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Market segmentation of an electric vertical takeoff and landing (eVTOL) air taxi commuting service in five large U.S. cities

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ABSTRACT

Many companies are developing prototypes for novel electric vertical takeoff and landing (eVTOL) aircraft to serve as air taxis in cities. These eVTOL air taxis are envisioned as a new form of shared transportation that has the potential to reduce commuting times in urban areas with congested roadway networks. In this study, an attitudinal survey of high-income commuters in five U.S. cities was conducted to better understand the segmentation of the market for future eVTOL urban air taxis. Factor analysis of eVTOL perceptions identified two dimensions: Concern and Enthusiasm. Cluster analysis of the scores on these factors identified six meaningful segments, which differed on a variety of demographic, travel behavior, and attitudinal variables, as well as on participants' inclination to adopt eVTOL travel. The study demonstrates how assessment of the sizes of the various air taxi market segments is affected by mean-centering the factor scores obtained from Likert-scale survey results; in particular, it finds that the conventional mean-centered factor scoring approach understates positive interest in eVTOL air taxis.

1. Introduction and motivation

Urban air mobility (UAM)—an emerging topic within the aeronautics and transportation research communities—involves intra-city passenger and cargo transportation via aircraft. One UAM application that has garnered considerable attention is an "air taxi" in the form of shared-use on-demand passenger services provided by fleet operators and transportation network companies (TNCs) (Holden and Goel, 2016; Straubinger et al., 2020). Interest in air taxi services has been motivated by the emergence of electric vertical takeoff and landing (eVTOL) aircraft that incorporate new technologies—including electric propulsion and autonomy—intended to: (1) reduce operating costs and community noise compared to traditional helicopters, and (2) enable trip time savings compared to cars by overflying ground traffic congestion (Antcliff et al., 2016; Rothfeld et al., 2021; Schrank et al., 2015; Swadesir and Bil, 2019; Vascik et al., 2018). Air taxi flights are anticipated to originate and terminate at "vertiports"[1] situated throughout a city, with network

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[1] A "vertiport" is a generalization of the term "heliport" that is used to indicate that it is designed for use by eVTOL aircraft instead of or in addition to traditional helicopters.

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operations optimized to achieve a balance between high aircraft utilization and operational performance metrics that influence customer demand, such as the times for waiting, boarding, deboarding, and access and egress (e.g., see Daskilewicz et al., 2018; Kreimeier et al., 2016; Narkus-Kramer et al., 2016; Preis and Hornung, 2022; Rothfeld et al., 2018; Swadesir and Bil, 2019). Trip purposes envisioned for UAM air taxis include airport transfers, commuting, leisure trips, and special generators such as sporting events (Al Haddad et al., 2020; Fu et al., 2019). The implementation and adoption of widespread UAM air taxi services will likely require many years, as issues such as aircraft certification, airspace management, and operational constraints are understood and addressed (Bradford, 2020; Cohen et al., 2021; Vascik et al., 2018).

Research in UAM has been increasing rapidly. In a meta-analysis of publications in a recent review article, Garrow et al. (2021) found that an exponential increase[2] in the number of publications focused on UAM has occurred from 2015 to 2019. As discussed by Garrow and colleagues, earlier publications originated primarily in the U.S. and were predominately associated with the National Aeronautics and Space Administration (NASA), which conducted some of the first UAM studies; emphasis then increased in Germany and across academia. Garrow and colleagues found that UAM publications have recently increased considerably within the transportation research community, which has examined UAM not only in isolation but also in comparison to shared ground-transportation services.

Much of the research related to UAM air taxi services has focused on consumer demand. Initial demand modeling efforts have focused primarily on conducting high-level assessments to understand if there are viable markets for UAM (Goyal et al., 2021) and how mission requirements for these markets—which tie directly to aircraft design specifications—vary across cities (Rothfeld et al., 2021; Roy et al., 2021). Identifying where UAM could offer door-to-door travel-time savings compared to other modes has been a key part of these high-level assessments (e.g., see studies by Akhter et al., 2020; Antcliff et al., 2016; Roy et al., 2018; Swadesir and Bil, 2019; Vascik et al., 2018). In many of these studies, the travel times and costs are compared across modes, and a value of time (VOT) is used to determine the fraction of consumers who would use the UAM mode. Sensitivity analyses of different values of time to aircraft design and operational parameters are also common. Examples of these parameters include cruise speeds, battery recharging times, and passenger boarding and deboarding times.

Other demand modeling approaches are more common within the literature on ground transportation, which has a long history of predicting demand for new technologies, including electric ground vehicles (EVs), autonomous ground vehicles (AVs), ride-hailing services, and carsharing services. Many of the ground-based studies center on surveys and focus on understanding how adoption of these new modes is influenced by modal attributes (e.g., time and cost), as well as individuals' characteristics, such as socioeconomic and demographic (SED) traits (e.g., household income, education, gender, and auto ownership) and attitudes, perceptions, and lifestyle characteristics (e.g., trust in technology, pro-environmental attitudes, residential location preferences, and other factors). Demand estimation for new modes is challenging, however, because past market data are not available to facilitate estimates.

As an initial step toward understanding potential markets for a new transportation mode, some authors have conducted market segmentation studies. These studies provide information about how SED and other characteristics relate to "enthusiasm for" and "intention to use" new modes, which can be helpful for assessing the size and promise of various market segments (e.g., early adopters, heavy users, or various geographic areas), improving demand models by accounting for heterogeneity in the importance given to various influential variables, fine-tuning service design, informing the timing of infrastructure investments and service rollouts, developing informational/marketing campaigns, optimizing revenue, and/or targeting future surveys to those who are more likely to be early adopters (Wedel and Kamakura, 2000). For example, Kim et al. (2019a) conducted a market segmentation analysis and identified seven potential market segments for the adoption of AVs in Georgia. Other market segmentation studies related to AVs uncovered segments reflecting perceptions of AV benefits and concerns (Menon et al., 2020), levels of willingness to adopt AVs as a new mode of transportation (Pettigrew et al., 2019), or an individual's level of enthusiasm for or skepticism of AVs (Nielsen and Haustein, 2018). Finally, Alemi et al. (2019) presented sociodemographic and behavioral profiles of three segments based on frequency of ride-hailing usage in California.

While relevant, results of market segmentation studies related to other new modes of transportation are still likely to differ from market segmentation of UAM air taxi demand. The demand that could be expected would reflect, in unknown shares: (1) a mode shift from ground transportation, (2) the realization of existing latent demand associated with the specific cost/benefit tradeoffs of the air taxi mode, and (3) the generation of entirely new demand. Our paper contributes to the literature by providing a market segmentation analysis with respect to future UAM air taxi services. It is similar in spirit to studies conducted in the ground-transportation literature (most notably that of Kim et al., 2019a) but provides one of the first survey-based analyses of market segmentation for UAM commuters.

In this study, data were collected on perceptions of the proposed new services, together with other attitudes and SED characteristics. Following a typical approach in marketing research (e.g., Pronello and Camusso, 2011), eVTOL air taxi perceptions were factor-analyzed, and the sample was clustered on the basis of the resulting factor scores. The clusters were then analyzed in terms of their additional characteristics (i.e., attitudes and SED traits). This market segmentation is a primary contribution of this paper, which should prove valuable to the development of future quantitative demand models. A second contribution of this work is an assessment of how the estimated size of various air taxi market segments is affected by the conventional practice of mean-centering the factor scores based on the attitudes measured by the survey. In particular, these findings show that the mean-centered factor scoring

[2] Based on a meta-analysis of publications in the American Institute of Aeronautics and Astronautics (AIAA) database, Garrow et al. (2021) found that the number of annual papers related to urban air mobility was 6, 11, 15, 74, and 120 for the years of 2015 to 2019. An exponential curve fit through these data points is y=exp(1.0194x) with an R^2 of 0.86.

approach substantially understates the positive interest in eVTOL air taxis among the study population of high-income commuters.

The paper is organized as follows. Section 2 reviews survey-based UAM research and factors that have been shown to influence adoption of new transportation modes. Section 3 describes the data used for the study, and Section 4 presents the methodology and results. Sections 5 and 6 discuss limitations and overall conclusions relevant to eVTOL air taxi demand, respectively.

2. Literature review

As noted previously, many of the ground-transportation studies are based on surveys and focus on understanding how adoption of these new modes is influenced by modal attributes, such as time and cost, as well as individuals' SED characteristics and attitudes, perceptions, and lifestyle traits. This section provides a broad overview of survey-based research related to UAM and reviews specific studies that have examined factors that influence demand for new transportation modes.

2.1. Survey-based UAM research

Numerous customer surveys of individuals' perceptions and intentions to use eVTOL aircraft have been conducted. Several of these studies are non–peer-reviewed and were conducted by aircraft manufacturers, including Airbus (Yedavalli et al., 2020) and Wisk (2021); potential UAM operators, such as Uber Elevate (Song et al., 2019); management consulting firms, such as Deloitte (Lineberger et al., 2019); and government organizations, such as NASA (Reiche et al., 2018). These studies provide insights into the factors that such sponsors hypothesized would be important for early or large-scale adoption of UAM, including perceptions of safety, willingness to share a flight with other passengers, and community acceptance. However, it is difficult to generalize results from these studies, as many focused on a customer segment that was of interest to the sponsor. For example, in the Uber Elevate study, many respondents were drawn from the Uber customer database, and the mode choice focused on understanding trade-offs among private auto, transit, UberPool, UberX, and UberAir (a new UAM mode). Similarly, in the Wisk study, only those individuals who expressed positive attitudes toward automation and were early adopters of new technology were surveyed.

On the academic side, several peer-reviewed studies have examined factors affecting the use and adoption of UAM. Based on a survey of 4,700 individuals, Ljungholm and Olah (2020) found that 14 percent of respondents would be "ready and comfortable to ride in a flying taxi" right now, 18 percent within the next year, 21 percent within the next five years, 20 percent in more than ten years' time, and 14 percent would never be comfortable. Al Haddad et al. (2020) examined community acceptance of UAM using a technology acceptance model and found that the value of safety is an important component of users' adoption of UAM over time. Eker et al. (2019) examined public perceptions as they pertain to safety and security of flying cars.[3] They found from a survey of 584 individuals in the U.S. that several sociodemographic characteristics influence perceptions toward safety and security, e.g., older individuals tend to be more concerned about safety and security issues. Han et al. (2019) examined customers' decision-making processes for adopting electric airplanes for traditional commercial flights. Based on a survey of 321 airline customers in the U.S. who had used an airline for traveling within the last year, they found that reducing consumers' perceived risk and increasing new product knowledge was critical to increasing the consumers' trust and positive attitudes toward electric airplanes, and their willingness to pay. Ahmed et al. (2021) conducted an online survey of 672 individuals and explored willingness to hire and willingness to pay for flying taxis and other shared flying car services with a correlated grouped random parameters bivariate probit framework. Factors such as respondent age and cost concerns were found to have overall homogeneous negative effects on willingness to pay, whereas perceived benefits including reduced travel time, ability to do non-driving activities during travel, and reduced CO_2 emissions were found to have overall positive effects. Ragbir et al. (2020) conducted two surveys, one in the U.S. (496 participants) and one in India (286 participants), to assess willingness to fly in fully autonomous air taxis in various flight conditions including rain vs. no rain, 5-minute flight vs. 30-minute flight, flight over land vs. over water, and flight over rural area vs. urban area. Assessing the data with a four-way ANOVA, they found that participants in both the U.S. and India were more willing to fly in good weather, for short flights, and over land; however, no statistically significant difference in willingness to fly was found for flights over rural vs. urban areas. The authors also found that willingness to fly was notably higher among Indian participants than U.S. participants.

