DOI: 10.13009/EUCASS2023-426
Aerospace Europe Conference 2023 – 10TH EUCASS – 9TH CEAS

Preliminary study of tracking vs boundary avoidance task effects on rotorcraft pilot involuntary response

Qiuyang Xia⋆ ⋆⋆ Davide Marchesoli⋆, Pierangelo Masarati⋆†, and Meng Liu⋆⋆
⋆Politecnico di Milano
Via La Masa, 34, Milan, Italy
⋆⋆Beihang University
37 Xueyuan Rd., Haidian Dist., BEIJING, China
qiuyang.xia@polimi.it · davide.marchesoli@polimi.it · pierangelo.masarati@polimi.it · liumeng@buaa.edu.cn
†Corresponding author

Abstract

Helicopters are used in harsh tasks that require operating in ground proximity, tracking targets while avoiding impact obstacles, namely a combination of point tracking and boundary avoidance objectives. A simplified helicopter simulation task is used to investigate point tracking and boundary avoidance tasks. The analysis of variance is used to study the effects of task conditions on participants' tracking errors and input aggression. The overall tracking error shows a negative correlation with input aggression. The participants tend to have higher input aggression and lower tracking error near the boundaries, exposing the switching of input strategies under different task conditions.

1. Introduction

Current high-performance rotorcraft have been developed to meet the increasing demands of various missions. During the process of creating and operating the aircraft, engineers and pilots must anticipate and manage unfavourable occurrences known as Rotorcraft-Pilot Couplings (RPCs).[1] These phenomena emerge from the undesired and unexpected coupling between the pilot and the vehicle and can lead to instabilities of both oscillatory and non-oscillatory nature, degrading handling qualities, increasing structural strength requirements, and potentially resulting in catastrophic accidents.

Before 1995, the aircraft and rotorcraft communities referred to Aircraft- and Rotorcraft-Pilot Coupling events as Pilot Induced Oscillations (PIO) and Pilot Assisted Oscillations (PAO).[2,3] Such denominations put inappropriate emphasis on the role of pilots as the primary cause of A/RPCs, whereas the culprit of the phenomenon lies in the proneness of the vehicle to adverse interaction with the pilot.

Boundary-Avoidance Tracking (BAT) is a pilot-task model proposed by Gray,[4,5] which stems from the consideration that in the process of performing flight tasks, pilots not only need to complete the task of "maintaining specific conditions" (point tracking, a "positive" objective) but also typically need to "avoid certain conditions" (boundary avoidance, a "negative" objective), such as clearance from obstacles, or staying away from dangerous operational conditions, like the stall for fixed-wing aircraft or vortex-ring susceptible envelope for helicopters.

Boundary avoidance tracking can capture the struggle between the positive and negative objectives of the pilot while describing the onset of the corresponding PIO phenomenon.

This study is based on a simple hardware flight simulator. Flight simulation plays an important role in areas such as human-machine interaction, pilot modelling, and situational awareness. Lu and Jump[6] established and determined the pilot model and parameters under the BAT task using flight simulation tasks, while Feng *et al.*[7–9] used flight simulation tasks to determine the relationship between task design, situational awareness of subjects, and work performance. Zanoni *et al.* used flight simulation to study the biomechanical feedthrough of the upper limbs of pilots and the effect of the task on pilots' muscular activation.[10–12]

An important element of the task design of this study lies in its randomness. Several previous studies about boundary avoidance used periodic tasks,[13,14] which would cause participants to learn the regularity of the task goals and predict their trajectory, thus affecting the tracking performance and objectivity of the experiment and model fitting.

DOI: 10.13009/EUCASS2023-426

2. OBJECTIVE AND APPROACH

This research investigates the pilot's response to the simultaneous and contrasting goals of point tracking and boundary avoidance in a simplified simulated flight task; the main aim of this study lies in pilots' tracking performance and input aggression under different task conditions regarding both point tracking and boundary avoidance tracking. Section 3 describes the methodology of this study. Section 4 describes the data analysis procedure. Section 5 presents the results of the experiments. Conclusions are finally drawn in Section 6.

