Presented at the 2025 AIAA DATC/IEEE 44th Digital Avionics Systems Conference (DASC), Montreal, QC, Canada, 2025
DOI: doi:10.1109/DASC66011.2025.11257285 https://ieeexplore.ieee.org/Xplore/


# Simulator Evaluations of Assistive Hover Automation Concepts for a Lift Plus Cruise eVTOL Vehicle

Thomas Lombaerts
*Intelligent Systems Division*
*KBR / NASA Ames Research Center*
Moffett Field, CA, USA
thomas.lombaerts@nasa.gov

Kimberlee Shish, John Kaneshige
*Intelligent Systems Division*
*NASA Ames Research Center*
Moffett Field, CA, USA
kimberlee.h.shish@nasa.gov
john.t.kaneshige@nasa.gov

Amber Villa, Michael Feary, Kevin Monk
*Human Systems Integration Division*
*NASA Ames Research Center*
Moffett Field, CA, USA
amber.n.villa@nasa.gov
michael.s.feary@nasa.gov
kevin.j.monk@nasa.gov

Loran Haworth
*Human Systems Integration Division*
*SJSURF / NASA Ames Research Center*
Moffett Field, CA, USA
loran.a.haworth@nasa.gov

Mieczysław Stegliński, Elif Kürklü
*Intelligent Systems Division*
*KBR / NASA Ames Research Center*
Moffett Field, CA, USA
mieczyslaw.steglinski@nasa.gov
elif.kurklu@nasa.gov

Nelson Iwai, John Archdeacon
*Human Systems Integration Division*
*ASRC / NASA Ames Research Center*
Moffett Field, CA, USA
nelson.iwai@nasa.gov
john.archdeacon@nasa.gov

***Abstract*—Electric Vertical Takeoff and Landing vehicles have the potential to enable cost effective Urban Air Mobility applications. These concepts also pose several challenging handling and control problems, which must be addressed prior to safe and efficient urban operations. This paper presents simulator evaluations of several Assistive Hover Automation concepts that are designed to assist pilots in transitioning to and maintaining a stabilized hover prior to landing. They were evaluated extensively in the Vertical Motion Simulator at NASA Ames Research Center. The experiments were built upon relevant operations with additional test cases exploring variations in glidepath angles and environmental conditions. This paper focuses on specific performance metrics during the approach and at touchdown, combined with pilot activity. It was found that the AHA concepts assist in improving performance while reducing the required pilot activity, also resulting in a more streamlined approach, transition to hover, and touchdown in a shorter time.**

***Index Terms*—Urban Air Mobility, eVTOL, Simulator Evaluation, Automation, Lift Plus Cruise.**

## I. Introduction

Winged electric Vertical Takeoff and Landing (eVTOL) vehicles that can take off and land vertically like a helicopter and cruise like an airplane have the potential of increasing operational capabilities while maintaining a high degree of efficiency. Like all eVTOL vehicles, winged eVTOL vehicles suffer from slow response times during low speed and hover maneuvering, exacerbated by adverse effects of unfavorable wind directions on the wings. Thus, certain unfavorable glide paths and/or environmental conditions impose strict constraints for pilots in terms of anticipating path transitions and energy management while achieving the minimum required levels of precision. Simplified Vehicle Operations (SVO) is a term adopted by the aviation community for “the use of automation to reduce the number of skills a pilot or operator of an aircraft must acquire to achieve the required level of operational safety [1].” The term Simplified Vehicle Controls (SVC) is meant to convey a subset that focuses on the aircraft handling skill category. The Simplified Vehicle Control Concepts that were developed for this conceptual Lift Plus Cruise eVTOL vehicle, including the Assistive Hover Automation (AHA) strategies evaluated in this study, are discussed in greater detail in [2].

Funded by NASA’s Airspace Operations and Safety Program’s (AOSP) Air Mobility Pathfinder (AMP) project

## II. Lift Plus Cruise Vehicle

The Lift Plus Cruise (LPC) conceptual model, which is used in this study and shown in fig. 1, was designed by NASA’s Revolutionary Vertical Lift Technology (RVLT) project [3]. The vehicle is designed to takeoff and land vertically using lifting rotors, and to cruise in forward flight with a separate pusher prop and the lifting rotors stowed. The vehicle can optimize power consumption efficiency by staying on the wing as long as possible. As a result, the proposed operational concept is to quickly accelerate just after takeoff, and to quickly decelerate to hover just prior to landing. More details about the vehicle model, the flight regimes and how the control effectors are blended throughout the flight envelope are given in [2].

Fig. 1. NASA RVLT Lift-Plus-Cruise conceptual model

## III. Assistive Hover Automation (AHA) Concepts

Three different Assisted Hover Automation (AHA) concepts were implemented and evaluated to compare the effects of different levels of automation on safe and efficient approach to landing maneuvers.

- The AHA-0 concept arms a baseline "hover" mode, which engages only when the forward groundspeed decreases below 10 knots. The "hover" mode is similar to contemporary state of the art fly-by-wire response types with translational rate control (TRC).
- The vector-based AHA-1 concept commands a nominal decelerating rate of 2.5 knots/s and a decrab maneuver, transitioning to the same aforementioned hover mode below 10 knots forward groundspeed. A "predicted hover location" is shown on the navigation display during the transition to hover that can move slightly based on the environmental conditions (like wind).
- The target-based AHA-2 concept performs the same aforementioned nominal decelerating and decrab transition to a "commanded hover target point" that is shown on the navigation display and locked on the ground. The target point can be moved by the pilot via the inceptors.

Ref. [2] discusses more details of each concept and all the included features, combined with some illustrating simulations of approaches.

## IV. Experiment method

This section discusses the facility used for the experiment in Sec. IV-A, together with a brief description of the participants in Sec. IV-B and a discussion of the evaluation metrics in Sec. IV-C

### A. Vertical Motion Simulator

The Vertical Motion Simulator (VMS) is the ideal facility to evaluate lift mode transitions and low speed operations because of its large motion envelope. The VMS motion system, shown in Fig. 2 and Fig. 3, is an uncoupled six-degree-of-freedom research motion simulator, with different interchangeable cockpit cabs and configurable flight deck instrumentation systems, wide-view outside visual display systems, electric control loaders and a high fidelity motion system. It is located in, and partially supported by, a specially constructed 120 ft tower. More information about the simulator can be found in Ref. [4]–[6].