Additionally, a number of revealed and stated preference surveys have examined UAM mode choice and attempted to quantify potential mode shares for this new mode as a function of time, cost, SED characteristics, and other factors. With respect to stated preference surveys, Fu et al. (2019) modeled mode choice among private car, public transportation, autonomous taxi, and autonomous flying taxis using 248 responses from an online stated preference survey for the Munich area and found that younger individuals and older individuals with higher incomes are more likely to adopt a UAM service during the market-entry stage. Song et al. (2019) estimated a mode choice model that included UAM based on a survey conducted by Uber of 2,607 residents from Dallas–Ft. Worth and Los Angeles (many of which were drawn from the Uber customer database) and found VOTs ranging from 11.15 to 36.78 USD/hour for different travel-time components. Based on a joint stated and revealed preference survey of more than 5,000 individuals in the Greater Jakarta region of Indonesia, Ilahi et al. (2021) estimated a mode choice model that included two emerging modes: on-demand ground transport and UAM, and found that a 1 percent increase in travel cost for UAM would reduce the probability of choosing UAM by 2.07 to 9.55 percent. Haan et al. (2021) developed a measure of demand for air taxi commuting in 40 U.S. cities. They leveraged cell phone data to generate an origin–destination matrix for the total number of commuters in each city to measure market size, and a mode

[3] Flying cars are distinct from eVTOL aircraft in that they can travel both on the ground (as a car) and in the sky (as a plane).

choice model developed from a stated preference survey (1405 participants) and census data to determine market share for the air taxi mode. They found that air taxi commuter demand is largely concentrated in New York, Los Angeles, and Washington, D.C., with lower demand in other major U.S. cities.

Several studies using revealed preference mode choice data have also been adapted for UAM applications with similar goals of quantifying mode shares for UAM or network-level reductions in travel times. For example, Rimjha et al. (2021a, 2021b) estimated mode choice for an air taxi service for commute trips and trips to airports based on revealed preference surveys and datasets. That is, Rimjha and colleagues initially estimated a model based on existing modes and then incrementally added in a UAM alternative to conduct their analysis. They found that UAM demand is highly sensitive to cost, e.g., the number of UAM trips decreases by 34 % when the UAM cost per mile in USD increases from 1.00 to 1.20. Several researchers have also added a new UAM alternative to existing mode choice models that are part of traditional ground-based demand models. For example, Peksa and Bogenberger (2020) estimated demand for a UAM commuter network in Bavaria, Germany, by adding a UAM network with 11 vertiports into the existing ground-transportation model developed in PTV Visum (PTV Group, 2022) for Munich and the surrounding area. The introduction of a UAM network resulted in network-level in-vehicle travel time savings across all modes of about 12,500 h per day for a base scenario. Rothfeld et al. (2021) also added a UAM mode to MATSim, an agent-based travel demand model calibrated for three geographies: the Munich Metropolitan Region, Île-de-France (i.e., the Paris area), and the San Francisco Bay Area. The authors found that the introduction of a UAM alternative would reduce the travel times for 3 percent of motorized trips in Munich, 7 percent in San Francisco, and 13 percent in Paris. Ploetner et al. (2020) added a UAM mode to an existing agent-based model for the Munich Metropolitan Area and examined the sensitivity of UAM demand to different UAM network designs and service levels. They found that UAM market shares were around 1 to 4 percent, depending on the scenario and distance. These studies of market demand for UAM highlight the importance of identifying different market segments (and particularly those with a higher value of time who would be willing to pay for the service) as well as the importance of identifying cities that have a higher potential for shifting modes shares to UAM.

Additionally, a review paper by Garrow et al. (2021) presented a meta-analysis of over 800 papers in the transportation and aerospace literature that includes a review of demand modeling approaches for UAM and a comparison to demand models for autonomous and electric ground vehicles. From the meta-analysis, Garrow and collaborators identified the need for additional research to develop more refined demand models that incorporate the timing of UAM adoption as well as one-way demand and the effect of parking constraints on demand for air taxi services.

2.2. Factors that influence travel behavior and demand for new ground technologies

In addition to survey-based studies specific to UAM, numerous studies conducted for ground transportation have identified factors that influence travel behavior and demand for new transportation modes. Several studies have found that interest in AVs, EVs, and shared modes of transportation is associated with SED characteristics and with attitudes, perceptions, and lifestyle traits. For example, individuals who are younger, more educated, have higher incomes, and are male have been found to have a higher interest in these newer transportation modes (e.g., see Dong et al., 2019; Hudson et al., 2019; Kopp et al., 2015; Liu et al., 2019; Potoglou et al., 2020; Sheela and Mannering, 2020; Spurlock et al., 2019; Vij et al., 2020; Wang and Zhao, 2019).

Numerous studies have found that individuals with pro-environmental attitudes are more likely to prefer EVs and/or AVs over conventional vehicles (Axsen et al., 2016; Biresselioglu et al., 2018; Kim et al., 2015; Potoglou et al., 2020; Smith et al., 2017; Sovacool et al., 2019; Tsouros and Polydoropoulou, 2020). Tech-savvy individuals and those who are early adopters of new technology have also been found to be early adopters of EVs or to have higher intentions of using AVs (Axsen et al., 2016; Bennett et al., 2019; Biresselioglu et al., 2018; Lee et al., 2020; Potoglou et al., 2020; Sweet and Laidlaw, 2019). At least one study (Rahimi et al., 2022) has found that a pro-multitasking attitude (as well as a pro-technology orientation) is positively associated with the willingness to pay for an AV.

Similarly, trust in new technology has been found to affect the adoption of new transportation modes, as trust in technology plays a major role in an individual's willingness to accept automation (Choi and Ji, 2015; Merat et al., 2016; Rahimi et al., 2022). This level of trust may be influenced by perceived passenger security and safety (Piao et al., 2016), the manufacturer's reputation (Deloitte Analytics Institute, 2017), or cybersecurity and data concerns (Kyriakidis et al., 2015).

Several studies have focused on the willingness of individuals to travel with strangers, and while some of those indicate a higher willingness to pay to travel alone, the result is not consistent. For example, Nielsen et al. (2015) found that in Denmark, some individuals did not want to share a ride with strangers due to "social awkwardness," whereas others viewed sharing a ride as an opportunity to "socialize" with others. Lavieri and Bhat (2019) found that individuals in the Dallas–Ft. Worth area were less sensitive to the presence of strangers when in a commute trip compared to a leisure-activity trip. The willingness to travel with strangers may also be related to modes, given that individuals are more accustomed to traveling with strangers by air than in an automobile.

A few studies have addressed the adoption of AVs by (or for) vulnerable users. For example, Lee et al. (2020) investigated US parents' willingness to allow AVs to transport their children. They found that greater willingness was associated with lower levels of concern about AVs' safety, greater comfort with technology, being male, being younger, living in an urban area, the child being older, and the child being male, among other factors. The age, income, education, and AV awareness of the respondents did not significantly differentiate between having low and high willingness. Bennett et al. (2020) modeled the willingness to travel in an AV of 211 blind people in the UK. Willingness was positively associated with optimism about the personal benefits of AVs (hope), a desire for independence, self-efficacy (internal locus of control), and presence of comorbidities. It was negatively associated with concerns about safety and affordability. Neither demographic variables (including age, gender, income, education, and ethnicity), length of time being blind, nor frequency of travel significantly influenced willingness.

The influence on travel behavior of a number of other attitudes, perceptions, and lifestyle traits has also been explored by research in ground transportation. For example, prior surveys have examined how one or more aspects of travel behavior are influenced by residential and mode choice preferences (Circella et al., 2021; Mokhtarian et al., 2001; Nielsen and Haustein, 2018), a predisposition for motion sickness (Kim et al., 2019b), opinions related to the perceived need to own and use an auto (Alemi et al., 2019; Kim et al., 2019b; Nielsen and Haustein, 2018; Sweet and Laidlaw, 2019), the perceived safety of different modes and trustworthiness of other individuals (Choi and Ji, 2015; Dong et al., 2019; Lavieri and Bhat, 2019; Liu et al., 2019), and preferences for being a driver or passenger (Circella et al., 2021; Haboucha et al., 2017; Kyriakadis et al., 2015). Several studies have also examined how a leisure-

Table 1
SED and typical commuting and air travel characteristics of the sample.

Characteristic	Category	Number (%)
Annual individual income (USD)	\$100–149.9 K	1,375 (55.0)
	\$150–199 K	598 (23.9)
	\$200 K or more	526 (21.0)
Gender	Female	1,173 (46.9)
	Male	1,326 (53.1)
Age (years)	18–24	101 (4.0)
	25–34	395 (15.8)
	35–44	652 (26.1)
	45–54	607 (24.3)
	55–64	559 (22.2)
	65+	159 (6.4)
	Unknown	26 (1.0)
Number of adults in household	1 adult	381 (15.2)
	2 adults	1,631 (65.3)
	3 or more adults	466 (18.6)
	Unknown	21 (0.8)
Number of children in household	No children or missing data	1,367 (54.7)
	1 child	464 (18.6)
	2 children	487 (19.5)
	3 or more children	181 (7.2)
Highest educational level	Some college with no degree, or less education	267 (10.7)
	Associate's degree	140 (5.6)
	Bachelor's degree	1,070 (42.8)
	Master's degree	667 (26.7)
	Professional or doctorate degree	355 (14.2)
Number of household vehicles	No vehicles	31 (1.2)
	1 vehicle	668 (26.7)
	2 vehicles	1,247 (49.9)
	3 or more vehicles	553 (22.1)
Owns a hybrid vehicle	Owns hybrid	449 (18.2)
	Does not own hybrid	2,019 (81.8)
	Not relevant as does not own a vehicle	31 (1.2)
Number of annual air trips	1 roundtrip (RT) per week or more	146 (5.8)
	1–3 RTs per month	434 (17.4)
	7–11 RTs per year	554 (22.2)
	1–6 RTs per year	1,079 (43.2)
	Fewer than 1 RT per year	286 (11.4)
Typical mode to work	Auto and other (e.g., motorcycle, vanpool)	2,093 (83.8)
	Transit	219 (8.8)
	Bike or walk	84 (3.4)
	Rideshare	95 (3.8)
	Unknown	8 (0.3)
Rideshare usage	Never	575 (23.0)
	At least once a week	262 (10.5)
	2–3 times per month	475 (19.0)
	Once a month	270 (10.8)
	4–11 times per year	321 (12.8)
	2–3 times per year	346 (13.8)
	Once a year or less	250 (10.0)
Typically makes stops on way to work	Yes	847 (33.9)
	No	1,652 (66.1)
Congestion level near home when leaving for work	Little to no congestion	951 (38.1)
	Minor congestion	742 (29.7)
	Moderate congestion	577 (23.1)
	Heavy congestion	229 (9.2)
Self-reported one-way travel time to work	1–19 min	446 (17.8)
	20–39 min	714 (28.6)
	40–59 min	667 (26.7)
	60–89 min	476 (19.0)
	90+ minutes	196 (7.8)

oriented lifestyle, time pressure, and general sense of well-being influence travel (e.g., Circella et al., 2021; Haboucha et al., 2017; Mokhtarian et al., 2001; Neufeld and Mokhtarian, 2012; Sweet and Laidlaw, 2019).

