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Characterizing the Pilot Experience during Motion-Simulated eVTOL Approaches

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Acronyms and Definitions

AAM	advanced air mobility
AAMS	Aircraft Automation Modeling and Simulation
ACEL-RATE	Aerospace Cognitive Engineering Laboratory–Rapid Automation Test
AEP	Automation Enable Pilot
AHA	Assistive Hover Automation
AMP	Air Mobility Pathfinders
AOI	area of interest
AOSP	Airspace Operations and Safety Program
eVTOL	vertical takeoff and landing via distributed electric propulsion
FATO	Final Approach and Takeoff
ft	feet
HQR	handling quality rating
IMC	instrument meteorological
kts	knots
KFGS	knots forward groundspeed
LPC	Lift-Plus-Cruise
NAS	National Airspace System
NASA	National Aviation and Space Administration
OTW	out the window
PFD	Primary Flight Display
UAM	Urban Air Mobility
VMS	Vertical Motion Simulator
VTO	vertical takeoff and landing

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Executive Summary

NASA's Air Mobility Pathfinders project is part of an ongoing effort to support the integration of Advanced Air Mobility (AAM) vehicles into the National Airspace System for expanded transport and emergency operations in rural and urban environments. Increasingly autonomous powered-lift vehicles that combine the capabilities of airplanes and helicopters will expand the flexibility and scalability of operational AAM concepts. The present study recruited pilots to fly motion-simulated descent and approach scenarios using a conceptual electric Vertical Takeoff and Landing aircraft model. Findings outline the observed impacts of environmental conditions and proposed assistive hover automation concepts on attention allocation, workload, handling quality, and overall pilot sentiment. Considerations for future research and ongoing regulatory efforts are discussed.

1 Introduction

NASA's Air Mobility Pathfinders (AMP) project is part of an ongoing effort to support the integration of advanced air mobility (AAM) vehicles into the National Airspace System (NAS). To minimize noise and optimize energy management, the next generation of air vehicles may include winged, powered-lift aircraft capable of vertical takeoff and landing via distributed electric propulsion (eVTOL) that also enables forward flight without use of the lifting rotors. Innovative eVTOLs that essentially combine the capabilities of rotary- and fixed-wing aircraft will expand the flexibility of operational AAM concepts [1] that aim to evolve aviation infrastructure through a wider range of transport and emergency operations in rural and urban environments. As the scalability of this new technological framework continues to mature, flight controls will become increasingly autonomous through Simplified Vehicle Operations in order to maintain sufficient safety in high-density airspace [2]. Simplified vehicle control systems seek to offset aerodynamic challenges associated with transitioning from forward flight to low speed and hover maneuvers, where eVTOL vehicles are susceptible to slower response times and more instability in the presence of wind gusts (see [3] for more detail on the performance implications of variable lifting rotor and propulsion configurations). The development of new flight control concepts with assistive

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automation and intuitive display elements will ease pilot training requirements and the handling skills required to execute AAM operations with optimal efficiency and safety.

Stationed at the National Aviation and Space Administration's (NASA) Ames Research Center, the Aircraft Automation Modeling and Simulation (AAMS) subproject conducts human-in-the-loop research to support the development of industry representative aircraft, automated systems, and procedural training considerations. The present study was the second in a series of Automation Enabled Pilot (AEP) studies aiming to establish a reference for AAM industry regulators to evaluate operational procedures, pilot requirements, and conceptual aircraft. The preceding study (AEP-1) investigated handling deficiencies associated with various vehicle control methods, environmental conditions, and automation levels based on similar design, performance, and handling quality standards used to evaluate military rotorcraft [4]. The existing methodology was shown to be effective for evaluating an increasingly autonomous conceptual eVTOL vehicle in civilian airspace, and AEP-1 results can be found in [5].

The AEP-2 study highlighted in this report expanded the aircraft automation and procedures using an updated Lift-Plus-Cruise (LPC) aircraft model [6] equipped with predictive display interfaces for representative VTOL operations. Development efforts and scope definitions for AEP-2 are further discussed in [7]. The overall purpose of the study was to investigate challenges associated with transitioning from forward flight to a vertical landing with industry representative eVTOL aircraft and novel aircraft automation concepts. A primary objective was to determine the acceptability of pilot workload and whether automation impacted the handling skill required to execute the proposed approach procedures. In addition to objective performance [8] and subjective workload assessments, eye-tracking was introduced to evaluate the impact of various experimental conditions on pilots' scan patterns as they transitioned through the approach to hover and landing. Pilots' sentiment toward various display features, assistive hover automation concepts, and their overall experience performing the AAM scenarios under the proposed configurations are also discussed. Findings presented in this report and companion publications [7] [8] [9] [10] seek to inform a baseline for future automation studies and highlight important considerations for ongoing regulatory efforts in the AAM industry.

2 Methods

2.1 Test Apparatus and Procedures

Ten pilot participants of various backgrounds were recruited for the study. There were five test pilots and five operational pilots with at least 1000 flight hours of powered-lift experience and eVTOL decision-making authority in applications ranging from airworthiness and flight standards to industry manufacturing. On the day before data collection, pilots underwent a full day of training [9] on test procedures in the Aerospace Cognitive Engineering Laboratory–Rapid Automation Test (ACEL–RATE) fixed-base simulator. During familiarization training, pilots were outfitted with the Tobii Pro 3 Glasses that were later used to collect eye tracking data. The glasses came equipped with corrective lenses when required to accommodate pilot prescriptions. Once training was complete, pilots completed a checklist to verify their understanding of the objectives, task proficiency, and comfort with the eye tracking device.