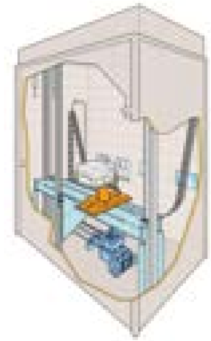
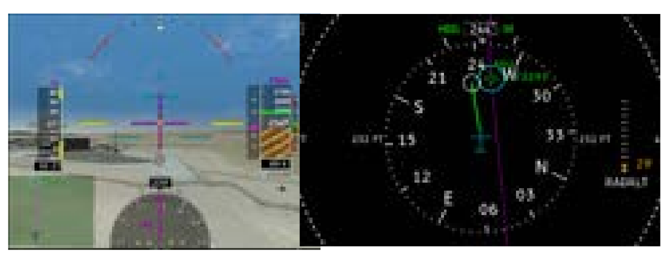


Fig. 2. Drawing with layout of the Vertical Motion Simulator

Fig. 3. Picture of the VMS cab on the beam

The cockpit for these evaluations, shown in Fig. 4 (inside), was configured for a single pilot in the front seat and a flight test engineer in the back seat. The installed inceptors consisted of left and right passive sidesticks. The left sidestick serves as accelerator/decelerator, the right stick has three degrees of freedom for vertical, lateral and directional by twist. The pedals only work as brakes. The out-the-window visual system provides a 130 degree field-of-view, as well as left and right chin windows. Three liquid crystal display (LCD) screens were used to display flight instrumentation. These displays were representative of primary flight displays (PFD) (Fig. 5(a)) and map (Fig. 5(b)), and a secondary flight display containing lifting rotor status and control authority information.

Fig. 4. VMS Cockpit



(a) Primary Flight Display

(b) map display

Fig. 5. Cockpit displays used during the simulator experiments

A more detailed discussion of the cockpit displays and their symbology, shown in Fig. 5, is given in Ref. [7]. Most relevant symbology in the PFD for the discussion in this paper is the green target marker shown in Fig. 5(a), which shows the targeted flight path angle and track angle. Fig. 5(b) shows the hover marker on the synthetic vision-based map, as the location where the vehicle will come to a steady hover flight condition. Coloring of the circle and needle marker varies with AHA concept and flight mode. In hover mode for AHA-2, this circle becomes the target hover point which the pilot steers directly through the inceptors.

### *B. Group of Pilot Participants*

A diverse group of pilot participants was invited to thoroughly evaluate and compare the different AHA modes in the VMS at NASA Ames Research Center and to assess their individual merits. The total pool of AEP-2 participants consists of 11 male pilots in total, including 6 test pilots, from four different areas, all of which have evaluation roles with powered lift eVTOL and with at least 1,000 hrs of flying experience:

- Airworthiness (3 test pilots)
- Aircraft Evaluation (3 pilots)
- Flight Standards (2 pilots)
- Industry (eVTOL manufacturers) (3 test pilots)

The participants spent one training day in the fixed base ACEL-RATE simulator ahead of the data collection day. The training focused among others on aircraft performance, automation and inceptor strategy. This group size of pilots is insufficient for a full statistical analysis but satisfactory for observing certain trends between the independent conditions.

### *C. Metrics*

A wide variety of evaluation metrics and other variables of interest were included in the data analysis process after the simulator experiments. This paper highlights a subset of the most relevant metrics for a comparative analysis between the three different AHA concepts in the various representative operational conditions with different glide paths and wind directions. The evaluation metrics, listed below, focus primarily on performance metrics and comfort criteria relevant to the mission task and on quantities representing the pilot activity on the different inceptors as an indicator of physical workload. Further descriptions of maneuvers, data collection and analysis can be found in [8]–[10].

*1) Performance criteria:* Performance criteria are split up between the ones who apply for the approach trajectory and the ones that focus on the touchdown point.

*a) Trajectory metrics:* The values for the trajectory metrics are given in Table I. Please note that the speed deviations only apply as speed gates at the relevant markers.

TABLE I
TRAJECTORY METRICS SPECIFICATIONS

| Maneuver | Desired | Adequate |
|---|---|---|
| altitude deviation | ± 1/2 dot | ± 1 dot |
| crosstrack deviation | ± 1/2 dot | ± 1 dot |
| speed deviation[a] | ± 5 kts | ± 10 kts |

[a] Applies only at the relevant speed gates.

*b) Touchdown point metrics:* The values for the touchdown metrics are given in Table II.

TABLE II
TOUCHDOWN METRICS SPECIFICATIONS

| Maneuver | Desired | Adequate |
|---|---|---|
| distance to touchdown target | ± 5 ft | ± 10 ft |
| overshoot beyond landing zone | ≤ 10 ft | ≤ 20 ft |
| vertical speed | ≤ 240 ft/min | ≤ 360 ft/min |
| longitudinal speed | -0.5 / +2 kts | -1 / +4 kts |
| lateral speed | ± 1 kts | ± 2 kts |
| hover time | 15 s | 30 s |
| heading error | ± 5 deg | ± 10 deg |

*2) Comfort criteria:* In the context of passenger and crew comfort, load factors along all three axes should stay between some limit threshold values as specified in Table III.

TABLE III
LOAD FACTOR LIMIT SPECIFICATIONS

| Axis | Objective | Desired | Adequate |
|---|---|---|---|
| longitudinal $n_x$ | 0 g | ± 0.2 g | ± 0.3 g |
| lateral $n_y$ | 0 g | ± 0.1 g | ± 0.2 g |
| vertical $n_z$ | 1 g | ± 0.2 g | ± 0.3 g |

*3) Pilot Activity:* Pilot inceptor activity, representing the physical workload, is analyzed by means of the RMS values of the movements of the individual cockpit inceptors. Subjective pilot ratings were collected for the handling qualities via Cooper Harper ratings [11] and Bedford ratings for the workload. [12] Desired and Adequate ratings for both are defined in Table IV.

TABLE IV
PILOT RATINGS SPECIFICATIONS

| Rating scale | Desired | Adequate |
|---|---|---|
| Handling qualities (Cooper Harper) | ≤ 3 | ≤ 4 |
| Workload (Bedford) | ≤ 3 | ≤ 4 |

## V. PROCEDURE WITH MANEUVERS FLOWN

Two maneuvers were considered for the analysis results presented here, namely a VMC (visual meteorological conditions) intermediate and final approach segment, and an IMC (instrument meteorological conditions) final approach segment only. Both were flown manually with flight director guidance.

### *A. VMC intermediate and final approach*

This segment counts 6 runs per AHA. The aircraft is set up in a turn to final with unlimited visibility (VMC), 1.2 nautical miles away from the landing zone. The independent variables are wind directions (three) and approach angles (two). The three wind directions are: a) no wind and no gusts, b) right or left 17 kts quartering headwind with 5 kts gusts, and c) right or left 17 kts quartering tailwind with 5 kts gusts. Each one of these were flown with glide paths of 6 (nominal) and 12 degrees (steep case). All runs were randomized across participants to mitigate learning effects.

### B. IMC final approach only

This segment counts 4 runs per AHA, where the aircraft starts on the glidepath about 0.8 nautical miles away from the landing zone at 490 ft above ground level in the clouds followed by a breakout at 250 ft with good visibility below (IMC to 50 ft above decision altitude). The independent variables are wind directions and approach angles as before. The two wind directions are: a) right or left 17 kts quartering tailwind with 5 kts gusts, and b) right or left 17 kts crosswind with 5 kts gusts. Also these runs were randomized across participants.