In summary, both market demand for new transportation modes and travel behavior have been shown to be influenced by multiple factors. Results from ground transportation may be valuable to the UAM community, but there is a need to conduct more survey-based research for UAM demand studies to better understand the characteristics of its potential users, including their attitudes toward UAM and their inclination to adopt such services. Our paper contributes to this research area by providing a market segmentation analysis for UAM commuting demand, using constructs to capture various attitudes, perceptions, and lifestyle traits that have been previously shown in the literature to be important for describing travel behavior.

3. Empirical setting

The data analyzed in this study were collected from April to June 2018 using an internet-based survey of commuters from five large U.S. cities. Respondents were recruited through an online opinion panel service provider. To minimize the nonresponse bias associated with people who have a low interest in such a service declining to take a survey about it, the recruitment message simply told individuals that the purpose of the survey was to "understand your daily travel patterns" and would ask "about your attitudes and current travel patterns." To use the limited budget for understanding the individuals that have the greatest motivation and financial ability to choose the new service for commuting purposes, only those who were full-time workers, traveled to a work location outside the home at least two days per week, and had an annual personal income of at least $100 K were eligible to participate in the study. Initially, the study targeted individuals with one-way commute times of at least 45 min, but due to recruiting difficulties, this criterion was relaxed during the survey execution period. The survey provider had been instructed to lower the threshold to 30 min, but a review of the responses shows that this criterion was eliminated altogether. Nevertheless, 49.4 percent of the sample commutes at least 45 min, and 68.6 percent commutes at least 30 min.

The analysis database includes 2,499 respondents who reside and work in the Atlanta, Boston, Dallas–Ft. Worth, San Francisco, or Los Angeles combined statistical areas (CSAs). A total of 499 responses were obtained for Atlanta and 500 responses from each of the other CSAs. The cities included in the study represent distinct morphologies and transportation infrastructures. Atlanta and Dallas are both radial cities with no geographic boundaries to limit outward expansion. Boston, San Francisco, and Los Angeles are coastal cities that have geographic features affecting commute patterns and commute times. For example, the San Francisco Bay only has four bridges connecting the East Bay to areas in San Francisco and the cities of Silicon Valley. Uber had selected two cities in the U.S. for testing eVTOL flights; both of these cities (Dallas and Los Angeles) are included in this study.

The survey instrument contained multiple sections (Binder et al., 2018); we focus here on three sections that were used for the market segmentation analysis. The first of these sections asked questions about respondents' current commute and air travel, and collected SED information. The second section asked respondents about their views on a variety of issues directly or indirectly related to travel, with several questions focused on attitudes, personality, and lifestyle characteristics. The third section introduced the concept of eVTOL aircraft, and individuals were asked for their opinions about three conceptual constructs related to eVTOL aircraft: battery technology, proximity of the service, and overall impressions.

Table 1 shows the SED and typical commuting and air travel characteristics of the sample, which were compared to "population" data as represented by the U.S. census. The sample is relatively balanced in terms of gender. As expected, the share of people attaining the highest educational level (which is typically correlated with income) is greater in the sample data than in the census data. A larger percentage of two-adult households is found in the sample data, although the frequency distributions for the number of children are similar in each. A larger percentage of individuals in the age range of 25–64 is found in the sample (and smaller percentages of individuals in the age ranges of 18–24 and 65+) compared to the census data, which would be expected given that requirements for the study included that individuals be working full-time and earn at least $100 K a year. In the sample, 84 percent of respondents typically commute in an auto, 9 percent by transit, 3 percent by biking or walking, and 4 percent by ride-hailing, which is similar to the shares reported in the census for these areas. Vehicle ownership is higher in the sample, with just 1.2 percent of households not owning a vehicle, compared to 9.5 percent based on census data for these regions. Respondents were much more likely to have used ride-hailing modes, with 77 percent having done so, compared to 40 percent in the 2017 National Household Travel Survey (NHTS, 2018). This ride-hailing experience is relevant because phone apps similar to those used by current TNCs have been envisioned for air taxi service. Similarly, almost one in five respondents owns or leases a hybrid vehicle, which is important from the standpoint that these respondents have experience with ground vehicles partially powered by batteries—another one of the technologies envisioned for air taxi aircraft.

Although the sample is not representative of the population in every way, the primary purpose of this study is to uncover relationships among variables rather than purely to describe a population (Babbie, 2009; Groves, 1989, Chapter 1). For example, if the sample were used to estimate the true share of various incomes in the population, the lack of a fully representative sample would be problematic, but a model based on the sample can properly predict commuting air taxi usage *given income*. Nevertheless, since a key purpose of the present paper is to describe market segments, it must be recognized that the sample is only intended to represent the *portion* of the entire population that has relatively high incomes and relatively long commutes.

Table 2 summarizes 14 constructs we used to capture individuals' views on a variety of issues directly or indirectly related to travel. We hypothesized that various travel, personality, and lifestyle constructs could help identify different market segments for an eVTOL taxi service. We then identified these constructs through a review of the literature discussed in Section 2.2. The constructs reflect individuals' mode preferences (via the mode preference construct, as well as the car-oriented, motion sickness, ride-hailing convenience, driving/car safety, control, and trust constructs); perception of their current commutes (commute benefit construct); attitudes

Table 2
Attitudinal statements related to travel, personality, and lifestyle traits in the survey, grouped by initial construct.

Constructs and Associated Attitudinal Statements
Car-oriented
I am fine with not owning a car, as long as I can use/rent one any time I need it[a]
I need a car while I am at work[b]
Mode preference
I prefer to walk rather than drive whenever practical[c]
I would prefer to take transit rather than drive whenever practical[b]
I would take transit more often if I had a guaranteed ride home when I had to leave work late
Traveling by air makes me nervous
I like traveling by airplane
Motion sickness
I would tend to feel sick if I tried to read while in a plane[a]
Ride-hailing convenience
Using a ride sharing service, such as Lyft or Uber, is more convenient overall than driving
If I were to use a ride sharing service, such as Lyft or Uber, I would have to wait too long to be picked up
Driving/car safety
Traveling by car is safer overall than taking transit[b]
Using a ride sharing service, such as Lyft or Uber, is safer overall than driving[b]
Control
I would usually rather have someone else who is trustworthy do the driving[d,e]
Being in a car makes me nervous if someone else is driving[d,f]
Trust
People are generally trustworthy[g]
Commute benefit
My trips to and from work are generally pleasant
My trips to and from work are stressful
Pro-environment
I rarely consider the impact of the environment in my daily choices[h]
I limit my driving to help improve air quality[e]
Technology
My phone is so important to me, it's almost a part of my body[a]
I'm worried that technology invades my privacy too much
Early adopter
I often introduce new trends to my friends or family[a,c,g]
I like to wait a while rather than being first to buy new products[a]
Leisure-oriented lifestyle
At this stage in my life, having fun is more important to me than working hard[e,i]
I'm too busy to do many of the things I'd like to do[c,f]
Pro-high density
I like the idea of living somewhere with large yards and lots of space between homes[c]
I like the idea of living in a neighborhood where I can walk to shops[e]
Subjective well-being
I am generally satisfied with my life[e]

Sources: [a]Kim et al. (2019b)[b]Handy et al. (2005)[c] Neufeld and Mokhtarian (2012)[d] Haboucha et al. (2017) [e] Mokhtarian et al. (2001) [f] Circella et al. (2021) [g] Mokhtarian et al. (2009) [h] Al Haddad et al. (2020) [i] Sweet and Laidlaw (2019).

toward the environment (pro-environment construct); attitudes toward new technologies (technology and early adopter constructs); and time pressures (leisure-oriented lifestyle construct). Constructs related to residential location preferences and general well-being were also included (pro-high density and subjective well-being constructs, respectively). Twenty-one of the 28 statements included on the survey (see Table 2) were taken directly from the literature; the seven new statements we designed capture opinions that are of particular interest to the current study, i.e., attitudes toward air travel, perceptions related to the convenience of ride-hailing services, and beliefs about whether commuting is stressful.

The travel, personality, and lifestyle traits shown in Table 2 formed the basis for one factor analysis. Individuals' reactions to, and perceptions of, a new eVTOL service formed the basis of the second factor analysis. For contextual purposes, it is helpful to review the description of the eVTOL aircraft as it was presented to respondents:

"*NASA and many companies are spearheading research to develop an air taxi service for cities. The aircraft:*

- Are battery powered
- Carry two to four passengers
- Travel within a city at cruise speeds of 150 mph
- Could be used for getting to and from work faster
- Have efficient security checks with no lines
- Take off and land vertically like a helicopter
- Take off and land at locations in a city such as tops of buildings and parking decks
- Have a ride quality and cabin noise level similar to large aircraft

- Are much quieter than helicopters, both for the community and for the occupants of the aircraft
- Travel at about the altitude where traffic helicopters fly
- Are flown by certified pilots
- Do not fly in hazardous weather conditions (such as thunderstorms)
- Meet stringent safety requirements mandated by the U.S. Federal Aviation Administration"

Several points merit further discussion. First, we intentionally noted "NASA and many companies" in the positioning as this is reflective of what is occurring, with the U.S. National Aeronautics and Space Administration playing an important role in UAM development. Based on a meta-analysis of unique authors who published UAM-related work in the American Institute of Aeronautics and Astronautics (AIAA) database from 2015 to June 2020, Garrow et al. (2021) found that 31 percent were affiliated with NASA. Second, while there are varying opinions among aircraft manufacturers regarding whether eVTOL vehicles will ultimately be flown autonomously or with a pilot, the Federal Aviation Administration (FAA) has clarified the expectation that initial air taxi operations in the U.S. will be conducted with an onboard human pilot (FAA, 2023). Some of the other statements, such as "efficient security checks with no lines," are favorable to UAM, which was a conscious design decision on our part.[4] Given uncertainty as to whether UAM will even be a viable mode of transportation, as well as uncertainty about how operational details such as security checks will operate, we designed the survey to lean a bit positive in the description of UAM. The rationale is that if we found from the survey that there is insufficient interest in UAM even under these favorable circumstances, then there would be no need to delve further into more refined questions such as the actual time needed for security checks.