3. METHOD

3.1 Participants

Fourteen participants volunteered and took part in the experiments. The participants had no specific helicopter training or former experience with the task. One of them was female, twelve of them had video game experience with controllers, and four of them had simulated or real-life fixed-wing piloting experience. The participants were briefed about the test procedure and its objectives, without excessive details, to avoid influencing the control strategies they were going to use. They were informed that they could call the end of the experiment at any time if they felt any physical or mental discomfort. All participants signed an informed consent form prior to the experiment.

3.2 Test Devices

The joystick utilized in this study is a ThrusterMaster developed by Guillemot Corporation S.A., France. It has two main sticks. The left one only moves in the longitudinal direction, simulating the "collective" inceptor of a helicopter. The right one moved in both longitudinal and lateral directions, simulating the "cyclic" inceptor of a helicopter. The simulated task was developed and operated on a laptop, with an Intel Core i5-7300HQ processor, Nvidia Geforce GTX1060 6 GB VRAM graphics card, and 16 GB of RAM. The laptop's operating system was Windows 10 21H2, version 19044.1645.220403-0835. The joystick was connected to the laptop using its USB cable. Figure 2 shows the set-up of the experiment.

Figure 1: The joystick used for the test.

3.3 Experiment Design and Procedures

3.3.1 Task Design

The tasks were designed based on a helicopter tracking task and the concepts of "point tracking" and "boundary avoidance tracking" (BAT). During the task, the participants receives visual information from the monitor. Two types of information are displayed on the monitor, the "point" to be tracked and the "boundary" to be avoided. Two types of tasks were performed: one without "boundary", where participants could focus on the "point tracking" task; the other with "boundary", where the participants were told to conduct a point tracking task (a "positive" objective) while avoiding the boundaries (a "negative" objective), such that once the boundary was touched, the task would fail immediately.

DOI: 10.13009/EUCASS2023-426

Figure 2: The experiment's set-up.

3.3.2 GUI Design

The GUI was designed in Scalable Vector Graphics (SVG) format. The participants would see the interface of Fig. 3, whose main elements are:

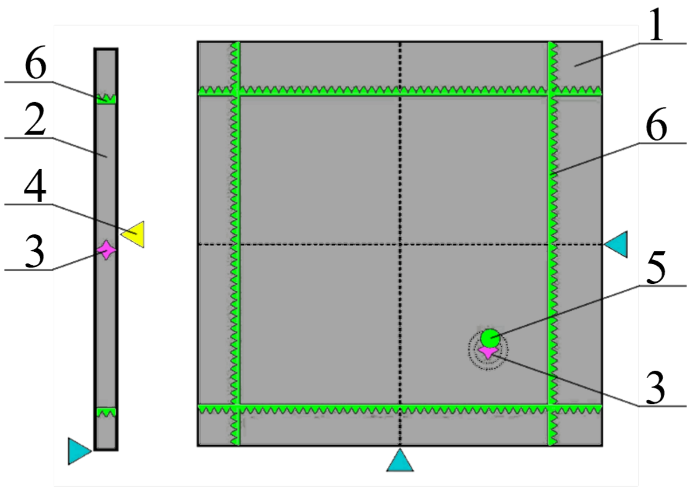

Figure 3: GUI interface.

1. a square scale, related to the cyclic stick;
2. a vertical scale, related to the collective stick;
3. purple diamonds, indicating the point tracking target indicators;
4. a triangle indicator, displaying the pointer of the collective stick;
5. a dot indicator, displaying the pointer of the cyclic stick;
6. sawtooth boundaries, for boundary avoidance tracking tasks.

DOI: 10.13009/EUCASS2023-426

The vertical and horizontal axes of the square scale correspond to the longitudinal and lateral components of the cyclic stick's motion, respectively. Among the displayed elements, (4) and (5) would change colour according to the distance between the target and the pointer, as an indicator for the participants to adjust their controlling strategies; (6) would also change colour if the pointer were close to that specific boundary, as a visual proximity warning.