## VI. Analysis of simulation results

The analysis of the simulation results follows the same outline as Sec. IV-C. Performance criteria are considered first in Sec. VI-A. Comfort criteria are only discussed from an overall perspective in Sec. VII. Sec. VI-B focuses on the pilot activity via the inceptors.

### A. Performance criteria

The performance criteria are split up between trajectory metrics in Sec. VI-A1 and touchdown metrics in Sec. VI-A2. Only select metrics are considered here to focus on relevant trends.

*1) Trajectory metrics:*

*a) Glideslope intercept and capture:* Fig. 6 compares altitude errors during glideslope intercept and capture across automation concepts, wind directions and approach path angles, as a function of along track distance to the touchdown point. The relevant evaluation area ends at decision height above the landing zone, indicated by the vertical hatched line. Higher automation does not show major improvements across the conditions studied here. There are only minor differences on the nominal approach angle with headwind or no wind. AHA didn't assist with altitude, the deviations are more a result of differences in pilot technique, which was learned via the post-sim debriefings.

*b) Crosstrack deviation:* Fig. 7 compares crosstrack errors during final approach across automation concepts, wind directions and approach path angles, as a function of along track distance to the touchdown point. Higher automation shows clear improvement in crosstrack deviations for all approach angles and both wind directions in the final approach. Although not shown here, this decrease in crosstrack deviations across automation concepts is less when the earlier turn and capture are also included in the performance metrics analysis. This potentially highlights a limitation to the repeatability of the improvement provided by the automation as more complete operations are considered.

*c) Speed deviation:* Fig. 8 shows speed profiles during final approach across automation concepts, wind directions and approach path angles. The trends show less variation in speed profiles and improved predictability with increased automation. Especially the steep approach path requires more corrections in AHA-0.

*2) Touchdown point metrics:*

*a) Distance to center point of TLOF (touchdown and liftoff) area:* Fig. 9 shows box plots of the distances between touchdown location and target across automation concepts, wind directions and approach path angles. Fig. 9(a) focuses on the approach and fig. 9(b) highlights the final approach. Generally, AHA-2 shows smaller distances compared to lower automation concepts across all angles and wind directions. AHA-0 and AHA-1 show some extreme outliers for tailwind, especially for the steep approaches.

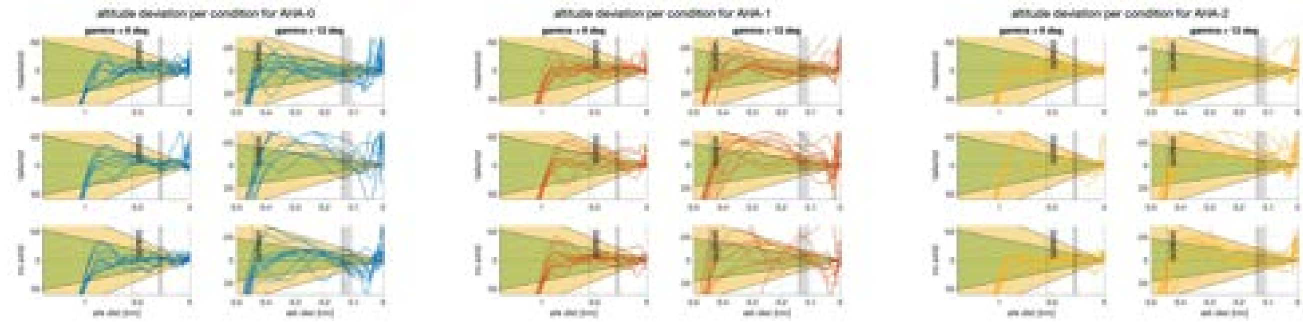
*b) Overshoot of touchdown area:* Fig. 10 shows the box plots of the overshoot distances beyond the TLOF area for approach (Fig. 10(a)) and final approach (Fig. 10(b)). Ignoring a few statistical outliers, the general trend shows that AHA-2 achieves desired performance across the board for all conditions. AHA-1 still meets adequate performance, but AHA-0 shows inadequate performance, especially for tailwinds with nominal approach angles. Overshoots are particularly hazardous for congested or elevated airports. Another trend that was observed but is not shown in these graphs, is that the pilots who did achieve desired performance with AHA-0 typically needed more time. This indicates an early deceleration, trading off a longer time to land for a shorter overshoot distance.

*c) Vertical speed:* Fig. 11 shows box plots of the vertical speed at touchdown across automation concepts, wind directions and approach path angles. Omitting a few statistical outliers, all sink rates at touchdown ended up in the desired range across all independent variables, except for AHA-0 at the nominal approach path with a tailwind in Fig. 11(a).

*d) Longitudinal groundspeed:* Fig. 12 shows box plots of the longitudinal speed at touchdown across automation concepts, wind directions and approach path angles. Omitting a few statistical outliers, most speed values are within the desirable range. However, higher automation levels show a narrower spread in speed values. The statistically significant values (ignoring the outliers) change with wind direction, but seem consistent over approach angles.

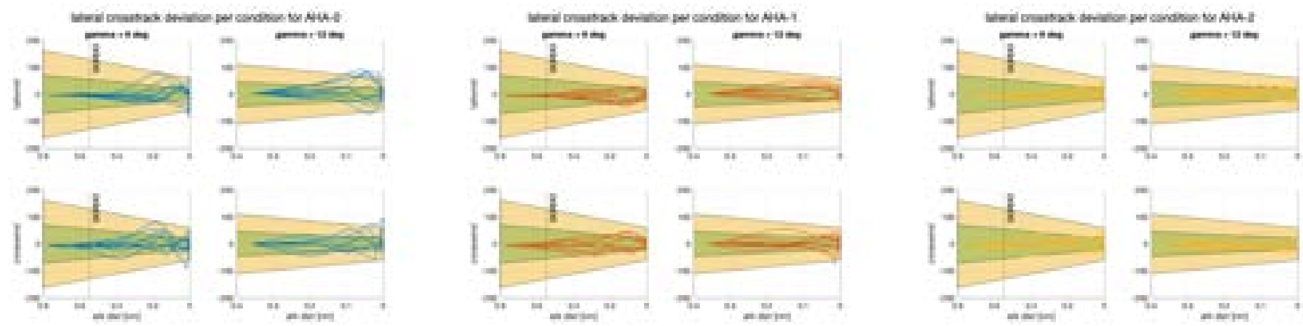
*e) Lateral groundspeed:* Fig. 13 shows box plots of the lateral speed at touchdown across automation concepts, wind directions and approach path angles. Across all wind directions and approach angles, at least half of the data points are consistently within the desirable range for AHA-2. For the other automation concepts, some combinations of wind and angle result in less than half of the datapoints within desirable performance, but they are still mostly adequate.