Table 3 summarizes three constructs that were used to capture individuals' views on eVTOL aircraft. The constructs relate to battery technologies, pros/cons of proximity, and overall impressions. Note that, notwithstanding the favorable-leaning description of the service, the assessment of respondents' perceptions of the technology included equal numbers of negatively- and positively-oriented attitudinal statements, signaling respondents that it was "okay" to dislike the technology.

4. Methodology and results

Fig. 1 provides an overview of the methodology employed in the study. Specifically, it illustrates how the survey data were used to identify market segments for a commuting air taxi service and how these market segments are associated with various attitudes, preferences, SED characteristics, previous air travel and commute patterns, and other variables. In this section we interlace methodology and results, presenting each major step of the methodology followed by the results of that step, so the reader can immediately apprehend the application of the method in question. We first discuss the factor analysis, followed by the cluster analysis, and finally an analysis of the resulting cluster profiles (market segments).

4.1. Factor analysis

4.1.1. Choosing and interpreting the number of factors

As mentioned previously, two exploratory factor analyses (EFAs) were conducted: one involving general opinions about travel as well as personality and lifestyle constructs, and the second related to eVTOL aircraft. In designing the attitudinal portion of the survey and conducting the subsequent analyses of this paper, the methodology used by Mokhtarian et al., 2009 was followed. For the fourteen original travel, personality, and lifestyle constructs and three original aircraft constructs, at least one positively oriented and at least one negatively oriented statement for each construct was included; the only exceptions were for the constructs of motion sickness, trust, and subjective well-being, which did not naturally lend themselves to generating two statements (see Tables 2 and 3 for a list of these statements and their corresponding constructs). Although the literature recommends including three to five statements for each construct (e.g., see Fabrigar et al., 1999), in view of the large number of constructs included on the survey (and consistent with the discussion in Dolnicar (2013)) the number of statements per *initial* construct was limited to two in most cases to reduce respondent fatigue. Also taken into account was the expectation that, since some of the constructs were related, they were likely to combine in the empirical analysis, and indeed, all but one of the *final* factors have three or more statements loading on them.

To condense the larger sets of interrelated statements into smaller sets of more distinct constructs to facilitate the market segmentation analysis and future demand models, common factor analyses using oblique rotation (Rummel, 1970) were conducted using SPSS (IBM, 2018). To select a preferred factor solution, the study first identified the number of factors with initial eigenvalue greater than or close to 1 and examined the scree plot, which graphs the factor number against the percentage of variance explained by the associated factor. The "elbow rule" was used with the scree plot to determine at which point additional factors did not explain much variability in the data. Information about the eigenvalues and scree plot was used to suggest a maximum number of factors to include in the final solution. The pattern matrix of the obliquely rotated factor loadings was examined to evaluate whether the factor interpretations were intuitive.[5] The factor correlation matrix was then inspected to determine if any factors were highly correlated

[4] It is also notable that within the U.S., regulations pertaining to security for boarding aircraft with nine or fewer passengers allow security checks to be done directly by the pilot. While the pilot may not ultimately handle security measures implemented as part of a UAM system, there is a regulatory precedent from helicopter and related charter services that support efficient security-line processes and motivated the inclusion of this statement on the description.

[5] Specifically, high-magnitude factor loadings signify a strong association between the corresponding item and factor, and therefore factors were interpreted on the basis of what their highly-loading items had in common.

Table 3
Attitudinal statements in the survey related to eVTOL perceptions, grouped by initial construct.

Constructs and Associated Attitudinal Statements
Battery technology
I like the idea of battery-powered aircraft for helping the environment
I would be afraid to travel in a battery-operated aircraft
Proximity
I like that these aircraft can take off and land close to my home and work locations
I would be afraid to fly in an aircraft that takes off and lands vertically within a city with tall buildings
Overall impressions
I would find it exciting to travel in one of these eVTOL aircraft
These aircraft would cause more problems than they would solve

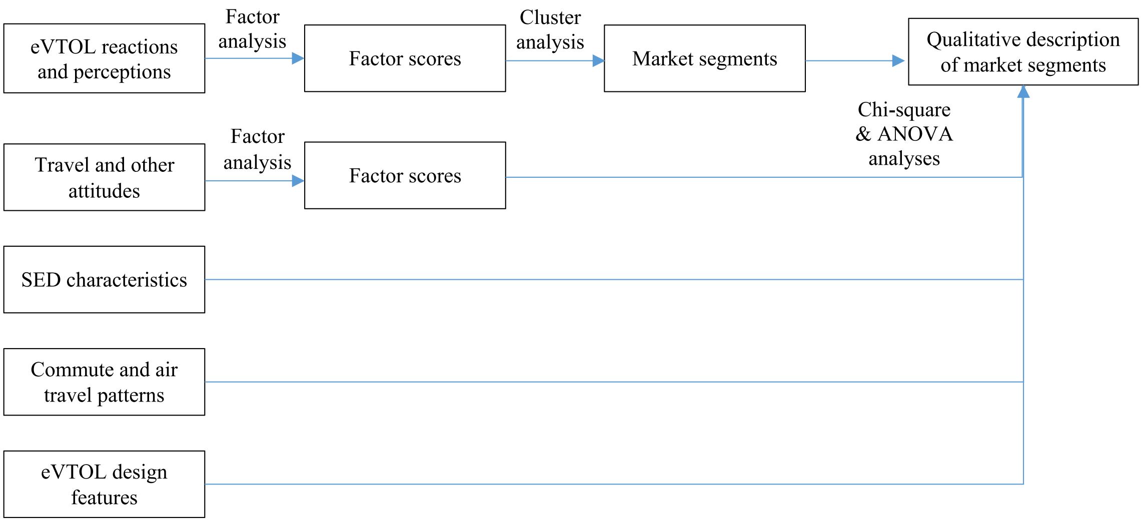

Fig. 1. Methodological overview of market segmentation analysis.

(which could create collinearity issues in later demand modeling activities). The study iterated through several choices for number of factors to deal with interpretability issues, including removal of items that did not load highly on any factor, and sometimes testing their re-inclusion with a different number of factors. Eventually, a final preferred solution was chosen for which all retained items had loadings of at least 0.30 in magnitude on at least one factor; the 0.30 threshold for factor loadings is consistent with the cutoff suggested by a number of factor-analysis scholars in the context of exploratory attitudinal measurement, including Child (1990) and Fabrigar et al. (1999). Then, Bartlett scores on each factor for each person were produced and saved for subsequent analysis.

4.1.2. Results for the travel, personality, and lifestyle constructs

The survey contained 28 attitudinal items, initially conceptually associated with 14 travel, personality, and lifestyle constructs. As shown in Fig. 2, the eigenvalue-greater-than-1 criterion pointed to six or seven factors, while the scree plot had an elbow at seven, which pointed to retaining six factors (Costello and Osborne, 2005). The eight-factor and seven-factor solutions were less robust and interpretable. The preferred six-factor solution provided intuitive results and eliminated just four of the original 28 statements; the solution accounted for 38.2 percent of the variance in the data. The three highest correlations between the scores on any two factors in the preferred solution were 0.20, 0.16, and 0.10; all other correlations were between −0.10 and 0.08.

For completeness, we show all of the items included in the survey on Table 4 organized by the initial constructs, including four statements that did not have any factor loadings higher than 0.30 in magnitude and were excluded from the final specification. Table 4 is helpful for evaluating the results of the factor analysis, specifically by visualizing the relationships between the initially conceived constructs and the empirically derived ones. Table 4 also helps to visualize which statements loaded onto factors and how many times a particular statement loaded onto multiple factors.

The first factor, labeled Pro-collective Modes, has six items with loadings of 0.30 or more associated with it. These items include statements favorable toward transit and ride-hailing, as well as expressing a willingness not to own a car and a preference for not driving. The Dislike of Flying factor has positive factor loadings for statements relating to being nervous or feeling sick if reading when flying, and a negative loading associated with the statement “I like traveling by airplane.” The Low Stress Commuting factor is positively associated with commuting being pleasant, and negatively associated with it being stressful. The Pro-Car factor has seven items loading on it, all positively. The items relate to needing a car for work, considering driving safer than transit, and not wanting to

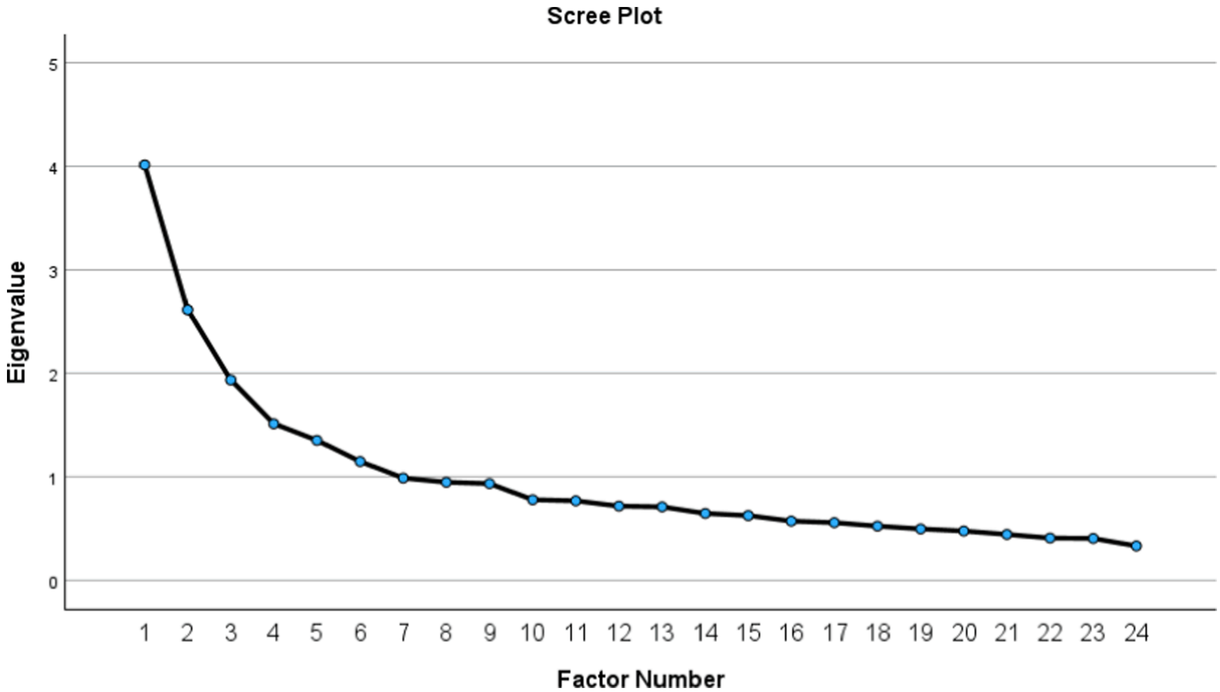

Fig. 2. Scree plot for the factor analysis of the travel opinion, personality, and lifestyle statements.

wait for a ride-hailing pickup, but also include some broader lifestyle markers, such as liking air travel, preferring lower-density residential environments, being an early adopter of new trends, and generally being satisfied with life.

