo Nagamachi in the 1970s. It is defined as “translating technology of a consumer's feelings and image for a product into design elements” (Nagamachi, 1995). Kansei Engineering focuses on the consumer's psychological feelings and needs as a response to interactions with certain products or designs. It was originally used to design new products based on customers' feelings and demands. Major activities for Kansei Engineering involve: 1) capturing the customers' common feelings about the product in terms of psychological estimation; 2) identification of design characteristics of the product; and 3) development of relationships between design characteristics and customers' feelings, which allow adjustments of the product to maximize customers' satisfaction (Smith & Smith, 2013). In order to capture customers' feelings, the semantic differential (SD) method (Osgood, 1964) was primarily used to measure and decompose

the psychological meaning of the product. Even though Kansei Engineering has been developed and used in Japan, typically for designing products, a similar approach using SD has been used in many human factors studies. For instance, the NASA-TLX (Task Load Index) was developed by NASA to assess the level of human operators' mental workload (Hart & Staveland, 1988). Another example is the research on development and validation of multidimensional measures of display clutter (Kaber et al, 2008; Kim et al., 2011).

Objectives of the Study

The objective of the current study is to investigate the common perceptions of the external UAM design features along with preferences by adopting the methods of Kansei Engineering, the measure of perception, as a preliminary study. The study included identifying distinctive design features, finding common descriptor terms of the UAM's external design, illustrating descriptor terms, representative UAM design, and preferences in a 2-dimensional conceptual map to understand the common perception towards UAM designs. It should be noted, however, that the study is for perceived design features in terms of human-centered design, and did not go into the technical and/or mechanical feasibility of the designs, such as aerodynamics, propulsion power, capacity, size, location of the battery, etc.

UAM EXTERNAL DESIGN FEATURES

In an effort to standardize the model of a UAM, various existing external models of hypothesized UAM's were collected. There were six main components of existing models to analyze: the existence of wing (yes or no), the general shape of cabin (ground vehicle, airplane, helicopter), where the rotor was placed (on the wings or on the body), the position of the rotor (top, body, or bottom), the shape of the rotor (exposed, in a rim, or fully protected), and the movement of the rotor (fixed or pivoting). There was a total of 216 total combinations, but four main existing concepts were selected for this study: fixed-wing with dedicated lift fans, fixed-wing with motors that transition, multi-rotor with underslung cabin, and multi-rotor with underslung rotors. Fixed-wing with dedicated lift fans has fixed or rotating wings that will provide most of the lift during horizontal flight. There will be dedicated fans for lifting the vehicle vertically. Fixed-wing with motors that transition would be similar to the fixed-wing with dedicated lift fans, but the fans used specifically for lifting would also be able to transition or rotate in a way that aids horizontal flight after takeoff. The multi-rotor with underslung cabin features multiple rotors above the main cabin that can either be ducted or non-ducted to provide most of the lift in all phases of flight. The final model, multi-rotor with underslung rotors, features multiple rotors that are below the main cabin, allowing for a generally more compact design.

COMMON DESCRIPTOR TERMS OF UAM EXTERNAL DESIGN

Candidate Descriptor Terms

The study aimed to identify descriptor terms that common people may describe the external features of UAM design. As originally developed by Osgood (Osgood, 1964) and applied in many historical studies to assess human perception in workload (Hart & Staveland, 1988), display clutter (Kaber et al., 2008), and other Kansei Engineering studies (Smith & Smith, 2013), sets of semantic pairs were prepared and analyzed to find common factors among them.

A total of 30 semantic pairs that could possibly describe UAM external design were collected and prepared from various resources including articles, websites, and thesauruses. Table 1 shows the collected descriptor terms.