*f) Hover time:* Fig. 14 shows box plots of the hover time until touchdown across automation concepts, wind directions and approach path angles. Increased automation concepts show shorter hover time indicating better performance and predictability. The final approach trends in Fig. 14(b) show the clearest trends. All AHA-2 runs showed either desired or adequate performance. For AHA-1, half of the runs were consistently adequate but not desired across all wind directions and approach angles. A significant share of AHA-0 runs could not achieve adequate performance levels. In general, similar but not as clear trends are visible in Fig. 14(a) for the approach.




(a) AHA-0 (b) AHA-1 (c) AHA-2

Fig. 6. Altitude error during glideslope intercept and capture across automation concepts, wind directions and approach path angles




(a) AHA-0 (b) AHA-1 (c) AHA-2

Fig. 7. Crosstrack error during final approach across automation concepts, wind directions and approach path angles

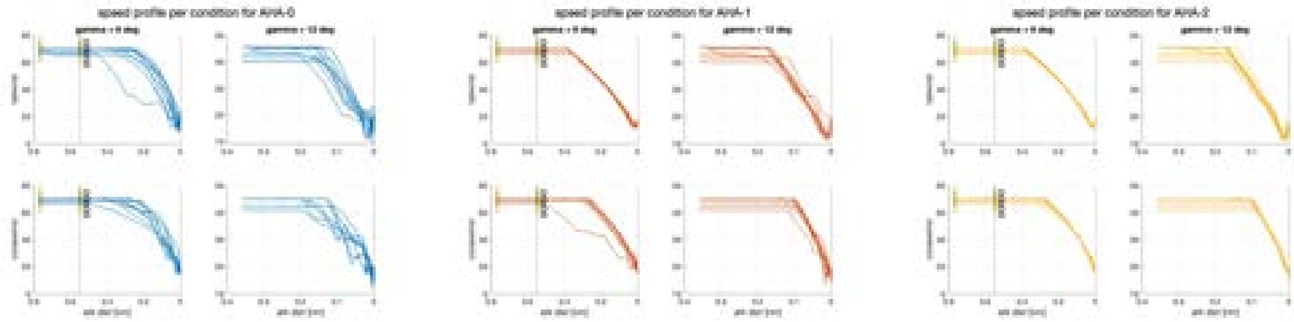
*g) Heading:* No clear trends were found for heading at touchdown. Pilots mentioned that heading deviation was a low priority metric and not considered in high workload situations.

### B. Pilot Activity

Fig. 15 shows root mean square box plots of pilot inceptor activity for the final approach across automation concepts, wind directions and approach path angles. This graph focuses on deflections in twist $\delta_{\mathrm{twist}}$ and throttle $\delta_{\mathrm{thr}}$ and omits longitudinal $\delta_{\mathrm{lon}}$ and lateral $\delta_{\mathrm{lat}}$ stick deflections, since the latter don't show any significant trends across independent conditions. The trends in twist action $\delta_{\mathrm{twist}}$ show the beneficial effect of the automatic decrab function in AHA-1 and AHA-2. These two automation levels exhibit significantly reduced pilot activity in twist across all wind directions and approach angles. The trends in throttle action $\delta_{\mathrm{thr}}$ show the beneficial effect of the automatic deceleration feature in AHA-1 and AHA2. However, AHA-1 maintains a nominal deceleration rate which can still be perturbed by turbulence and other disturbances, and thus needs only minor throttle adjustments towards the end. AHA-2 on the other hand shows the same decelerating behavior while also closing in on a touchdown target set by the pilot. This removes almost all throttle inputs towards the end. A more detailed discussion in the functionalities of the aforementioned automatic decrab and automatic deceleration features of the respective AHA modes is included in [2].

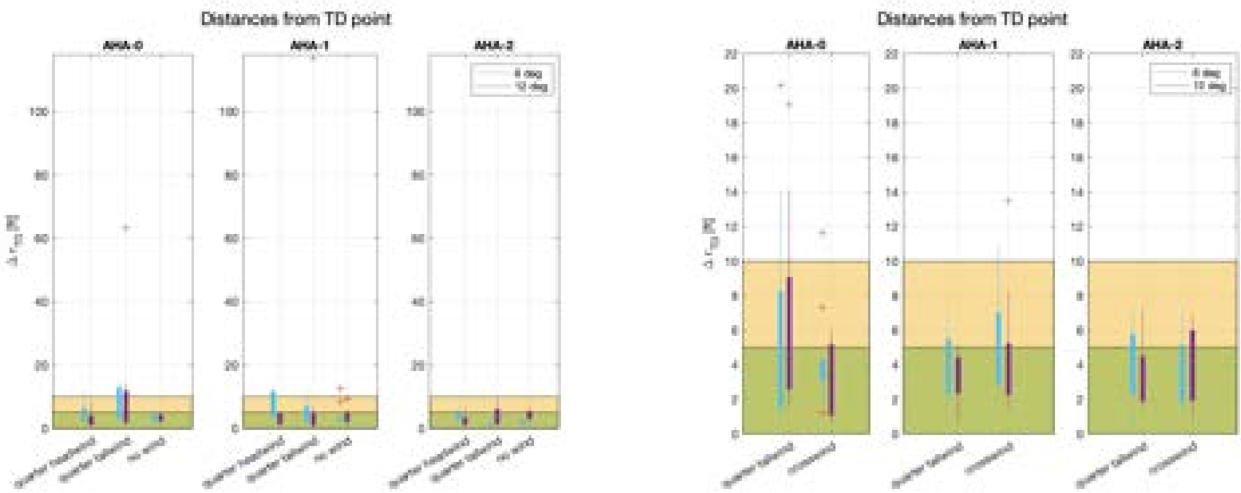
## VII. Major findings

This section summarizes the general observations from the analysis of performance criteria in Sec. VI, and more precisely how many pilot participants were able to achieve either desired performance, adequate performance or neither of both. The threshold values to distinguish between them were given in Sec. IV-C in Tab. I, II and IV. Fig. 16 focuses on one specific scenario of the approach with automation concept AHA-0, no wind and a nominal approach path of 6 deg. The X-axis shows that there were 9 pilots who provided ratings. The bars in the chart from top to bottom indicate overall pilot performance for respectively approach glidepath deviation, approach crosstrack deviation, heading at touchdown, distance to target at touchdown, vertical speed, longitudinal speed and lateral speed at touchdown, overshoot, energy used for hover (not considered in this publication), hover time, handling qualities rating and workload rating. The colors reflect the performance levels as follows: desired is green, adequate is yellow and neither of both is red. A 95 percentile threshold was used for the glideslope and crosstrack deviations. This means that if a pilot's performance was mostly in the desired performance area, and temporarily dipped into