The Pro-Environment factor displays positive loadings for statements associated with preferring transit or walking over driving, and limiting one's driving for environmental reasons. The factor also has negative loadings for the statements "I rarely consider the impact of the environment in my daily choices" and "Traveling by car is safer overall than taking transit." Interestingly, the Pro-Environment factor was found to be important in both the UAM context as well as other studies, as reviewed in Section 2, in the context of AVs, EVs, and shared mobility. Finally, the Technologically Cautious factor has positive loadings associated with privacy concerns and preferring to wait a while before buying new products, and a negative loading associated with introducing new trends to friends or family. The Technologically Cautious factor is also common across the UAM and ground-transportation studies, as reviewed in Section 2.

Overall, although the factors did not reproduce the hypothesized constructs completely faithfully,[6] they did capture some well (notably the Low Stress Commuting and Technologically Cautious factors), and the original constructs recombined in logical ways to form the remaining factors. Only two of the original fourteen constructs failed to associate with any factors—those of leisure-oriented lifestyle and trust. The latter outcome is not surprising, given that only one of the twenty-eight items pertained to trust.

4.1.3. *Results for the eVTOL perceptions*

Although three conceptual eVTOL perception constructs of interest were initially identified (i.e., reaction to battery technologies, pros/cons of proximity, and overall impressions), the factor analysis empirically identified two factors: as shown in Fig. 3, two factors had initial eigenvalues greater than 1 and the scree plot also revealed a clear elbow below two factors. Given that the pattern matrix for this two-factor solution was intuitive and all statements had loadings of 0.30 or higher, this was selected as the final preferred solution. Together, these two constructs explained 54.2 percent of the variance in the data,[7] and the correlation between the resulting scores on the two factors is −0.41. Given the large sample size (2,499), a correlation of this magnitude is not expected to be problematic in future analyses.[8] Allowing this moderate correlation is considered preferable so as to reflect the natural relationship between the two identified constructs, rather than distorting that relationship by forcing them to be orthogonal.

[6] Exploratory factor analysis is a different approach to attitude measurement than confirmatory factor analysis. With EFA, it is very common that factors do not come out exactly as envisioned. However, as long as the factors are interpretable and logical, they are perfectly usable for the desired purpose of measuring pertinent latent constructs.

[7] For an oblique rotation, it is not appropriate to separate the total amount of variance explained into factor-by-factor amounts because the correlation of the factors means that a given factor is partly accounting for other factors' variance as well as its own.

[8] Conventional wisdom (e.g., Kennedy, 2008, Chapter 12) indicates that if expected relationships are statistically significant even in the presence of multicollinearity, there is no need to worry about it. Given that larger samples yield smaller standard errors, which improves statistical significance, a sample this large gives little cause for concern about the effects on future analyses of a moderate correlation between the two factors.

Table 4

Rotated factor loadings (pattern matrix) by original statement category for travel opinions, personality, and lifestyle constructs (N = 2,499). Note: hyphens signify loadings less than 0.30 in magnitude, which are suppressed from the display to facilitate interpretation. Items marked with * did not load strongly on any factor and were removed from the final specification.

Survey Statement	Factor Loadings					
	Pro-Collective Modes	Dislike of Flying	Low-Stress Commuting	Pro-Car	Pro-Environment	Technologically Cautious
(1) Car-oriented						
I am fine with not owning a car, as long as I can use/rent one any time I need it	0.541	–	–	–	–	–
I need a car while I am at work	–	–	–	0.385	–	–
(2) Mode preference						
I prefer to walk rather than drive whenever practical	–	–	–	–	0.544	–
I would prefer to take transit rather than drive whenever practical	0.420	–	–	–	0.490	–
I would take transit more often if I had a guaranteed ride home when I had to leave work late	0.396	–	–	–	–	–
Traveling by air makes me nervous	–	0.778	–	–	–	–
I like traveling by airplane	–	−0.522	–	0.334	–	–
(3) Motion sickness						
I would tend to feel sick if I tried to read while in a plane	–	0.511	–	–	–	–
(4) Commute benefit						
My trips to and from work are generally pleasant	–	–	0.754	–	–	–
My trips to and from work are stressful	–	–	−0.772	–	–	–
(5) Pro-environment						
I rarely consider the impact of the environment in my daily choices	–	–	–	–	−0.370	–
I limit my driving to help improve air quality	–	–	–	–	0.447	–
(6) Driving/car safety						
Traveling by car is safer overall than taking transit	–	–	–	0.420	−0.335	–
Using a ride-sharing service, such as Lyft or Uber, is safer overall than driving	0.737	–	–	–	–	–
(7) Ride sharing convenience						
Using a ride-sharing service, such as Lyft or Uber, is more convenient overall than driving	0.737	–	–	–	–	–
If I were to use a ride-sharing service, such as Lyft or Uber, I would have to wait too long to be picked up	–	–	–	0.335	–	–
(8) Control						
I would usually rather have someone else who is trustworthy do the driving	0.651	–	–	–	–	–
Being in a car makes me nervous if someone else is driving	–	0.374	–	–	–	–
(9) Leisure-oriented lifestyle						
At this stage in my life, having fun is more important to me than working hard*	–	–	–	–	–	–
I'm too busy to do many of the things I'd like to do*	–	–	–	–	–	–
(10) Pro-high density						
I like the idea of living somewhere with large yards and lots of space between homes	–	–	–	0.386	–	–
I like the idea of living in a neighborhood where I can walk to shops	–	–	–	–	0.394	–
(11) Technology						
My phone is so important to me, it's almost a part of my body*	–	–	–	–	–	–
I'm worried that technology invades my privacy too much	–	–	–	–	–	0.311
(12) Early adopter						
I often introduce new trends to my friends or family	–	–	–	0.372	–	−0.440
I like to wait a while rather than being first to buy new products	–	–	–	–	–	0.696
(13) Subjective well being						
I am generally satisfied with my life	–	–	–	0.300	–	–
(14) Trust						
People are generally trustworthy*	–	–	–	–	–	–

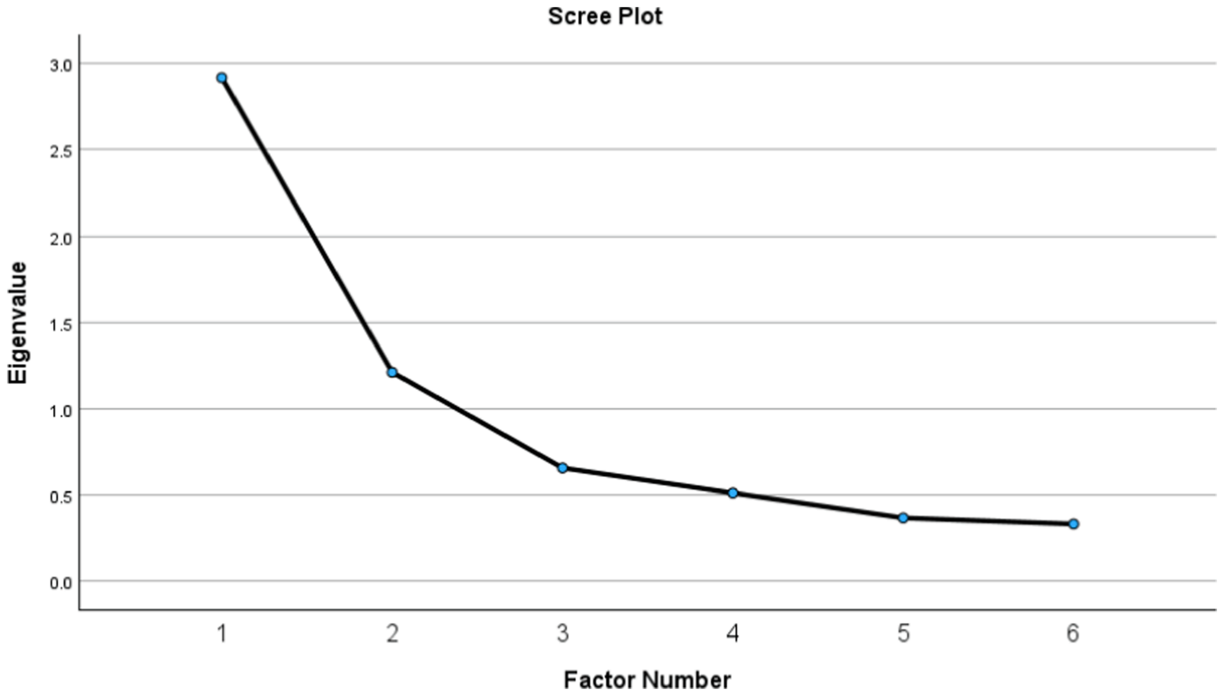

Fig. 3. Scree plot for the factor analysis of the eVTOL perceptions.

Inspection of the factor loadings shown in Table 5 indicates that one factor (i.e., Concern) captured all the negatively oriented items, and the other (i.e., Enthusiasm) captured the positively oriented ones. We find this result to be conceptually satisfying, as it reflects the reality that a given person can perceive both positive and negative aspects of the technology, rather than assuming that if she agrees with a positive statement she must tend to disagree with a negatively oriented one. Specifically, the two statements relating to being afraid of eVTOLs and the one statement saying such aircraft "would cause more problems than they would solve" all loaded heavily onto the eVTOL Concern factor. Conversely, the statements referring to eVTOLs helping the environment, taking off and landing at convenient locations, and being an exciting way to travel all loaded heavily onto the eVTOL Enthusiasm factor.

4.1.4. Calculation of non–mean-centered factor scores

When factor scores are created, they are nearly always mean-centered (and often fully standardized). In practice, the responses to the original attitudinal items or statements (which, in this case, are measured on a Likert-type scale for which 1 = strongly disagree, …, 5 = strongly agree) are first themselves standardized (in the usual fashion, by subtracting the sample mean and dividing by the sample standard deviation for each item)—call them "Z-items." Then, at the conclusion of the factor analysis, scores for each person, on each factor in the desired solution, are formed as weighted linear combinations of the individual's Z-items, where the weights (referred to as "factor score coefficients") are larger for items that are more strongly associated with the factor in question (as indicated by the magnitudes of the *loadings* of each item on the factor, such as those shown in Table 2 for the two eVTOL perception factors). Because each Z-item has a mean of zero, any linear combination of Z-items, i.e., any factor score created from them, will also have a mean of zero.