The descent and approach scenarios were performed inside the high-fidelity Vertical Motion Simulator (VMS) at Ames Research Center [11] [12] [13]. The VMS was configured to simulate the aircraft characteristics of a conceptual LPC powered-lift vehicle model depicted in Figure 1 [6]. The winged eVTOL under test utilized lifting rotors during takeoff and landing and a pusher propellor during cruise. Pilot participants completed at least 45 approach scenarios across three simulation sessions with varying levels of automation, glidepath angles, and wind direction. The approach profiles were designed to be representative of envisioned Urban Air Mobility operations [1] and utilized a standard instrument approach procedure [14] [15] to execute a vertical landing on a simulated vertiport [16] located at Edwards Air Force Base.

Figure 1. Lift-Plus-Cruise Aircraft Model.

Generally, the primary goal for each scenario was to safely touchdown within 10 feet of the landing zone while limiting hover time to 30 seconds or less. Meteorological conditions also varied, but low-visibility scenarios rarely applied to the final approach segments that are of primary interest in this report. This report will mainly focus on pilot interaction with displays while performing the primary landing task during the final approach segment. More information regarding the performance criteria, inceptor configuration, traffic conflicts, initial approach segment, and approach procedure development can be found in companion papers [7] [9] [8] [10].

2.2 Display Areas of Interest

2.2.1 Out-the-Window Displays

Front Windows. As shown in Figure 2, the Front Window displays served as a synthetic visual representation of the surrounding environment with a 130° field-of-view.

Chin Windows. Positioned on either side of the pilot's seat, the Chin Window displays presented a constant 45° look-down view of the environment beneath the aircraft.

Belly Camera. The Belly Camera display presented a 90° look-down view of the environment beneath the aircraft. Unlike the other displays, the belly camera was not visible by default. Pilots retained the option to activate this feature in place of the Map display via a toggle switch located on the inceptor. This was most prevalent when approaching the hover point, which was where the landing target typically appeared into the Belly Camera's view. Toggle switch indicators (i.e., Belly Camera 'On' vs. 'Off') in the data logs were used to distinguish whether pilots were viewing the Belly Camera or Map when analyzing attention on Areas of Interest.

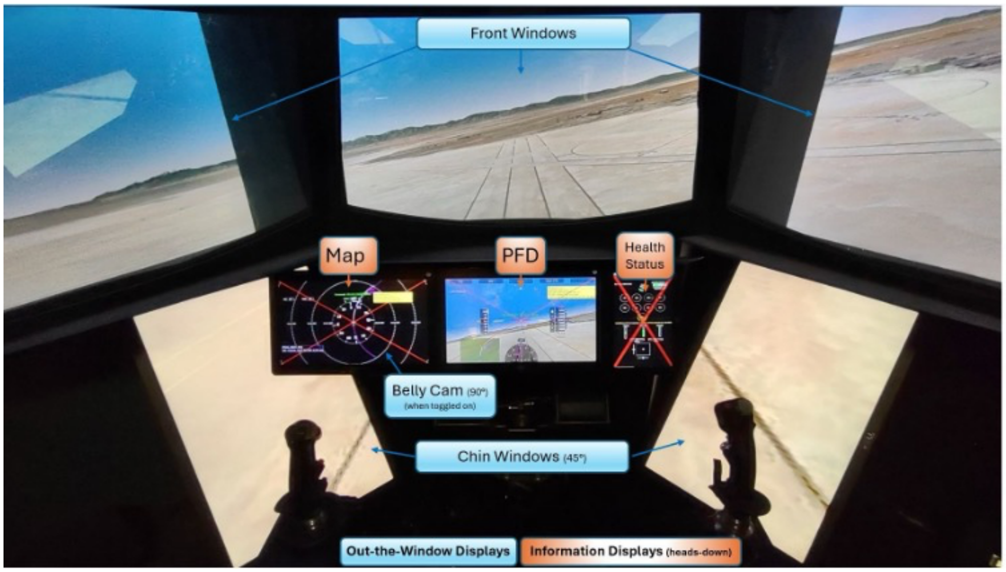


Figure 2. Display AOIs from the pilots' point-of-view.

2.2.2 Heads-Down Information Displays

PFD. The Primary Flight Display (PFD) contained the synthetic horizon view, horizon line, current and target speed, flight director with path guidance and mode annunciators, flight path markers overlaying the touchdown point, and glideslope indicator.

Map. The Map served as the navigation display in Track Up Orientation, containing the following information elements: aircraft symbol, true airspeed, current heading, landing target, predicted hover point (circle), range rings, wind velocity, and wind direction.

Health Status Display. The Health Status display contained the battery level remaining, automation condition, and thrust and effector limits that enabled pilots and researchers to monitor the saturation of control positions that defined their performance.

2.3 Experimental Manipulation

2.3.1 Assistive Hover Automation (AHA)

AHA-0. Manual Deceleration. Serving as a baseline configuration, AHA-0 required pilots to manually decelerate the aircraft enroute to the hover point until the aircraft reached 10 knots (kts) forward groundspeed (KFGS). Hover mode would automatically engage at this point unless the pilot pre-emptively armed the mode by pressing the hover button. Once hover mode was engaged, the automation applied an altitude and direction hold while continuing deceleration to 0 kts. The map presented a leader line showing the predicted track of the aircraft, and it was the pilot's responsibility to correct the aircraft's position if drifted off course by wind gusts.

AHA-1. Transition to Hover. Once AHA-1 hover mode was armed, the automation commanded a deceleration at 2.5 kts per second and a decrab maneuver to aid the transition to the hover point. The map presented a leader line with the predicted track and a circle depicting the predicted hover point at the projected end of deceleration. This predictive hover circle still drifted dynamically in the presence of wind gusts, and pilots were still responsible for making course corrections to maintain landing precision.