3.3.3 Simulink Module

The Simulink module of Fig. 4 was integrated into MATLAB 2022a to generate and output the signals related to target and boundary movement, collect the input signals from the joystick, and filter them through the helicopter transfer function discussed in Section 3.3.4.

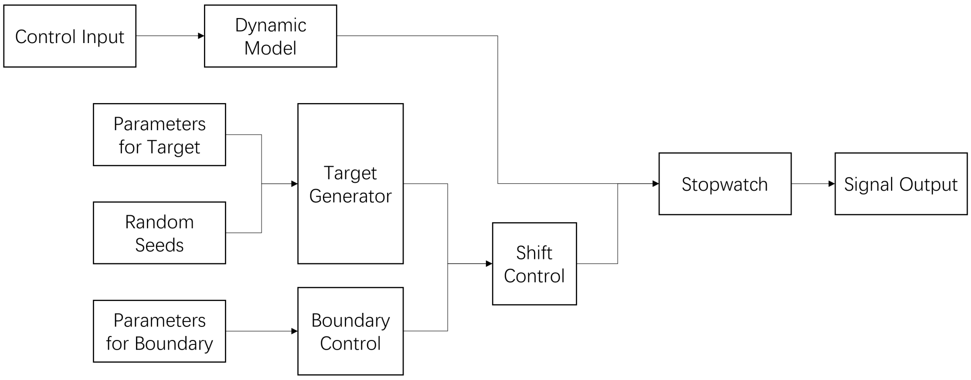

Figure 4: Simulink Module.

Several parameters control the movement of the target and boundaries. For target movement, the adjustable parameters include motion speed, direction, and duration, stance duration, maximum position, and task duration. For boundary motion, the adjustable parameters include motion speed, lower limit position, and type of motion pattern. Random target motion parameters were set within certain limits. Figure 5 shows an example of one-axis target movement.
Random seeds were utilized to generate reproducible random signals. By selecting a sequence of random seeds, the participants would individually experience a set of unpredictable random tasks, while tasks were consistent among all the participants.

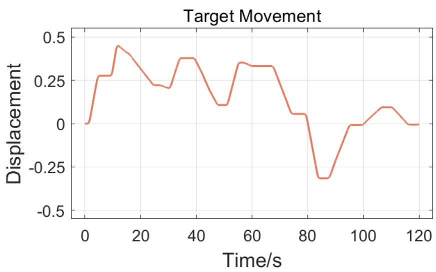

Figure 5: Target Movement.

Boundary movement patterns could be configured as four types, meaning "discrete","continuous", "discrete with shifting", and "continuous with shifting". Figure 6 shows the boundary movement patterns.
In the definition of the tasks, care was taken to make them always attainable; no task required getting too close to a boundary or even having to cross one, to reach the target.

3.3.4 Simplified Helicopter Dynamics

A second-order transfer function is implemented in this study as the Dynamic Model of Fig. 4. The structure of this transfer function mimics the function used in[15] to describe the helicopter dynamics along the vertical axis in hover. The parameters of the transfer function have been tuned to find a trade-off between realism and feasibility/difficulty of the task. No claim is made on the fidelity or even the representativeness of such a dynamic model. The resulting transfer function is