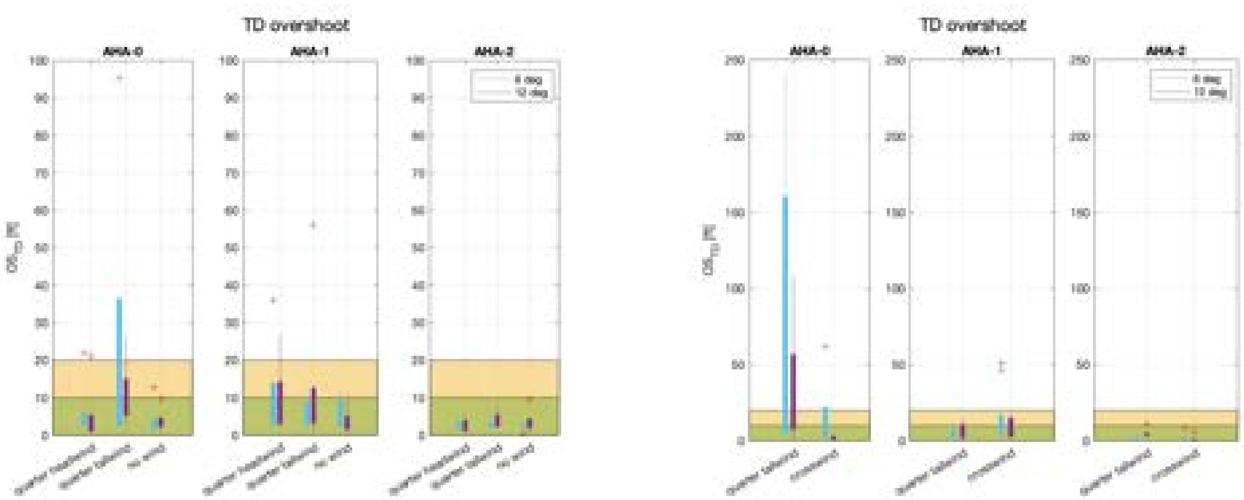
(a) AHA-0 (b) AHA-1 (c) AHA-2

Fig. 8. Speed profile during final approach across automation concepts, wind directions and approach path angles



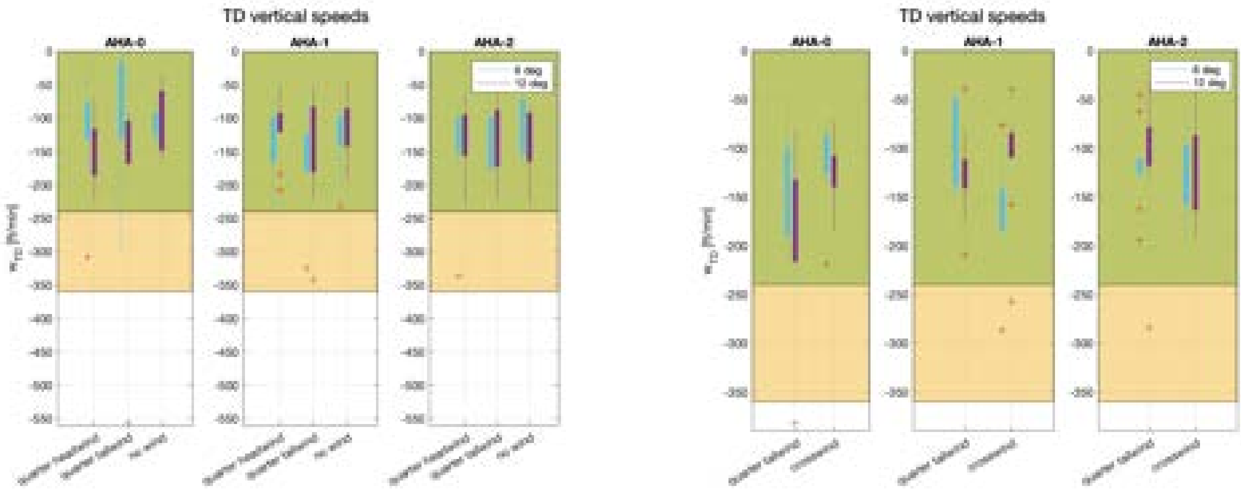

(a) approach (+ = outlier) (b) final approach (+ = outlier)

Fig. 9. Distance of touchdown location to center point of TLOF area across automation concepts, wind directions and approach path angles



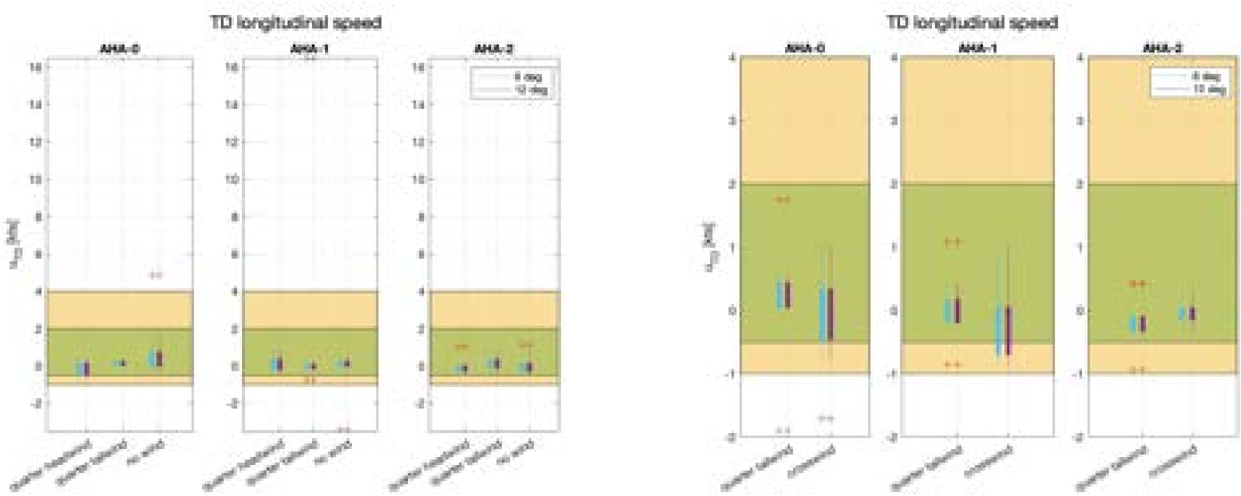

(a) approach (+ = outlier) (b) final approach (+ = outlier)

Fig. 10. Box plots of overshoot values beyond the TLOF area across automation concepts, wind directions and approach path angles




(a) approach (+ = outlier)  (b) final approach (+ = outlier)

Fig. 11. Box plots of vertical speed at touchdown across automation concepts, wind directions and approach path angles