AHA-2. Transition to Hover Point. When hover mode was engaged in AHA-2, the aircraft automatically decelerated and decrabbed on its way to the commanded hover point. Contrary to the airmass-referenced track projections in the other AHA conditions, the commanded track in AHA-2 was earth-referenced and the hover circle remained locked on target without any deliberate inceptor inputs from the pilot. The lateral/longitudinal position holds applied to the right/left sticks in addition to the automatic deceleration and decrab allowed pilots to concentrate on managing their altitude while flying to the stable hover point.

2.3.2 Glideslope and Wind Conditions

The secondary independent variables of interest were glideslope and wind direction. Glideslope refers to the 6-degree (°) vs. 12° glidepath angles of the approaches flown by pilots throughout the study (Figure 3). To test performance within controllability requirements specified in the FAA Advisory Circular for Powered-Lift certification [17], pilots experienced four wind conditions from the left and right directions over the course of the study: Quartering Headwind (17kts with 5kts gusts), Quartering Tailwind (10kts with 5kts gusts), Crosswind (17kts with 5kts gusts), and No Wind (baseline).

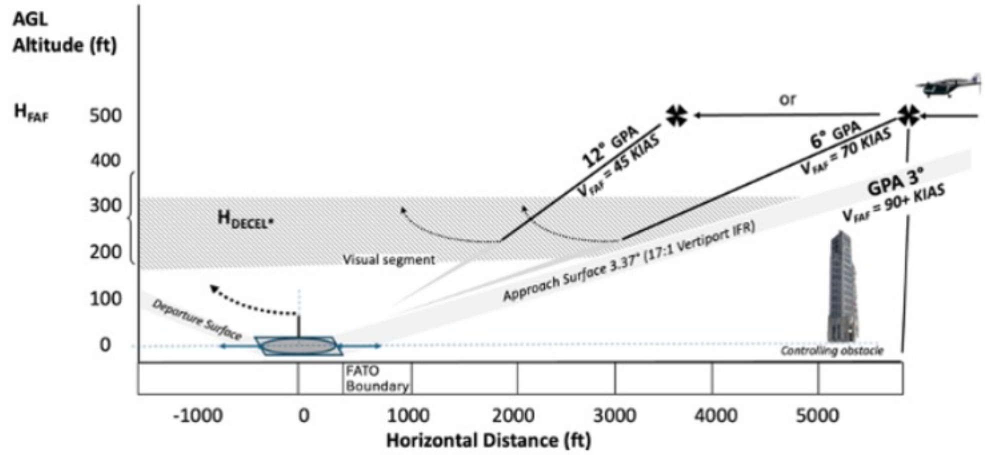


Figure 3. Approach profile at varying glideslopes.

2.4 Measures

2.4.1 Attention Allocation

Attention allocation data reported in this paper focused mainly on nominal scenarios where approaches were completed with an uninterrupted landing touchdown, as opposed to off-nominal scenarios where pilots executed an early go-around shortly after initiation in response to a perceived traffic conflict. Unless otherwise stated, attention allocation data is reported as the relative percentage of time (out of 100%) spent looking at each display area of interest (AOI) in the approach segments of interest. Approach segments are binned by horizontal distance to touchdown. For the purposes of this analysis, the Final Approach and Takeoff (FATO) area refers to the final 60 ft (horizontally) of the approach leading to the target touchdown point.

Touchdowns were considered ‘overshoots’ when they exceeded the desired 10 ft. buffer beyond the landing zone, as defined by the performance criteria in [8]. In addition to individual AOIs, cumulative data is presented for the two AOI groupings: Information displays and out-the-window (OTW) displays that solely present synthetic views of the environment outside the aircraft.

2.4.2 Post-Scenario Ratings

Pilots were instructed to verbally assess the workload and handling quality ratings (HQR) for each run immediately after completion. Using talk-aloud protocol, a researcher guided pilots through the decision trees embedded within the Cooper-Harper HQR Scale [18] (1—Excellent & Highly Desirable to 10—Uncontrollable with Major Deficiencies) and Bedford Workload Scale [19] (1—Insignificant to 10—Impossible). The HQR scale (Figure 4) evaluated the level of pilot compensation needed to attain adequate control performance, while the workload scale (Figure 5) evaluated the level of spare capacity for additional tasks and pilots' subjective ability to maintain sufficient effort to complete the primary task. Generally, a rating of 7 or above for a scenario on each scale is indicative of a major performance deficiency requiring improvement and high workload that is intolerable, respectively. Ratings between 4–6 indicate moderate task workload deemed as adequate but requiring improvement to consistently achieve desired performance. Ratings between 1-3 indicate low workload and pilot compensation required for the task; these ratings are referred to as 'Satisfactory' in this report since they suggest that no improvements are necessary. The results section focuses on the self-assessments given for the final approach segments that included the hover and landing tasks.