In addition to the computational convenience of having standardized scores, we speculate that a conceptual reason for mean-centering is the supposition that attitudes, being subject to context effects, social desirability biases, and other sources of volatility, do not have an "absolute zero," but rather can only be measured relative to the attitudes of other people. On the other hand, however, standardizing the raw item responses destroys the ability to detect any "overall leanings" in the sample—all responses are measured relative to the sample mean for that item, even if that mean is markedly positive or noticeably negative with respect to the item in question. As a result, "using the zero mean [of a mean-centered factor score] as the cutpoint will generally separate the sample into two roughly balanced groups for a given factor… [which can be] conceptually unsatisfying" (Deng et al., 2015, p. 8). For example, in this study's application, the majority of respondents agreed or strongly agreed with the item "I like that these aircraft can take off and land close to my home and work locations," representing an aspect of enthusiasm for the eVTOL aircraft that we would want our factor scores to reflect. Yet, since the sample mean for that item is 4.1 (see Table 6), then a response of "agree" (=4) would translate to a *negative* Z-item value, because it is below the mean. In turn (given its positive coefficient for the Enthusiasm factor, as shown in Table 6), an "agree" response on this item would, therefore, counterintuitively contribute *negatively* to the Enthusiasm factor score. Thus, while acknowledging the merits of the conventional approach, this study investigates an alternative that preserves the *prima facie* content of individuals' original responses to the raw items.

In a little-known brief research note, Thompson (1993) proposes a simple non–mean-centered (NMC) alternative to the traditional

Table 5
Rotated factor loadings (pattern matrix) for eVTOL perception constructs (N = 2,499).

Attitudinal Statement (*Initial Construct*)	Factor Loading Concern	Enthusiasm
I like the idea of battery-powered aircraft for helping the environment (***Battery technology***)	0.018	0.558
I would find it exciting to travel in one of these eVTOL aircraft (***Overall impressions***)	−0.064	0.767
I like that these aircraft can take off and land close to my home and work locations (***Proximity***)	0.018	0.800
I would be afraid to travel in a battery-operated aircraft (***Battery technology***)	0.761	0.016
These aircraft would cause more problems than they would solve (***Overall impressions***)	0.618	−0.086
I would be afraid to fly in an aircraft that takes off and lands vertically within a city with tall buildings (***Proximity***)	0.845	0.051

mean-centered (MC) factor scores. As described by Thompson and applied by Deng et al. (2015) and Kim et al. (2020), to compute NMC factor scores, variables are first standardized by converting them to Z-items. Then the original variables' means are added back onto the Z-items so that the transformed variables still have unit variances,[9] but their distributions are now centered around the original means of the raw variables (rather than centered around zero). Finally, because a simple horizontal shift does not change the association of the item with the factor, the non–mean-centered Z-items are linearly combined by applying the same factor-score coefficients that were used to create the mean-centered factor scores, to compute the NMC factor scores. Mathematically, for a given factor, the respective equations for the mean-centered and non–mean-centered scores are:

$$MC = \sum_{j=1}^{6} Z_j \, FSC_j \tag{1}$$

$$NMC = \sum_{j=1}^{6} (Z_j + \overline{X}_j) \, FSC_j = \sum_{j=1}^{6} Z_j \, FSC_j + \sum_{j=1}^{6} \overline{X}_j \, FSC_j = MC + \sum_{j=1}^{6} \overline{X}_j \, FSC_j \tag{2}$$

where Z_j is the standardized form of item j, $\overline{X}_j$ is the mean of (the unstandardized) item j, and FSC_j is the factor score coefficient for item j.

Table 6 provides a comparison of MC and NMC scores on the eVTOL Enthusiasm factor, assuming the respondent answered "neutral" (i.e., 3) for all six of the pertinent items. Because neutral is below the mean responses for the items loading most strongly on this factor (the first three items), the conventional mean-centered factor score for this putatively neutral respondent is actually substantially negative, at −1.28. Thus, taking "neutral" at face value should mean that any MC factor score above −1.28 should be considered Enthusiastic, whereas the mean-oriented perspective would require the MC score to exceed 0 for that to be the case.[10]

Following the steps presented in Table 6, it can be shown that *mean* responses on each item (which would yield an MC score of 0, for *both* factors) translate to an NMC *Enthusiasm* score of 5.25 and an NMC *Concern* score of 3.47. In fact, the equations above show that:

$$\mathrm{NMC}_{\mathrm{Concern}} = \mathrm{MC}_{\mathrm{Concern}} + 3.47 \text{ and } \mathrm{NMC}_{\mathrm{Enthusiasm}} = \mathrm{MC}_{\mathrm{Enthusiasm}} + 5.25 \tag{3}$$

for *every* case. That is, the non–mean-centering operation simply translates all conventional scores on a given factor by the same fixed quantity, $\sum_{j=1}^{6} \overline{X}_j FSC_j$.

4.2. Cluster analysis

The results of the factor analysis for the aircraft constructs provide a useful framework for conceptualizing potential market segments. For example, individuals who have high Enthusiasm and low Concern may be more likely to be early adopters of air taxi service, those with high Enthusiasm but high Concern may need incentives, and those with low Enthusiasm and high Concern may be late adopters or never adopt the air taxi service. Those with low Concern and low Enthusiasm may be indifferent.

Accordingly, once the factor analysis was completed, a cluster analysis on the aircraft constructs was conducted to identify market segments that differed in their levels of Concern and Enthusiasm for eVTOL air taxis. Applying the *K*-means clustering technique in SPSS (IBM, 2018), solutions were produced for predefined numbers of clusters ranging from two to eight. Consistent with Mokhtarian et al., 2009, the number of clusters was selected based primarily on the criteria of interpretability and ability to maintain statistically robust sample sizes; our final preferred solution has six clusters. Fig. 4 (MC) and Fig. 5 (NMC) plot the six clusters based on the eVTOL

[9] Maintaining a standard variance is especially important when the variables are measured on substantially different scales, but even when measured on the same scale, as is the case here, allowing the variances to differ would change the appropriate factor score coefficients.

[10] Similarly, from the NMC perspective, the non–mean-centered score for the all-neutral respondent is 3.97, signifying that in this application, an individual would be considered Enthusiastic if her non–mean-centered score on that factor is greater than 3.97. In particular (calculations not shown), someone with *mean* values on each item (which are higher than neutral for the first three—positively oriented—items and lower than neutral for the last three—negatively oriented—items) would have a non–mean-centered score of 5.25 (substantially higher than the neutral point of 3.97), reflecting the considerable enthusiasm shown by the mean level of agreement with the first three items. Thus, taking "neutral" at face value should mean that any NMC factor score above 3.97 should be considered Enthusiastic, whereas the mean-oriented perspective would require the NMC score to exceed 5.25 for that to be the case. Accordingly, from either perspective it can be seen that the NMC approach identifies more individuals who are Enthusiastic about eVTOL travel, based on preserving the face-value neutral of the Likert scale.

Table 6
eVTOL factor score coefficients and computation examples.

Attitudinal Statement	Concern FSC[a]	Enthusiasm FSC	MC and NMC Enthusiasm Score Computation Examples Mean	Std. Dev.	Raw Resp. (neutral)	Std'd. Response (Z–Item)	MC Factor Score Element[b]	Un-mean-centered Z-Item	NMC Factor Score Element[b]
I like the idea of battery-powered aircraft for helping the environment	0.007	0.209	3.64	0.994	3	$\frac{3-3.64}{0.994} = -0.644$	−0.644 × 0.209 = −0.135	−0.644 + 3.64 = 3.00	3.00 × 0.209 = 0.626
I would find it exciting to travel in one of these eVTOL aircraft	−0.040	0.563	3.87	1.02	3	$\frac{3-3.87}{1.02} = -0.853$	−0.853 × 0.563 = −0.480	−0.853 + 3.87 = 3.02	3.02 × 0.563 = 1.67
I like that these aircraft can take off and land close to my home and work locations	0.014	0.558	4.07	0.890	3	$\frac{3-4.07}{0.890} = -1.20$	−1.20 × 0.558 = −0.671	−1.20 + 4.07 = 2.87	2.87 × 0.558 = 1.60
I would be afraid to travel in a battery-operated aircraft	0.416	0.012	2.86	1.17	3	$\frac{3-2.86}{1.17} = 0.120$	0.120 × 0.012 = 0.00144	0.120 + 2.86 = 2.98	2.98 × 0.012 = 0.036
These aircraft would cause more problems than they would solve	0.263	−0.039	2.77	1.11	3	$\frac{3-2.77}{1.11} = 0.207$	0.207× (−0.039) = −0.00808	0.207 + 2.77 = 2.98	2.98× (−0.039) = −0.116
I would be afraid to fly in an aircraft that takes off and lands vertically within a city with tall buildings	0.612	0.044	2.65	1.21	3	$\frac{3-2.65}{1.21} = 0.289$	0.289 × 0.044 = 0.0127	0.289 + 2.65 = 2.94	2.94 × 0.044 = 0.129
						Sum (MC factor score):	−1.28	Sum (NMC factor score):	3.97

[a] Factor score coefficient. [b] Item × Enthusiasm FSC.

Concern and Enthusiasm factor scores. The benefit of using the NMC score-based clusters can be seen by comparing the two figures. Notably, the MC and NMC solutions are identical, in the sense that precisely the same six clusters are identified in both cases. The difference between the solutions lies in where the origin is placed, which affects both the interpretation/labels of the clusters and the share of cases falling into the four quadrants of the two-dimensional plane defined by the Concern and Enthusiasm factors. That is, placement of the origin affects whether a given point on the plane would be considered to signify high or low Concern, and high or low Enthusiasm, with high or low being relative to the sample mean (the MC perspective), or with respect to the face content of the item responses (the NMC perspective).

In essence, the MC solution places the origin at the sample means—which, in the mean-centered perspective (Fig. 4), is the point (0, 0), but which, in the non–mean-centered perspective (Fig. 5), is the point (3.47, 5.25), as mentioned in Section 4.1.4. The NMC solution, by contrast, places it at the non–mean-centered *(neutral, neutral)* point, i.e., at (3.76, 3.97). Because the non–mean-centering shifts (0, 0) to (3.47, 5.25), and in fact shifts all points by exactly those same amounts (as shown in Section 4.1.4), using the "neutral" origin effectively shifts the clusters up (3.76 > 3.47) and to the left (3.97 < 5.25) relative to using the "mean" origin.

Turning first to the interpretation of the MC score-based clusters, the upper left quadrant, representing those that have high Enthusiasm and low Concern, has one clear segment that is labeled as Enthusiastic. These individuals are likely to be among the early adopters and those most excited about the new air taxi mode. The MC solution has another clear group in the upper right quadrant that is labeled as Cautiously Enthusiastic; these individuals could perhaps be swayed to use an eVTOL aircraft if their apprehensions and constraints could be addressed. The MC solution has two distinct segments in the lower right quadrant, which are labeled as Adverse and Strongly Adverse to reflect their high levels of Concern and low levels of Enthusiasm. The lower left quadrant has one clear cluster that is labeled Indifferent. These cases represent a small percentage of the overall sample (and due to their small number are excluded from the subsequent chi-squared and analysis of variance [ANOVA] analyses). The last cluster, which lies in all four quadrants, is labeled "Mixed," as there is a mix of different levels of Concern and Enthusiasm.

Turning to the interpretation of the NMC solution, whereas the MC solution had two segments in the lower right quadrant (i.e., Adverse and Strongly Adverse) and just one segment in the upper left quadrant (i.e., Enthusiastic), the NMC solution reverses this and now has two segments in the upper left (i.e., Super Enthusiastic and Enthusiastic) and just one segment in the lower right (i.e., Adverse). The mixed group also changes from C2 to C4 between the NMC and MC clustering. The segments in the lower left (i.e., Indifferent) and upper right (i.e., Cautiously Enthusiastic) are similar between the two solutions.