Table 1. Collected Candidate Descriptor Terms

Safe / Unsafe	Simple / Complicated	Exciting / Terrifying
Basic / Advanced	Erratic / Relaxed	Eccentric / Mundane
Predictable / Uneasy	Cool / Bizarre	Sensational / Distressing
Lustrous / Awkward	Sleek / Coarse	Exhilarating / Unsettling
Modern / Dated	Stylish / Odd	Freighting / Calming
Deliberate / Convoluted	Flexible / Restricted	Thoughtful / Strange
Overwhelming / Basic	Breathtaking / Horrifying	Peculiar / Invigorating
Sluggish / Quick	Risky / Reassuring	Intricate / Easy
Sophisticated / Rudimentary	Comfortable / Uncomfortable	Novel / Usual
Trustworthy / Treacherous	Conventional / Unconventional	Comprehensive / Incomplete

Sample UAM Designs

In order to find common descriptor terms among the candidate set, it was required to present sample UAM designs to participants. As identified in previous design feature analysis, the most distinctive design features of UAM were the existence of the wing (yes or not), the position of the rotor (bottom, body, or top), and rotor shape (exposed or protected by rims). A total of four UAM designs were prepared from existing models or developed as in-house 3D modeling. Figure 1 illustrates the 4 design models and their features.

Response Collection

An online survey was prepared in order to collect responses on how people perceived the designs and to analyze common descriptor terms people preferred. The survey asks participants to rate the 30 semantic pairs using a scale ranging from 1 to 10 for each UAM. Along with the ratings on the 30 semantic pairs, a rating on semantic pairs asking general preference (like vs. dislike) was asked in the survey. The order of UAM design models was presented randomly to avoid the ordering effects. After obtaining an IRB Exempt from the University of Michigan (HUM00188053), the survey was disseminated. A total of 43 responses were collected after

screening out invalid responses such as reckless or incomplete responses. The respondents' ages ranged from 18 to 50 years old, consisting of 21 males and 22 females.

	Model	Existence of Wing	Position of Rotor	Rotor Shape
A		No	Bottom	Exposed
B		Yes	Body	Protected by Rims
C		Yes	Body	Exposed
D		No	Top	Protected by Rims

Figure 1. Four UAM Designs and Distinctive Features

Factor Analysis Results and Descriptor Terms

A factor analysis was conducted to find latent factors among the 30 semantic pairs as well as determine how many factors are necessary to describe external UAM design. The ratings for the pairs of descriptor terms were submitted to a principal component analysis with an orthogonal Varimax rotation. Through the analysis of the scree plot and the cumulative eigenvalue, five factors were identified as latent variables explaining 70% of the total variance of the external UAM designs. Table 2 shows the 5 factors and the factor loading values of each pair to the factor. Based on internal discussions of the intuitiveness of descriptor terms, the representative semantic pairs for each factor were selected.

Consequently, 5 descriptor terms consisting of semantic pairs were identified. Those are:

- Factor 1: Safety (“Safe / Unsafe”) - Safety refers to how participants rated different samples based on if they thought certain features would make the UAM appear safe or unsafe to ride. Safe / Unsafe was chosen as it was the most intuitive to describe the safety of different external features of UAMs.
- Factor 2: Comfort level (“Comfortable / Uncomfortable”) - Comfort level refers to how the design of the vehicles yields feelings of comfort for participants. Comfortable /

Uncomfortable was chosen as the descriptor term for this section.

- Factor 3: Novelty (“Novel / Usual”) - Novelty refers to how the design generates the feeling of originality and unfamiliarity in the participants.
- Factor 4: Simplicity (“Simple / Complicated”) - Simplicity refers to the overall level of perceived complexity for each design.
- Factor 5: Advances (“Basic / Advanced”) - Advances refer to how futuristic the overall design looks.