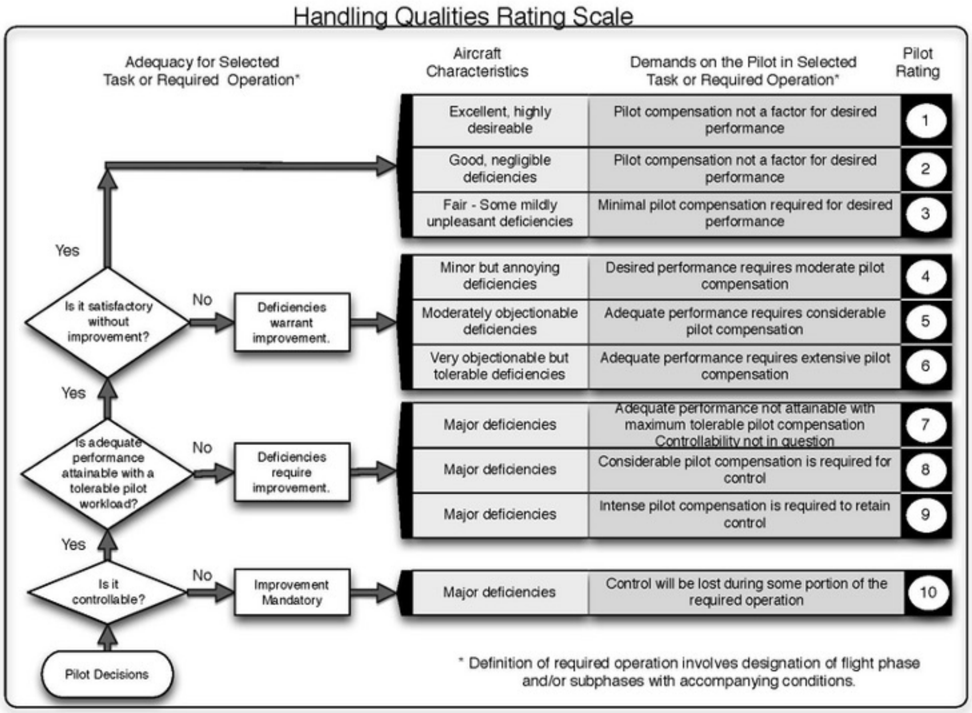


Figure 4. Cooper-Harper Handling Qualities Rating Scale.

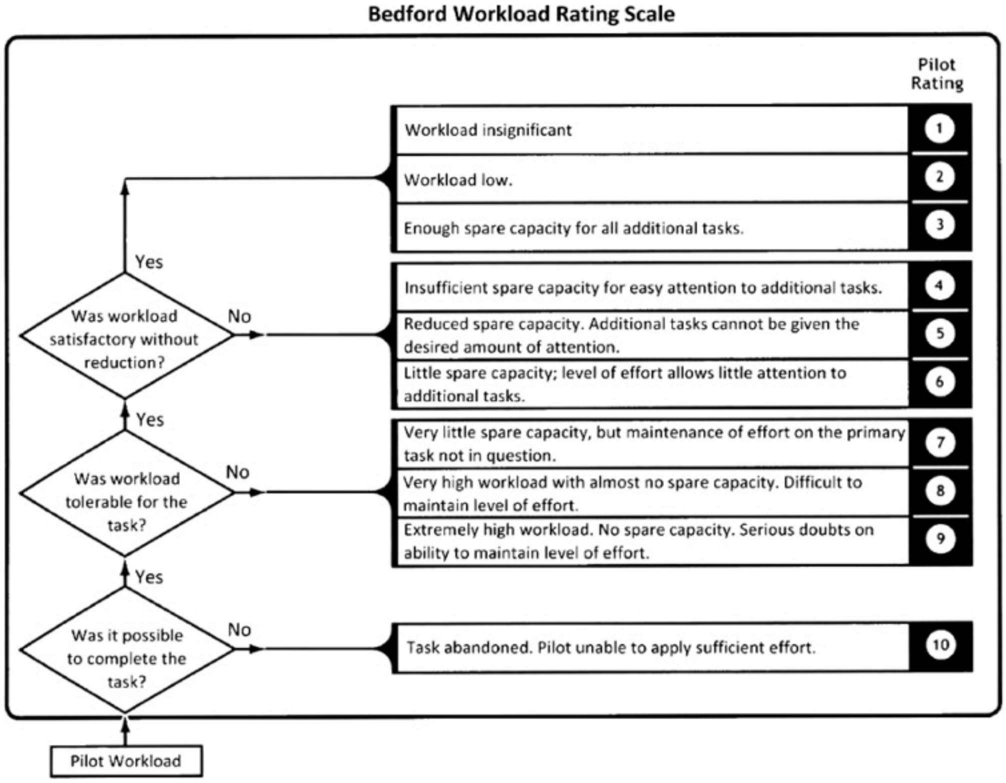


Figure 5. Bedford Workload Rating Scale.

2.4.3 Post-Simulation Ratings

Once all planned scenarios were completed for the day, researchers administered a post-simulation questionnaire followed by a debrief interview [7] that solicited open-ended feedback. Pilots selected responses on a series of Likert-scales (1—Negative sentiment; e.g., ‘Poor’, ‘Strongly Disagree’ to 5—Positive sentiment; e.g., ‘Perfect’, ‘Strongly Agree’) regarding their opinions on various aspects of their test experience, such as display feature utility [10], procedural tempo, usability, training sufficiency, and readiness for real-world applications.

3 Results

Results reported in this section focus mainly on eye-tracking and quantitative subjective data pertaining to the 311 nominal (of 420 total) cases where there were no planned traffic conflicts or go-arounds in anticipation of conflicts that ended the scenario before the hover and landing. More information regarding the off-nominal traffic scenarios [10], objective landing performance during the landing phase [8], and debrief interview highlights [7] can be found in the cited companion publications.