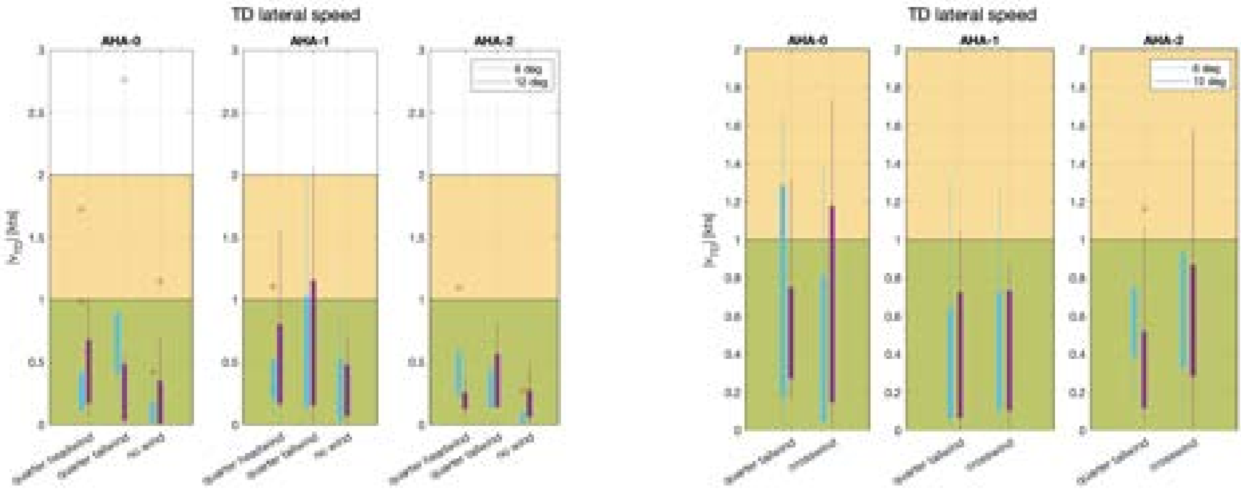

(a) approach (+ = outlier)  (b) final approach (+ = outlier)

Fig. 12. Box plots of longitudinal speed at touchdown across automation concepts, wind directions and approach path angles

adequate performance for less than 5% of the evaluation time, then performance would still be labeled as desired. However more than 5% adequate lowers the scoring to adequate. As an example, for the hover time, two participants achieved desired performance and five of them reached adequate performance. Two participants performed inadequately with respect to the aforementioned hover time metrics in Table II in Sec. IV-C.

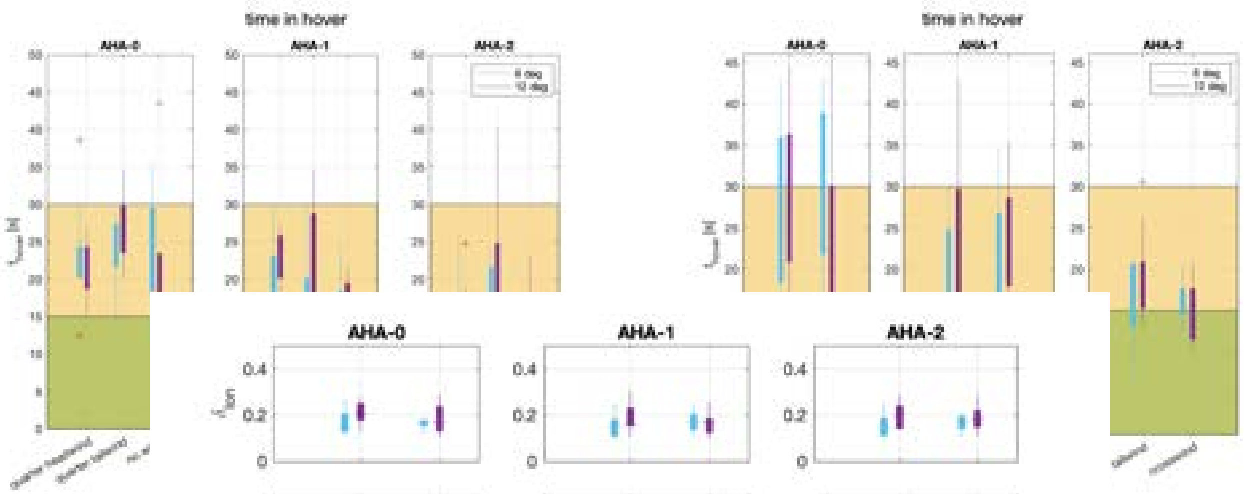
The bar charts, like the one shown in Fig. 16, are grouped per automation concept and wind direction versus path angle in Fig. 17, in order to observe certain trends. As an illustration, the bar chart from Fig. 16 appears in the top left corner of Fig. 17. Fig. 17 demonstrates multiple trends between all the independent conditions. In general, higher automation levels improve performance metrics numbers and handling qualities. They also reduce the workload. Especially within AHA-0, a steeper approach path and/or a disadvantageous wind direction (especially tailwinds) deteriorate performance numbers, handling qualities and workload. However, higher automation and especially AHA-2 significantly reduce this aforementioned drop in performance and pilot ratings for more challenging approach paths and wind directions. The two last columns in Fig. 17 show that performance metrics and pilot ratings for AHA-2 are more consistent across all operational conditions (wind directions and approach path angles), demonstrating that this automation concept is more capable for different operational and environmental conditions.

The main findings show that the higher automation AHA concepts assist in improving performance while reducing the




(a) approach (+ = outlier)  (b) final approach (+ = outlier)

Fig. 13. Box plots of lateral speed at touchdown across automation concepts, wind directions and approach path angles



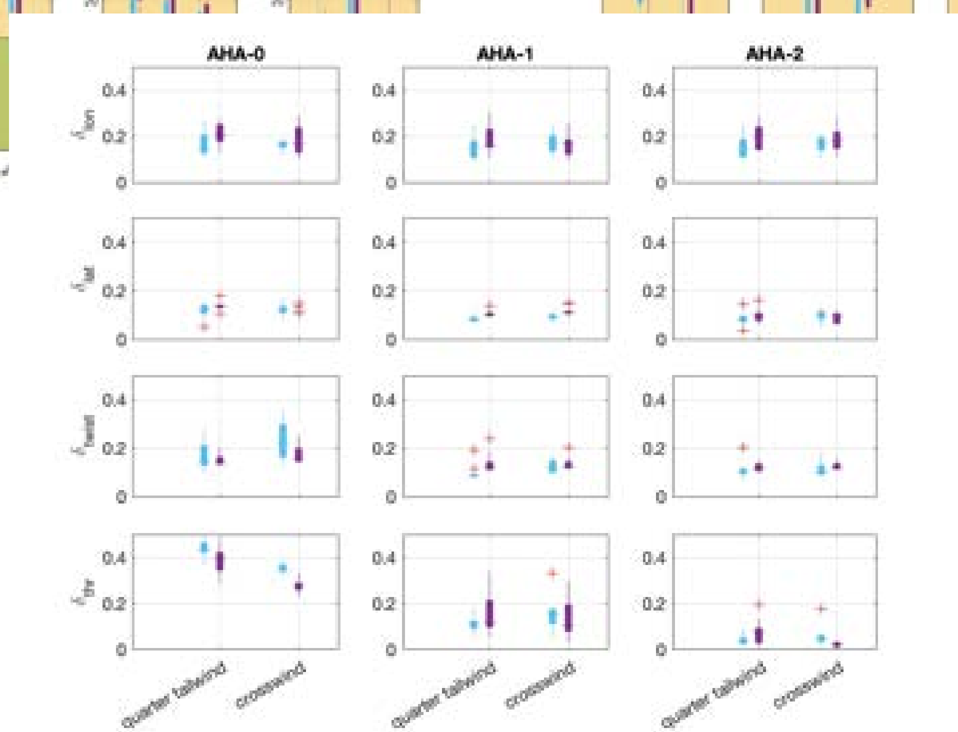




Fig. 15. Root mean square box plots of pilot inceptor activity for final approach across automation concepts, wind directions and approach path angles (+ = outlier)