Compared to the MC solution, the NMC solution shows that there is a higher percentage of respondents in the sample who could be early adopters. Almost 60 percent of the sample belong to the Super Enthusiastic and Enthusiastic clusters, the segments considered by the authors as more likely to be early adopters of the new eVTOL technology (in comparison, the MC solution shows that only 22 percent of the sample belongs to the Enthusiastic cluster and 37.5 percent belongs to either the Enthusiastic or Cautiously Enthusiastic cluster). Indeed, in considering the responses -to eight mode choice trade-off questions (not shown), it is noted that in the NMC

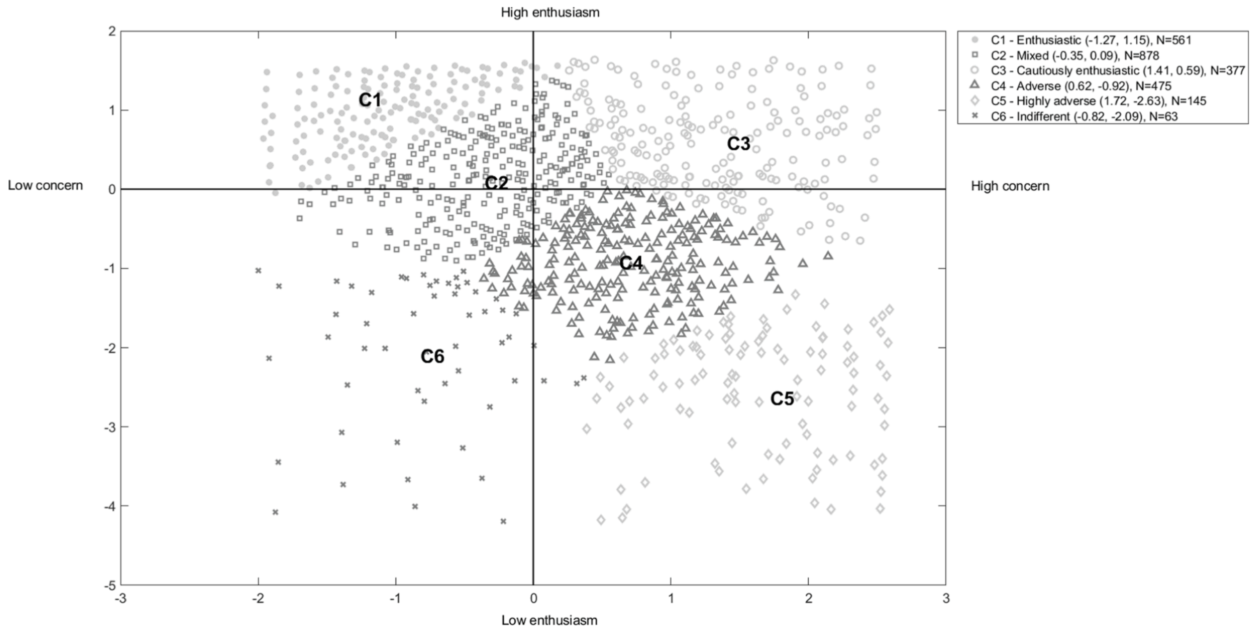

Fig. 4. Six clusters using mean-centered factor scores (N=2,499).
Note: The (*x*,*y*) coordinates following the cluster names in the legend represent the cluster centroids.

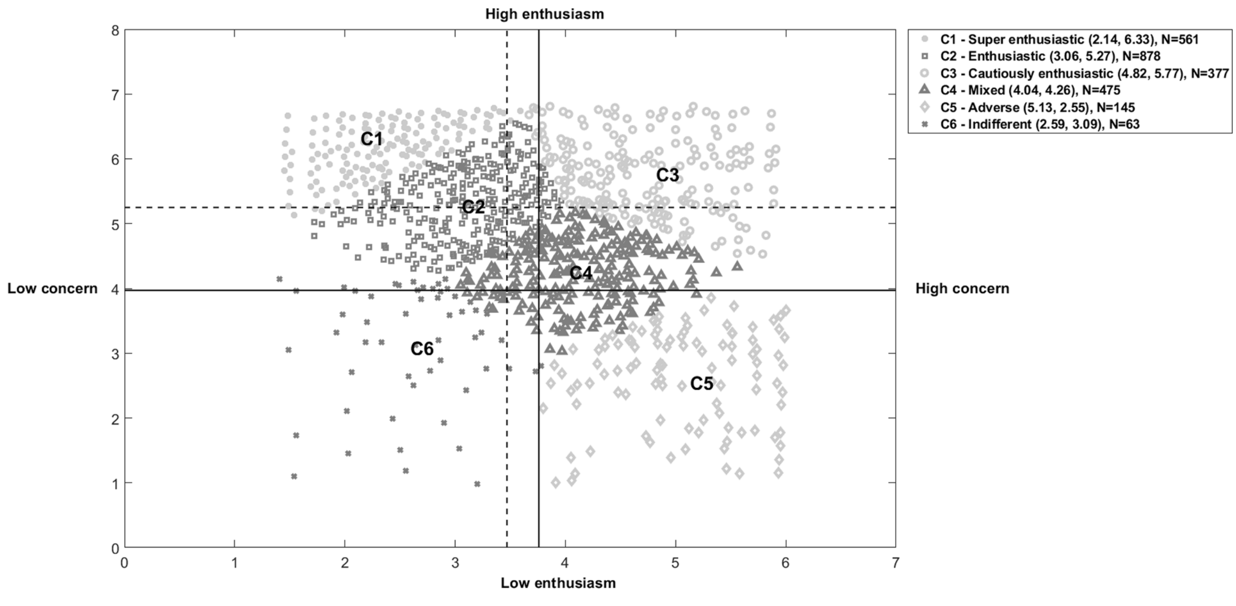

Fig. 5. Six clusters using non–mean-centered factor scores (N = 2,499).
Notes: Figure is centered at (3.76, 3.97), the (*neutral*, *neutral*) point for the NMC score pairs, as shown by the solid lines. The axes corresponding to the MC solution are shown by the dashed lines and are centered at (3.47, 5.25). The (*x*, *y*) coordinates following the cluster names in the legend represent the cluster centroids for the NMC solution.

solution, the percentage of respondents who never selected eVTOL is 1.2, 5.6, and 9.8 percent for the Super Enthusiastic, Enthusiastic, and Cautiously Enthusiastic clusters, respectively. In contrast, these percentages are 24.4 percent for the Mixed and 78.6 percent for the Adverse. The NMC solution provides a clear linkage to the percentage of respondents who never select eVTOL; that is, the percentage of respondents who never select eVTOL is monotonically increasing across the Super Enthusiastic, Enthusiastic, Cautiously

Enthusiastic, Mixed, and Adverse segments. In contrast, in the MC solution, this linkage is less clear-cut for the Enthusiastic, Cautiously Enthusiastic, and Mixed segments (at 1.2, 9.8, and 5.6 percent, respectively).

This is an important distinction between the MC and NMC results; in this application, using the standard MC techniques could lead to underestimating potential market sizes for eVTOL demand. Conceptually, this is because the NMC solution preserves the interpretation of "true neutral" from the Likert scale, whereas the MC solution centers the eVTOL Concern and eVTOL Enthusiasm factors relative to the means of the responses to the individual items. In this study, since a large number of respondents answered "strongly agree" or "agree" to the items associated with the eVTOL Enthusiasm construct, and tended to disagree with the items associated with the Concern construct, the NMC solution identifies a higher share of cases as belonging to the high Enthusiasm and low Concern quadrant than the MC solution does. For the NMC solution, 59.7 percent of cases belong to this quadrant; for the MC solution, 38.5 percent belong to this quadrant.

4.3. NMC cluster profiles

Statistical tests were conducted of the differences between clusters with respect to sociodemographic characteristics; current commute and air travel patterns; and travel, personality, and lifestyle constructs for the NMC solution with six clusters. For discrete-valued characteristics, such as gender, a Pearson's χ^2 test was used to identify whether the distribution of the characteristics differed by cluster. For continuous- or quasi-continuous-valued variables, a one-way ANOVA was performed to determine whether the means of each characteristic differed across clusters. A discussion of the Indifferents is omitted, as these constitute just 63 observations, or 2.5 percent of the sample.

When interpreting the results below, it is important to note that the results of the chi-square and ANOVA tests help identify how distributions across segments differ *in tendency*. For example, across the Adverse, Mixed, Cautiously Enthusiastic, Enthusiastic, and Super Enthusiastic segments, the percentages of females are 61.4, 53.9, 53.3, 44.2, and 38.0, respectively. The chi-square test shows that in the Adverse and Mixed groups, the percentage of females is statistically significantly higher than the sample average of 47.1 percent; however, for the Super Enthusiastic segment, the percentage of females is statistically significantly lower than the sample average. It can be said that "the Adverse segment has a higher proportion of women than the other segments do," which is not the same as saying that "all Adverse segment members are women." Table 7 summarizes characteristics that were statistically significantly associated with each cluster, and an online appendix provides the details of each statistical test involved.

The Adverse and Mixed segments share many characteristics. Compared to the other segments, they are more likely to be female, are more likely to have never used a ride-hailing service, are more likely to travel by air less than once per year, and tend to be less Pro-Environment than average. These segments differ, however, in that the Adverse tend to be older, have no children, and have either no college education or an associate degree. In terms of lifestyle and personality factors, the Adverse members tend to have higher scores on the Dislike of Flying and Technologically Cautious factors. In summary, of interest for the Adverse and Mixed segments is that, on average, both have had less exposure to ride-hailing and air travel than other segments.