3.1 Attention Allocation

The proportion of pilot attention dedicated to OTW vs. Information displays was determined by several factors. Firstly, Status and Chin Window displays were rarely referenced in nominal scenarios. Only 1% of pilots’ attention was dedicated to the Status display, mainly to glance at the automation condition at the very beginning and the control positions at the very end of the scenarios. Chin Window attention only spiked briefly when there was conflict traffic present on the helipad in the off-nominal scenarios covered further in a companion paper [10]. Therefore, these two AOIs are excluded from subsequent figures to reduce clutter. Pilots were more likely to focus on heads-down displays during the initial approach segment above the 200 ft. decision height (Figure 6), with 70% of their attention being dedicated to the Primary Flight Display (PFD) on average. During initial approach, pilots relied heavily on the PFD's flight director to conform closely to the flight path [10]. Heavy reliance on Information displays during this period was also likely impacted by the fact that there were more instances of poor-visibility instrument meteorological conditions (IMC) in the initial approach segment compared to the final approach.

Pilots' OTW attention consistently increased after they reached decision height and continued through the final approach. Across all participants, OTW and Information display attention were most evenly split once they were within 250-500 feet of the landing zone. Pilots increased utilization of the Belly Camera to orient themselves over the center of the touchdown point once they reached FATO and engaged hover, thus peaking their OTW attention at 67% on average during the landing phase (Figure 6). Although the belly camera was an optional display feature that required manual activation, pilots utilized it in 86% of the nominal runs. These findings align with pilots' favorable ratings of the Front Windows, flight director, and belly camera in their display utility rankings on the post-simulation questionnaire [10].

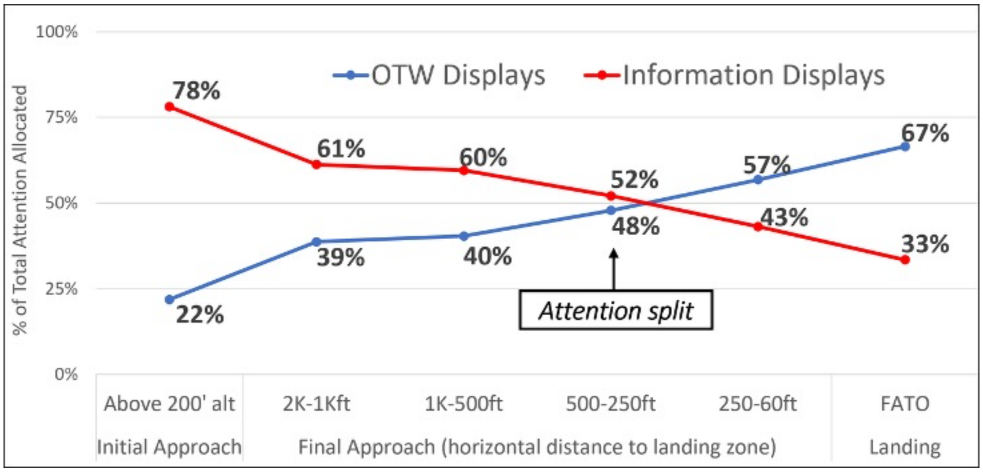
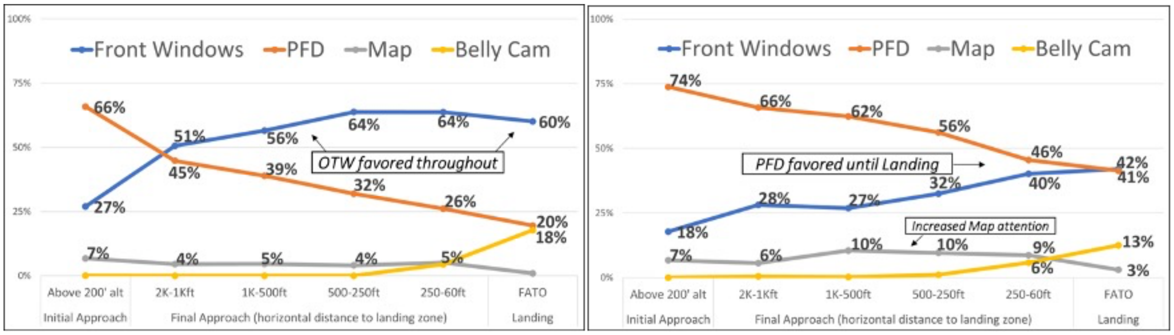


Figure 6. Attention allocation by AOI category.

The magnitude of the observed attention shifts along the approach was in part moderated by pilot background. Although pilot background was not explicitly intended as an experimental manipulation when developing the study, noteworthy attention allocation trends with similar sample sizes between the two groups led to this variable being included in the lessons learned.