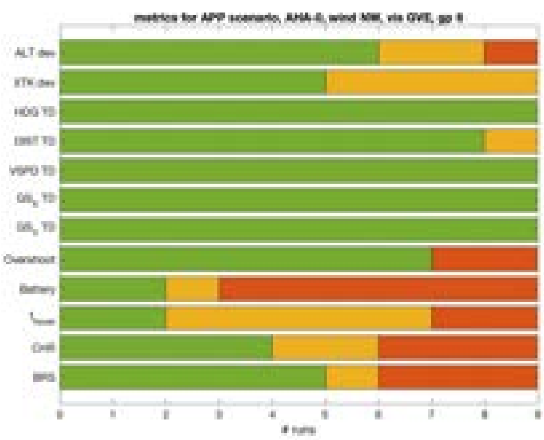



Fig. 16. Performance metrics bar chart for AHA-0 in no wind direction on a nominal approach angle

required pilot activity, also resulting in a more streamlined approach, transition to hover and touchdown in a shorter time. Overall, these results show improved landing performance with respect to accuracy, time, energy usage and pilot ratings for higher AHA concepts.

In the context of passenger and crew comfort, load factors along all three axes should stay between some limit threshold values around the objective value as was specified in Table III in Sec. IV-C. Fig. 18 analyzes load factor trends along all axes. Decelerations mostly translate to longitudinal $n_x$ load factors along the X-axis. The outline of Fig. 18 is similar as Fig. 17, with 3 bars per chart indicating from top to bottom respectively $n_x$, $n_y$ and $n_z$. The bar charts show how many pilots stayed either within the desirable, adequate or neither limits around the objective value, by means of the respective colors green, yellow and red. Lateral load factors are all within the desired range throughout all the independent variable combinations for all pilots. Vertical load factors too, except for a quartering tailwind with a steep approach angle in degraded visibility (pilots broke out of the cloud base at 250 ft, see also Sec. V-B), which compressed their time to flare and decelerate. Most pilots still achieved desired performance but a few of them dropped to adequate performance. Most interesting is the longitudinal load factor $n_x$ caused by deceleration. Headwind helped to keep the longitudinal load factors in the desired range for all automation concepts and approach angles. For all other wind directions, higher automation concepts show more consistent desired load factors for nominal approach angles. Higher automation concepts don't improve the metrics for steeper approach angles. Steep approaches with tailwinds in degraded visibility resulted in the worst $n_x$ metrics. At least half the participants reached inadequate levels across all AHA concepts due to the compressed time to flare and decelerate.

Surveys and comments echo the findings of the performance metric analysis. All but 1 pilot rated AHA-2 as their preferred automation concept, with many commenting on the ease of use, like: *"The AHA-2, being able to hit that button and let it do everything for you makes life a lot easier... I would like to have these features in every helicopter. My workload is very low."* While adequate performance was achievable, many pilots remarked on their lack of comfort with the steep approach scenario, commenting on their unusual nose down attitude and inability to see the horizon, like: *"a face full of dirt"*.

Overall, the higher automation concepts show improvements for performance metrics, pilot ratings as well as passenger and crew comfort criteria for nominal approach angles. However, during the simulator experiments it was also observed that higher automation concepts necessitate the use of additional cockpit display information, which increases the risk that the pilot's situational awareness, of for example other traffic nearby, is reduced in higher workload scenarios. This finding is the main topic of the companion papers [8], [10].

## Acknowledgment

The authors would like to thank the NASA Ames Vertical Motion Simulator (VMS) staff Matt Blanken, Sam Orth and Tejas Lotay for supporting this experiment.

## References

[1] "A rational construct for simplified vehicle operations (svo)," General Aviation Manufacturers Association, Washington D.C. and Brussels, Belgium, GAMA EPIC SVO Subcommittee Whitepaper, May 2019. [Online]. Available: https://gama.aero/documents/svo-whitepaper-a-rationale-construct-for-simplified-vehicle-operations-svo-version-1-0-may2019/

[2] J. Kaneshige, T. Lombaerts, K. Shish, and M. Feary, "Simplified vehicle control concept for a lift plus cruise evtol vehicle," in *AIAA AVIATION FORUM AND ASCEND 2024*. American Institute of Aeronautics and Astronautics, Jul. 2024, doi: 10.2514/6.2024-4207.

[3] C. Silva, W. R. Johnson, E. Solis, M. D. Patterson, and K. R. Antcliff, "VTOL urban air mobility concept vehicles for technology development," in *2018 ATIO Conference*. AIAA, jun 2018.

[4] G. Danek, "Vertical motion simulator familiarization guide," NASA Ames Research Center, Technical report NASA-TM-103923, May 1993. [Online]. Available: https://ntrs.nasa.gov/search.jsp?R=19940008535

[5] S. Beard, S. Reardon, E. Tobias, and B. Aponso, "Simulation system optimization for rotorcraft research on the vertical motion simulator read more: https://arc.aiaa.org/doi/abs/10.2514/6.2012-4634," in *AIAA Modeling and Simulation Technologies Conference*. American Institute of Aeronautics and Astronautics, 2012, no. AIAA 2012-4634.

[6] E. Lewis and N. Vuong, "Integration of matlab simulink models with the vertical motion simulator," in *AIAA Modeling and Simulation Technologies Conference*, no. AIAA-2012-4797. American Institute of Aeronautics and Astronautics, 2012.

[7] M. Feary et al., "Evaluation of novel v/stol aircraft control for expected aam operations," in *AIAA AVIATION 2023 FORUM*. American Institute of Aeronautics and Astronautics, jun 2023.

[8] A. Villa et al., "Simulator evaluations of increasing automation in an evtol vehicle on pilot performance of secondary tasks," in *IEEE Digital Avionics Systems Conference 2025*. IEEE, Sep. 2025.

[9] M. Feary et al., "Development of operational task elements for evaluation of advanced air mobility aircraft automation," in *IEEE Digital Avionics Systems Conference 2025*. IEEE, Sep. 2025.