Table 2. Rotated Component Matrix

Terms	Factors				
	1	2	3	4	5
Exciting / Terrifying	0.877	0.148	-0.104	-0.034	0.082
Trustworthy / Treacherous	0.838	0.196	-0.136	0.314	-0.137
Safe / Unsafe	0.828	0.098	-0.194	0.116	-0.006
Predictable / Uneasy	0.76	-0.012	-0.232	0.227	-0.066
Breathtaking / Horrifying	0.719	0.352	-0.036	-0.112	0.065
Sensational / Distressing	0.693	0.293	-0.072	0.179	0.222
Lustrous / Awkward	0.653	0.518	-0.12	0.253	0.113
Exhilarating / Unsettling	0.628	0.242	-0.343	0.074	0.117
Thoughtful / Strange	0.582	0.536	-0.05	0.163	0.197
Cool / Bizarre	0.569	0.312	-0.264	0.155	0.529
Sophisticated / Rudimentary	0.102	0.724	-0.126	-0.118	0.268
Stylish / Odd	0.36	0.71	0.002	0.033	0.319
Comfortable / Uncomfortable	0.129	0.707	-0.12	0.226	-0.023
Flexible / Restricted	0.551	0.658	-0.11	0.098	-0.137
Sleek / Coarse	0.324	0.647	-0.284	0.133	0.403
Deliberate / Convoluted	0.481	0.569	0.013	-0.158	-0.255
Intricate / Easy	-0.173	-0.14	0.767	-0.242	-0.059
Frightening / Calming	-0.445	-0.184	0.757	-0.128	0.019
Novel / Usual	0.075	0.321	0.713	0.045	-0.011
Risky / Reassuring	-0.426	-0.291	0.712	-0.093	-0.005
Erratic / Relaxed	-0.257	-0.288	0.645	-0.441	0.083
Peculiar / Invigorating	-0.077	-0.315	0.533	-0.331	-0.097
Eccentric / Mundane	-0.016	-0.024	0.419	0.223	0.343
Simple / Complicated	0.147	0.436	-0.106	0.774	-0.152
Conventional / Unconventional	0.348	0.026	-0.076	0.767	0
Overwhelming / Basic	-0.059	0.193	0.484	-0.702	-0.012
Sluggish / Quick	0.096	0.014	0.141	0.047	-0.878
Basic / Advanced	0.01	-0.308	-0.153	0.441	-0.691
Modern / Dated	0.3	0.424	0.178	-0.253	0.488
Comprehensive / Incomplete	0.433	0.121	0.175	0.188	0.448

Note: Shaded cells indicate the absolute factor loading value of variables exceeds 0.4 toward each factor.

CONCEPTUAL POSITIONING OF MODELS, DESCRIPTOR TERMS, AND PREFERENCE

A multidimensional preference analysis (MDPREF) was conducted, which is based on a principal component analysis to layout test objects (sample UAM external designs) and participants' responses on descriptor terms in the same 2-dimensional space. The objects were laid out as an ideal

point (centroid coordinate) and the descriptor terms were represented as vectors. However, in order to identify the relation of design samples and descriptor terms with general preference, the ratings of like/dislike were included in the mapping model. Table 3 shows the coordinator of the entities and Figure 2 shows the results of the MDPREF map illustrating the ideal points of the 4 sample UAM designs and vectors of the 5 descriptor terms and preference.

Table 3. Coordinates of Sample Designs and Descriptor terms

Centroid Coordinates			Vector Coordinates		
Sample Design	Dim 1	Dim 2	Descriptor Terms	Dim 1	Dim 2
A	0.101	-0.655	Safe/ Unsafe	0.831	0.02
B	-0.068	-0.03	Comfortable/ Uncomfortable	0.809	0.166
C	0.448	1.19	Simple/ Complicated	0.77	0.357
D	-0.607	-0.003	Basic/ Advanced	-0.216	0.822
			Novel/ Usual	-0.18	-0.69
			Dislike/ Like	-0.807	0.455

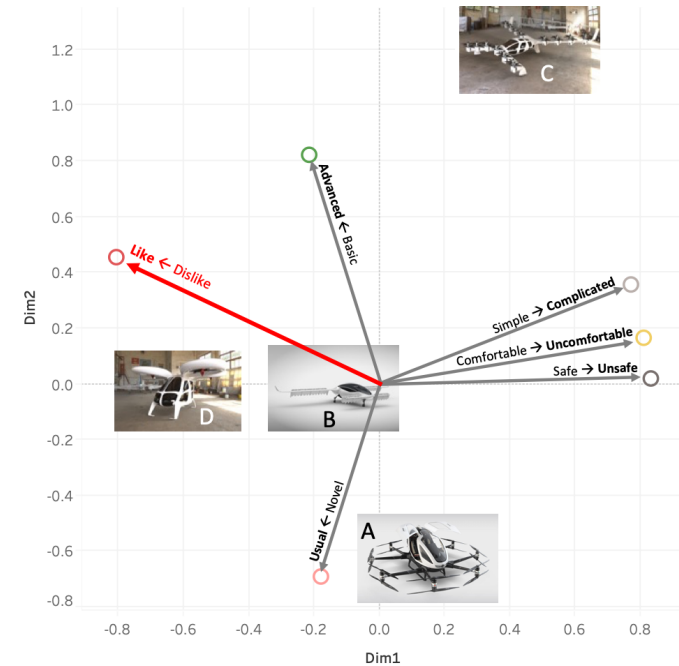


Figure 2. MDPREF of loading of UAM designs, descriptor terms, and preference

From Figure 2, it can be inferred that:

- In general, the 5 descriptor terms can be grouped into 2-dimensional ways. One includes “simple/complicated,” “comfortable/uncomfortable,” and “safe/unsafe”, which are directed as dimension 1. As the value in the Dim 1 increases it means “complicated,” “uncomfortable,” and “unsafe”. Thus, this axis may represent the level of

perceived anxiety or concerns. Another axis (Dim 2) consists of “advanced/basic” and “usual/novel”. Since the higher Dim 2 values are associated with “advanced” and “novel”, this dimension may imply a level of unique or progressive. Thus, the 5 dimensions of perceived characteristics of UAM external design can be represented in a 2-dimensional way including “anxiety” and “progressiveness.”

- Sample Design A is located at around the midpoint of Dim 1 and lower at Dim2, which means it is perceived as neutral in anxiety as well as usual and basic. In a similar manner, Design B is perceived as neutral in both dimensions, Design C as somewhat anxious and highly progressive, and Design D is located at the highly opposite side of anxiety and neutral in progressiveness.
- Preference vector shows people may highly prefer the opposite direction of anxiety (probably “calm”) design as well as moderately prefer progressive design. Among the 4 design samples, Design D was located most closely to the preference vector and Design A and C were not preferred.

DISCUSSION

The results of the study show that participants prefer a design that is not too novel but also not too familiar and a strong preference for designs that were perceived to be safer than unsafe. Design C presented too novel an idea for the concept of a UAM as the design is both unfamiliar to many participants and had very little resemblance to the other sample designs or already existing aircrafts. This resulted in participants perceiving it as unsafe. As the preference vector shows, participants prefer designs that stray away from feelings of anxiety and unsafety. This is consistent with previous research done by The Booz Allen (Reiche et al., 2018), as they found that 93% of focus group participants would be interested in using UAM, as long as there was a guarantee of safety. Safety is the minimum requirement participants would need to become interested in adopting the technology. Design B and D were the only designs that featured a protective ring around the rotors, suggesting that participants feel safer when the rotors of the vehicle are protected. Participant’s approval of Design D also suggests that participants would rather have rotors above the vehicle, similar to something they are already familiar with, today’s helicopters. The existence of wings versus the existence of rotors seemed to not have a significant impact on perceived safety as both Design B and C both have wings but a significant difference in their perceived safety. The results also suggest that the simpler the designs are perceived to be, the safer they appear to be. Designs B and D feature only two parts protruding from the body while Designs A and C have many more parts due to their many visible rotors. Finally, the cabin shape had an impact on the perceived comfort of the design. Designs B and C appear to have a flatter, more sleek

cabins, while Designs A and D feature cabins that appear to be taller and have more room. Participants selected Design D to have the highest perceived comfort as the cabin appears to be the largest of the four designs.

CONCLUSION

This study aimed to understand how people identify and describe the perceived external design features of UAM as well as what external features of a hypothetical UAM design would lead to a higher perceived level of preference using selected descriptor terms. There were a few limitations in the study due to the nature of it being preliminary, namely having a small number of responses to represent the population for semantic pair analysis, and that only four sample designs were used for data collection, even though many more conceptual designs for UAM's exist. In addition, the technical feasibility and cost to create these sample designs in real life were not a factor in the creation of these samples.

In the future to extend the study, a similar study using a virtual reality (VR) environment can be conducted using 3D models of external/internal UAM design. By putting 3D models of the external and internal UAM design into a VR space, participants could interact with the models and understand things like their size, process of entering, its movement, and more. Conducting a study in the VR space would allow for cost efficient testing of future designs for UAM, to see which models and characteristics are effectively preferred by users.

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