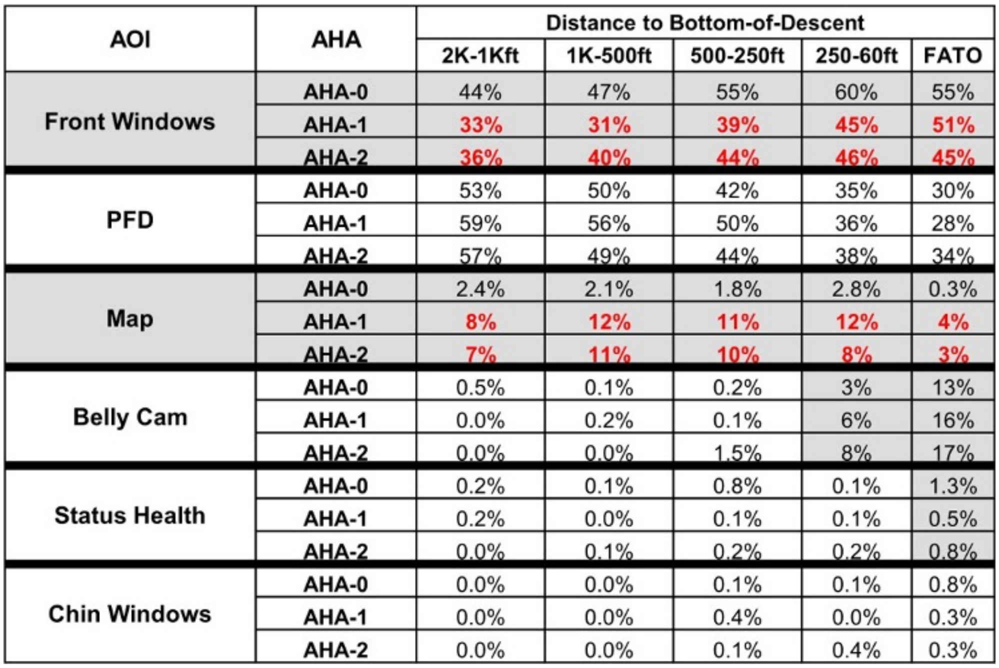
The nature of pilots' past experience actually had the strongest influence on scan pattern outcomes. Test pilots shifted their attention toward the Front Windows much earlier in the approach segment (Figure 7a), making it their primary display AOI throughout the full final approach segment into the landing phase where OTW attention peaked at 78%. On the contrary, Operational pilots maintained primary focus on the PFD until around 250 ft. to the landing zone and waited until FATO to evenly split their attention with the OTW displays (Figure 7b). The PFD attention allocation percentages from Operational pilots doubled compared to Test pilots during landing, and their attention toward the Map doubled along the final approach.



(a) Test Pilots. *(b) Operational Pilots.*

Figure 7. Attention Allocation by Pilot Background.

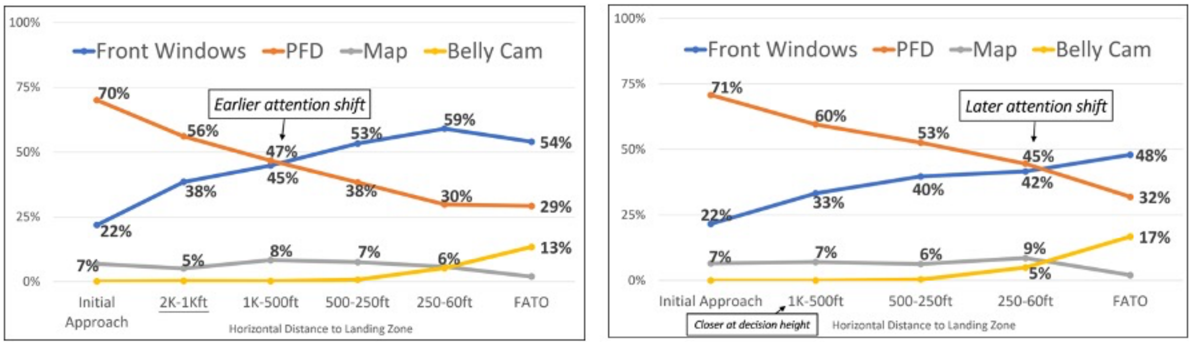
On average, higher AHA levels increased attention allocated to heads-down Information displays by 9–14% on final approach. It should be noted that the AHA-1 and AHA-2 conditions included a hover circle on the map that was not present in AHA-0, and interaction with this additional display element led to more attention being diverted away from the Front Windows as they approached the landing target with increased automation (Figure 8). This trend was slightly amplified in the AHA-1 condition where the hover circle moved dynamically along the map in response to winds. However, higher automation also allowed for increased monitoring of the Belly Camera at FATO to aid their landing performance. Pilots were also twice as likely to toggle on the Belly Camera before reaching FATO in the AHA-1 and AHA-2 conditions. Aside from the fact that the Belly Camera shared a display with the Map that pilots were already monitoring more at higher AHA levels, the more favorable workload ratings associated with increased automation 3.2 suggests there was also more capacity for spare attention to additional tasks.



AOI	AHA	Distance to Bottom-of-Descent				
		2K-1Kft	1K-500ft	500-250ft	250-60ft	FATO
Front Windows	AHA-0	44%	47%	55%	60%	55%
	AHA-1	33%	31%	39%	45%	51%
	AHA-2	36%	40%	44%	46%	45%
PFD	AHA-0	53%	50%	42%	35%	30%
	AHA-1	59%	56%	50%	36%	28%
	AHA-2	57%	49%	44%	38%	34%
Map	AHA-0	2.4%	2.1%	1.8%	2.8%	0.3%
	AHA-1	8%	12%	11%	12%	4%
	AHA-2	7%	11%	10%	8%	3%
Belly Cam	AHA-0	0.5%	0.1%	0.2%	3%	13%
	AHA-1	0.0%	0.2%	0.1%	6%	16%
	AHA-2	0.0%	0.0%	1.5%	8%	17%
Status Health	AHA-0	0.2%	0.1%	0.8%	0.1%	1.3%
	AHA-1	0.2%	0.0%	0.1%	0.1%	0.5%
	AHA-2	0.0%	0.1%	0.2%	0.2%	0.8%
Chin Windows	AHA-0	0.0%	0.0%	0.1%	0.1%	0.8%
	AHA-1	0.0%	0.0%	0.4%	0.0%	0.3%
	AHA-2	0.0%	0.0%	0.1%	0.4%	0.3%

Figure 8. Attention allocation on final approach by automation condition.