[10] K. Monk et al., "Characterizing the pilot experience during motion-simulated evtol approaches," NASA, Moffett Field, CA, USA, techreport NASA/TP-20250006571, 2025.

[11] G. Cooper and R. Harper, "The use of pilot rating in the evaluation of aircraft handling qualities," National Aeronautics and Space Administration, Washington D.C., Technical Note TN D-5153, April 1969. [Online]. Available: http://www.dtic.mil/get-tr-doc/pdf?AD=AD0689722

[12] A. H. Roscoe and G. A. Ellis, "A subjective rating scale for assessing pilot workload in flight: a decade of practical use," Royal Aerospace Establishment, Farnborough, UK, techreport 90019, feb 1990.

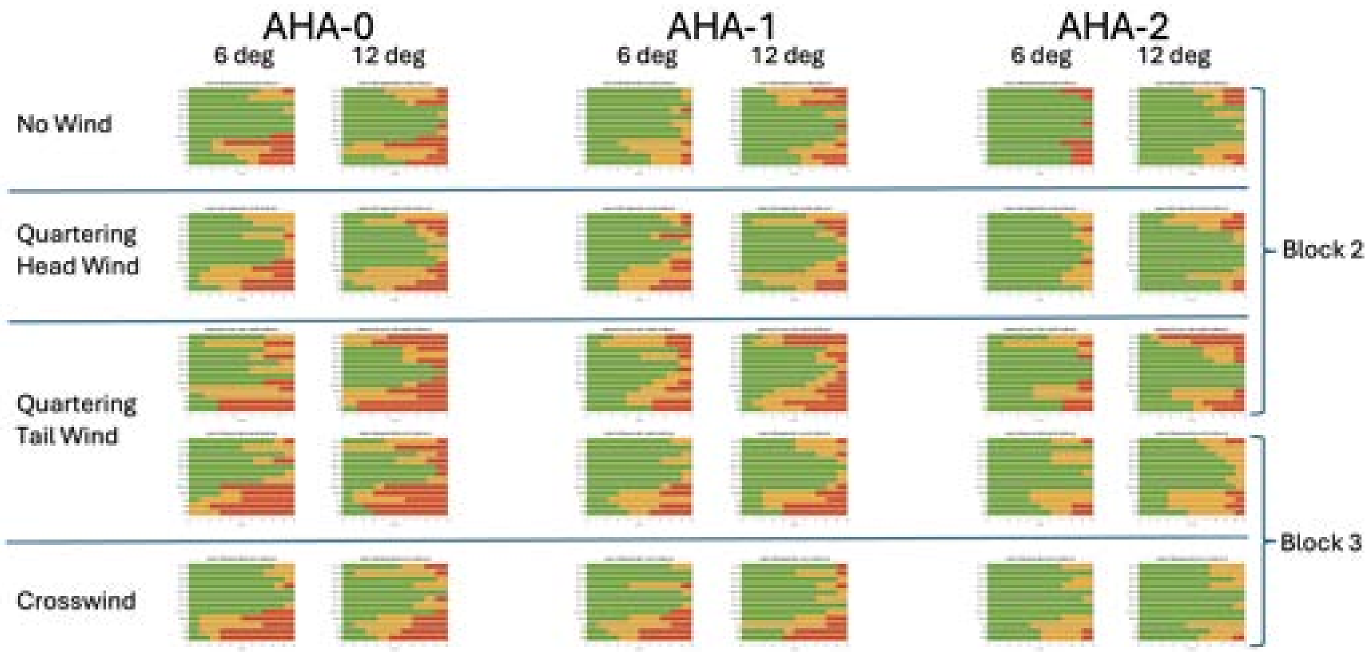



Fig. 17. Overview of performance metrics differences across automation concepts, wind directions and approach path angles

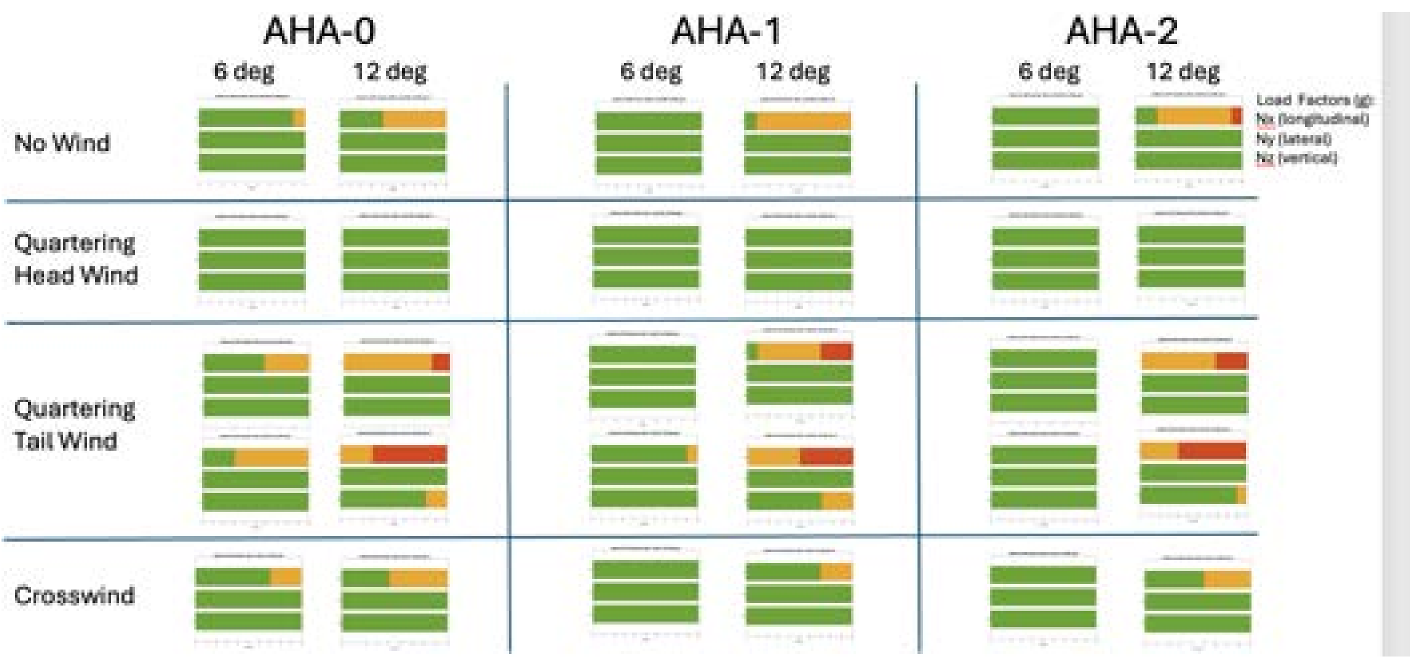



Fig. 18. Overview of load factor differences across automation concepts, wind directions and approach path angles