On average, individuals in the Cautiously Enthusiastic segment have more constraints on their travel. They are more likely to make stops on the way to work, to have two children (and thus may be juggling daycare and/or after-school activities with work), and to be in the 25–44-year-old age range. Compared to other segments, they are more likely to own a hybrid vehicle and to use that vehicle in a

Table 7
Characteristics associated with the NMC six-cluster solution[a]

	Super Enthusiastic (22.4 %)	**Enthusiastic** (35.1 %)	**Cautiously Enthusiastic** (15.1 %)	**Mixed** (19.0 %)	**Adverse** (5.8 %)
Gender	Male			Female	Female
Age	Less likely 65+	45–64	25–44		65+
Children			2		None
Education					Associate (2-yr college) degree or less
Commute time and congestion		60–89 min	40–59 min with congestion		60+ min
Stops		Less likely	More likely		
Vehicle ownership and type	Hybrid or no auto		Hybrid with HOV usage		
Favorable air taxi features	Battery-powered, Guaranteed ride home	Guaranteed ride home	Fuel- and/or battery-powered, Guaranteed ride home		
Ride-share frequency	1–4 times per month		2–4 times per month	Never	Never
Air travel frequency[b]	7+ round trips (RT) per year		1+ RT per week	Less than one RT per year	Less than one RT per year
Attitudes/ lifestyle/ personality	more Pro-Environment, less Dislike of Flying, less Tech. Cautious	less Dislike of Flying, less Pro-Car	more Pro-Collective Modes and Pro-Car, more Dislike of Flying, more Tech. Cautious	less Pro-Car and Pro-Environment, more Dislike of Flying	less Pro-Collective Modes and Pro-Environment, more Dislike of Flying and Tech. Cautious

[a] The Indifferent cluster has been omitted since its small size (N = 63) makes statistical testing unreliable. [b] RT = roundtrip.

high occupancy vehicle (HOV) lane. The Cautiously Enthusiastic segment is also more likely to have one-way commute times in the 40–59-minute range and to experience congestion. The Cautiously Enthusiastic segment tended to have the most exposure to air travel and ride-hailing. Individuals in this segment were more likely to use ride-hailing services at least once per week or two to three times per month and to travel roundtrip by air at least once per week. With respect to lifestyle and personality factors, it is interesting that the Cautiously Enthusiastic tend to have higher scores on both the Pro-Collective Modes and Pro-Car factors, suggesting a multimodal lifestyle that includes car along with other modes (to be selected as appropriate). In summary, the Cautiously Enthusiastic segment tends to have had a lot of exposure to ride-hailing and air travel, but is more likely to face constraints (such as the presence of children or the need to make stops on the commute) that could make the adoption of eVTOL travel more challenging.

The Enthusiastic segment is similar to the Cautiously Enthusiastic segment, but generally faces fewer constraints and is more likely to be in the 45–64-year-old age range. Individuals in this segment are less likely to regularly make stops on the way to or from work. They tend to see higher one-way commute times than the Cautiously Enthusiastic segment, particularly in the 60–89-minute range. Both segments are more likely to take an eVTOL flight if a guaranteed ride home is provided when the aircraft cannot fly in bad weather. Scores on the attitude, lifestyle, and personality factors for the Enthusiastic segment tend to be similar to those seen in the sample as a whole, although there are tendencies toward somewhat lower Dislike of Flying and Pro-Car factor scores.

The Super Enthusiastic segment tends to love the environmental aspects of the eVTOL design. Individuals in this segment are least likely to be 65 or older, more likely to be male, more likely either to own a hybrid or not to own an auto, and to be frequent air travelers who are more likely to take 7–11 roundtrips per year compared to other segments. Distinct from the Enthusiastic segment, the Super Enthusiastics are more likely than others to take an eVTOL aircraft if it operates only with battery power. With respect to attitude, lifestyle, and personality factors, this group tends to have higher Pro-Environment scores and lower Dislike of Flying and Technologically Cautious scores. It is interesting that the segment most enthusiastic about eVTOL aircraft has higher Pro-Environmental and lower Technologically Cautious scores, which are two of the attitudes that have most commonly been found to influence EV and AV adoption, as noted in the literature review in Section 2.

In summary, the market segments are both intuitive and informative. Those who are more enthusiastic and less concerned (i.e., fearful) about eVTOL travel have longer commutes, experience congestion, and have fewer constraints on their commutes. Consistent with the findings from the EV and AV literature, this study finds evidence that early adoption of eVTOL aircraft may be tied to Pro-Environment and Pro-Technology attitudes. There is also evidence that early adopters are more likely to be frequent ride-hail users and frequent air travelers, which is consistent with the fact that Uber (a company that focuses on ride-hailing and for which a large percentage of trips are to and from airports) is one of the companies seeking to enter into the eVTOL market.

Finally, whereas Table 7 and the preceding discussion focus on differences in various characteristics across clusters, it is also of interest from a service-provision standpoint to evaluate the differences in cluster distribution across metro areas. Fig. 6 portrays the shares of each cluster in the five metro areas of this study, and overall. It can be seen that San Francisco and Los Angeles have fairly average cluster distributions, whereas Dallas is more likely to have individuals who belong to the Super Enthusiastic cluster and less likely to have individuals who belong to the Adverse cluster. Boston is more likely to have individuals in the Adverse and Mixed clusters, and Atlanta is more likely to have individuals in the Cautiously Enthusiastic cluster.

5. Limitations

The focus of this paper is to describe potential market segments of demand for an urban air taxi commuting service. Respondents

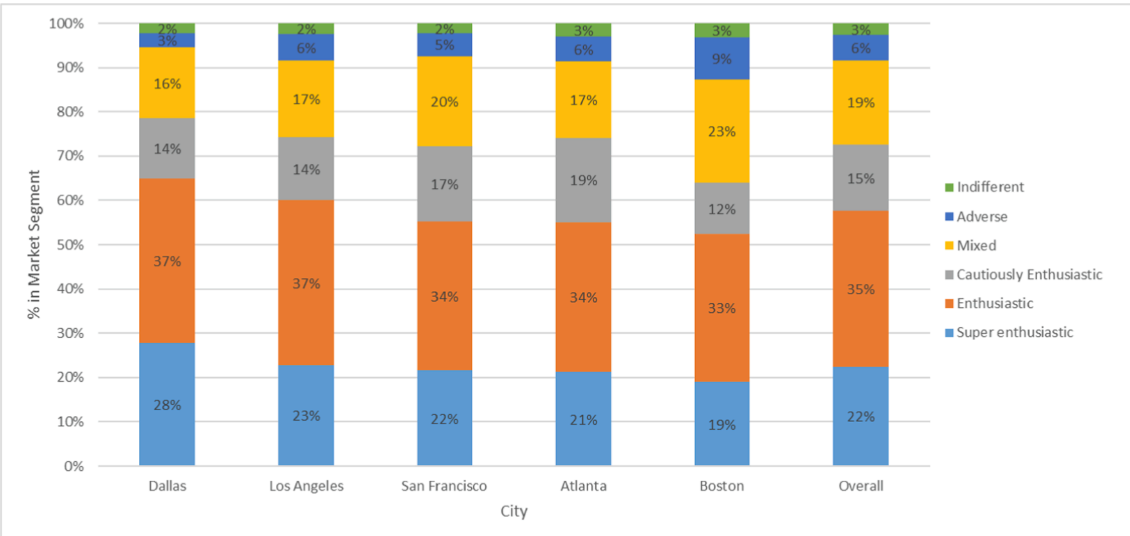

Fig. 6. Distribution of non-mean-centered market segments by city.

were drawn from five cities, representing somewhat distinctive characteristics, but results may not generalize beyond these five cities. Given that the study oversampled individuals who have annual incomes above $100 K, results may also not generalize to lower-income households, although such households are in any case unlikely early adopters of UAM for commuting due to more limited budgets. The segments identified in this study have face validity and are based on the responses of a diverse sample within the target population. However, an accurate assessment of the sizes of each segment is beyond the scope of the paper and would be challenging, since population-level data on this particular specialized population of interest (those with longer commutes and annual personal incomes above $100 K) is not available. Nevertheless, the characteristics of the sample as a whole are consistent with what we would expect for the target population, so the external validity of the results is likely to be high. On the other hand, it must also be acknowledged that attitudes toward a new technology that is not yet available, nor even universally familiar, are subject to substantial change over time. We also remind the reader (see Section 3) that the survey was designed to present a positive description of the technology, to gauge whether interest was sufficiently high under a scenario of efficient, customer-focused management. Accordingly, we do not suggest that the shares of people (even in the target population) holding specific attitudes toward eVTOL service (and thence the shares of people in each of our clusters) will remain stable over time, but they provide a useful early benchmark, and offer a number of meaningful insights into this emerging market.

6. Conclusions and directions for future research

To the best of our knowledge, this study represents the first (nonproprietary) systematic analysis of market segmentation for eVTOL air taxi service in a commuting context, and is one of only a few studies that have used non–mean-centered factor scores. Findings suggest that the conventional mean-centered factor scoring approach may substantially underestimate the eVTOL market. In the NMC solution (which evaluates responses against the neutral point on the scale) 72.6 percent of respondents were enthusiastic about eVTOL travel, compared to just 37.5 percent in the MC solution (which evaluates responses against the sample mean). Based on these results, other researchers should be encouraged to consider the advantages of the NMC approach, especially in cases where it seems reasonable to take responses to attitudinal statements at face value, rather than analyzing them only relative to those of others in the sample.

The study's findings also carry various implications for developing and marketing future UAM services. For example, the region-specific distributions of segment shares suggest that Dallas is a more propitious early market than Boston (Fig. 6). The characteristics of the Super Enthusiastic cluster (Table 7)—the most likely early adopters—suggest marketing service rollouts to hybrid or electric vehicle owners and frequent flyers. Since the next two likely adopting segments, the Enthusiastic and Cautiously Enthusiastic, comprise about half the potential market as defined by our study population, it will be essential to appeal to these segments if a UAM service is to be successful. To reach these segments, marketing campaigns will want to offer, and tout, a guaranteed ride home feature, and partnerships with ride-hail ground service providers could be synergistic.

There are many extensions to this work. The market segmentation developed in this paper will be valuable to the development of future quantitative demand models. As a next step using the current survey results, we plan to estimate discrete choice models of demand to understand consumers' willingness to pay for air taxi service in a commuting context. As noted earlier, sizable fractions of the more concerned/less enthusiastic segments *never* chose eVTOL travel in the stated preference scenarios offered. In view of that fact, it will be important to first model consumers' willingness to fly and then model mode choice, given eVTOL is considered by an individual. We intend to explore the use of dogit and/or other advanced discrete choice models to capture these two effects. Latent class versions of such models are also logical approaches, where the eVTOL Concern and Enthusiasm factors identified in the present study, together with other variables, could be specified to influence class membership probabilities. Random coefficient choice models offer another way to identify the parameter heterogeneity that is sure to exist in the population. In future data collections, broadening the analysis to other trip purposes, most notably airport transfers and leisure trips, is a clear extension that will be important to the aviation community and transportation planners.

Excitement within the aviation community for eVTOL aircraft is quite high, and it may be possible that eVTOL vehicles enter the market before fully autonomous ground vehicles do. Clearly, the introduction of eVTOL flights into the market (and its timing relative to that of autonomous ground vehicles) could have dramatic implications for transportation networks. To better model these potential impacts, a better understanding is needed of how individuals value privacy and convenience, e.g., would certain market segments prefer traveling *with others* in an autonomous ground vehicle over taking an air taxi, while other market segments would prefer traveling *alone* in an autonomous ground vehicle over an air taxi? Will these preferences differ by trip purpose and destination? We are currently analyzing results from a second survey of commuters conducted in the same five U.S. cities to investigate these and other dimensions of shared transportation under alternative future scenarios that account for the timing of autonomous ground service, as well as piloted and autonomous air taxi service.

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CRediT authorship contribution statement

Laurie A. Garrow: Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Patricia L. Mokhtarian:** Conceptualization, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Brian J. German:** Writing – original draft, Writing – review & editing. **John "Jack" S. Glodek:** Formal analysis, Visualization. **Caroline E.**

Leonard: Formal analysis, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tra.2024.104267.

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