During the 12° approaches, pilots shifted their attention away from the PFD closer to touchdown compared to 6° approaches (Figure 9). Visibility restrictions were a factor in this case, as one-third of scenarios featured IMC down to 50 ft above decision height (200 ft above ground level). The steeper 12° approach angle caused the aircraft to reach decision height later in the descent phase (i.e., closer to the landing zone) in these cases, thus forcing pilots to rely on their heads-down displays to stabilize their approach further into the approach path. The 12° approaches also required an additional 35-kt deceleration midway through the final approach, and this would have been monitored on the PFD. There was also a 4% increase in belly camera attention during the 12° approaches as pilots oriented themselves atop the landing target. The impact of Wind conditions on attention allocation was negligible, but there was an observed 3–4% increase in Belly Camera attention during landings with crosswinds and tailwinds, respectively.



(a) (b)

Figure 9. Attention allocation by glideslope: (a) 6° glideslope; (b) 12° glideslope

3.2 Post-Scenario Ratings

Across all conditions, the HQR (*M* = 4.53, *Med* = 4, *SE* = 0.10) and Workload (*M* = 4.57, *Med* = 4, *SE* = 0.10) scales returned very similar ratings from pilots of all backgrounds. Although the independent variables did slightly alter trends in post-scenario questionnaire responses, 92% of HQR and Workload ratings for each scenario were either equal to one another (49%) or within 1 unit (43%) on each scale respectively. Therefore, for the purpose of conciseness, the nearly identical ratings across both scales are consolidated into a single chart when reporting the observed trends below. Nevertheless, the reader shall remain aware of the distinction between the Cooper-Harper and Bedford assessments: the HQR scale queried subjective performance based on handling quality and pilot compensation, while the Workload scale evaluated operator demand and spare mental capacity for multi-tasking.

A Pearson correlation analysis revealed a moderate negative association between post-scenario ratings and automation condition. HQR ($r = -0.44$) and Workload ($r = -0.46$) both decreased as automation level increased, p's < .05. On average, the AHA-2 condition (*M* = 3.46, *Med* = 3, *SE* = 0.16) yielded more favorable HQR and workload ratings compared to AHA-1 (*M* = 4.67, *Med* = 4, *SE* = 0.19) and AHA-0 (*M* = 5.40, *Med* = 5, *SE* = 0.16). AHA-2 was the only automation condition that yielded a pilot compensation and workload rating of below 4 on average, with over half of the AHA-2 scenarios receiving a Satisfactory rating of 3 or lower on either rating scale (Figure 10). Conversely, the AHA-0 condition requiring manual deceleration accounted for over two-thirds (69%) of the scenarios that received Intolerable ratings of 7 or higher on the HQR and Workload scales. This trend favoring increased automation was sustained regardless of whether pilots were flying 6° or 12° approaches (refer to [10] for box plot).

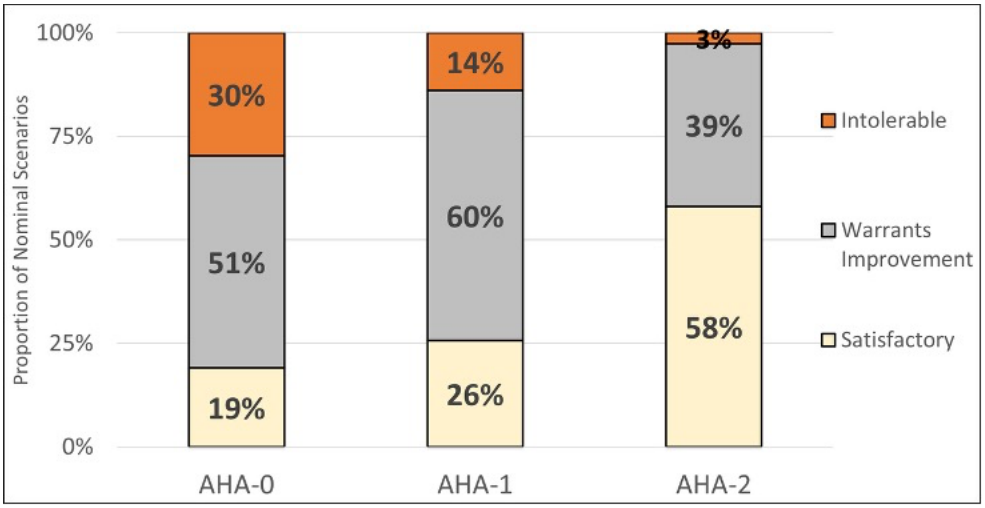


Figure 10. Post-scenario compensation/workload ratings by automation condition.

Moreover, post-scenario ratings revealed that the presence of wind slightly increased the pilot workload and compensation required to complete the task, especially when gusts blew from the rear of the aircraft. Tailwind ($M = 4.91$, $Med = 5$, $SE = 0.17$), Crosswind ($M = 4.8$, $Med = 4$, $SE = 0.25$), and Headwind ($M = 4.43$, $Med = 4$, $SE = 0.20$) tended to result in less favorable HQR and higher workload ratings compared to the No Wind ($M = 3.86$, $Med = 3$, $SE = 0.18$) condition (Figure 11). Tailwinds were present in all 3 of the AHA-2 scenarios that were rated as ’Intolerable’, and half of all AHA-0 scenarios with tailwinds received an ’Intolerable’ rating. This finding can be attributed to lessened time available to stabilize the approach in the presence of tailwinds. Only the No Wind condition yielded a median rating of ’Satisfactory’ on the HQR and Workload scales.

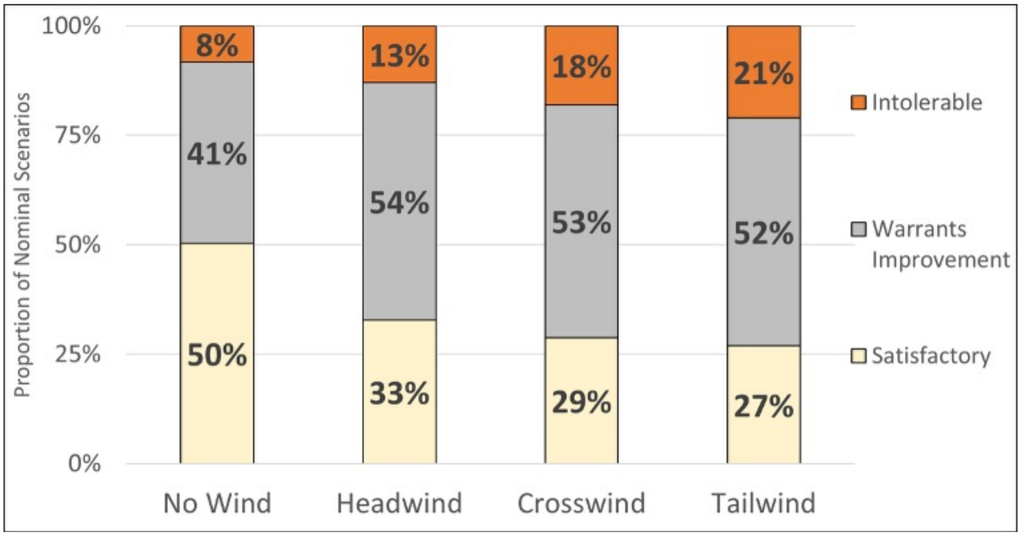


Figure 11. Post-scenario compensation/workload ratings by wind condition.

3.3 Post-Simulation Ratings

Post-simulation ratings are summarized in order of most-to-least favorable in Figure 12. All pilots rated the user interface as intuitive, and there was no negative sentiment regarding the sufficiency of the display information. The remaining list items received a slightly negative response from at least one pilot. However, the readiness for live flight testing and real-world operations were the only items where the pilot ratings did not skew toward positive sentiment on average, citing discomfort with the constrained time available to stabilize approaches in the current study designed to stress the performance envelope within the proposed operational concepts under test. The multi-day training session was rated as sufficient for executing the motion-simulated approaches, albeit there was an initial negative habit transfer challenge experienced by pilots with prior experience on rotorcraft equipped with inceptor configurations that were inverted compared to the augmented controls designed for the present study. Handling quality and workload sentiment received a wide range of responses on the post-simulation questionnaire, as demand varied based on the conditions on the scenario (3.2). Most pilots reported ample ability to visually acquire the landing environment but also expressed desire for a wider field-of-view and additional reference markings on the Belly Camera feed. With regard to the assistive hover automation concepts, there was unanimous preference for the AHA-2 configuration. The general consensus indicated that AHA-2's indefinite hover hold and automated deceleration afforded spare mental capacity to focus on a single axis of control (i.e., altitude adjustments). AHA-0 was ranked as the least preferred configuration by all but one pilot.

Figure 12. Post-simulation ratings (average and range of responses).

Pilots also rated the utility of the various display features (Table 1). For the AHA-1 and AHA-2 configurations, pilots ranked the hover circle (on Map), flight director (path guidance on PFD), and Front Windows as the three most useful display elements. The Belly Camera replaced the hover circle as a top three display element under the AHA-0 configuration despite the eye tracking data revealing a relatively minor increase in Belly Camera attention when landing in the higher automation conditions (Figure 8). In line with Figures 6 and 8, pilots indicated that the PFD elements were favored during the initial approach while the OTW displays (mainly the Front Windows and Belly Camera) became most useful for maintaining visibility of the landing area as they refined the precision of their touchdown point within the FATO boundary. Post-hoc analysis of VMS system logs revealed that despite its relatively sporadic attention allocation, the Belly Camera was toggled on in place of the Map by pilots during landing in 86% of nominal scenarios—most prominently when hover automation was enabled on a 12° glideslope. Chin Windows were ranked as the least useful feature and rarely referenced (Figure 8) for visual acquisition of the landing environment, though it should be noted that its lack of usage may have contributed to the close-calls observed with scripted conflict traffic on the landing zone during off-nominal scenarios discussed in [10].

Table 1. Post-Simulation Rankings of Display Features

Ranking	*Display Feature*
1	Flight Director
2	Front windows
3	Predictive hover circle (AHA-1 and AHA-2)
4	Belly camera
5	Approach slope indicator (PLASI)

4 Conclusion

The deleterious effects of reduced automation, wind gust presence, and steeper glideslope on subjective handling quality and workload aligned with the objective landing performance findings detailed in [8]. Increased levels of assistive hover automation mitigated the subjective and objective performance deficits associated with amplified winds. While the increased attention to heads-down cockpit displays afforded by higher automation was associated with better performance and lower workload in the AEP-2 study, the momentary diversion from OTW monitoring increased susceptibility to losses of separation during off-nominal scenarios [10]. Thus, future operations should maintain a healthy balance between assistive automation and operator vigilance to minimize vulnerability to unforeseen contingency events. Training implications should also be further explored based on the observed differences in scan patterns along the approach path based on pilot background. The mixed sentiment on real-world and live-flight readiness highlights the importance of continued refinement of augmented flight control systems for AAM operations with eVTOL vehicles. Further investigation on attention and task saturation is warranted as conceptual operations and vehicle models continue to mature. Follow-up motion simulation activities will build upon these findings by examining corridor operations with additional aircraft concepts (including quadcopter and tilt-wing) in all phases of flight, while also introducing airborne traffic avoidance to the scenarios.

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