$$H(s) = \frac{0.45}{s^2 + 0.3s} \tag{1}$$

DOI: 10.13009/EUCASS2023-426

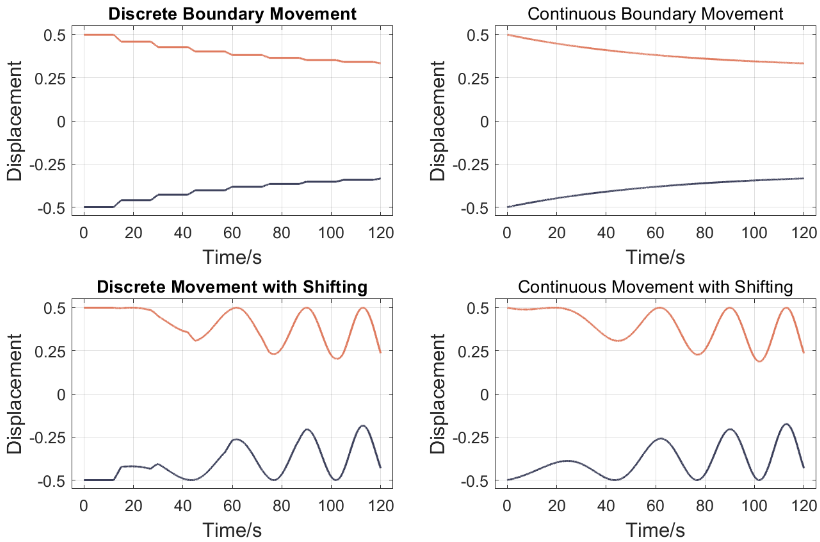

Figure 6: Boundary movement Patterns.

3.3.5 Task Patterns

The participants were instructed to operate only the cyclic stick, as operating two sticks at the same time proved to be too difficult among research group members under the configuration for this study. Correspondingly, target and boundary movements were only applied to the cyclic stick. The participants performed a sequence of 5 different types of tasks, 3 runs for each type (except for Task 0, which the participants could repeat as many times as they wished, for familiarization). The types of tasks are:

- Task 0: Point tracking task only, with no termination condition other than task duration. The maximum target movement was 60% of the scale's dimension. This task was for the participants to familiarize themselves with the joystick and response transfer function.
- Task 1: Point tracking task with boundary avoidance tracking, boundary movement is "discrete", no shifting movement.
- Task 2: Point tracking task with boundary avoidance tracking, boundary movement is "continuous", no shifting movement.
- Task 3: Point tracking task with boundary avoidance tracking, boundary movement is "discrete", with shifting movement.
- Task 4: Point tracking task with boundary avoidance tracking, boundary movement is "continuous", with shifting movement.

3.3.6 Index Definition

In this study, tracking error and input aggression are utilized to evaluate the performance and control strategy of the participants. The error is defined for the purpose of evaluating how well the participants performed the point-tracking task. Aggression is defined to evaluate how intensely the participants were manipulating the joystick. The larger the input amplitude or frequency, the larger the aggression is. Several definitions have been proposed, which differ in the norm that is used to evaluate the rate of the control input. Lu and Jump[6] proposed to use its 1-norm; in this work, the RMS is used instead, following the work of Gray.[16]
The indicators are defined as

$$\text{error} = \text{target} - \text{response} \tag{2}$$

$$\text{aggression} = \sqrt{\frac{1}{t_1 - t_2} \int_{t_1}^{t_2} \left|\dot{\delta}(t)\right|^2 dt} \tag{3}$$

where:

DOI: 10.13009/EUCASS2023-426

- target is the target movement signal;
- response is the response signal;
- $\delta(t)$ is the pilot's input signal; $\dot{\delta}(t)$ is its time derivative;
- t_1, t_2 are the start and end of a time interval for aggression analysis.

The signals are actually available as discrete time series, with a sample rate of 60 Hz. To evaluate the performance and aggression in a certain time period (the whole task run or a specific portion, for example), their root-mean-square (RMS) is calculated:

$$\text{error}_{\text{RMS}} = \sqrt{\frac{1}{n}\sum_{i=0}^{n}(\text{error}_i - \text{error}_{\text{mean}})^2} \tag{4}$$

$$\text{aggression}_{\text{RMS}} = \sqrt{\frac{1}{n}\sum_{i=0}^{n}(\text{aggression}_i - \text{aggression}_{\text{mean}})^2} \tag{5}$$

For the evaluation of a complete task run, the RMS value is directly calculated and the results are utilized as baseline data. For the evaluation of specific conditions within a task run, timestamps, when the conditions were met, are marked, and the corresponding error or aggression values are extracted to calculate the local RMS value. Data extracted from all task runs were grouped in terms of participants and task patterns respectively, and ANOVA was utilized to analyze the effect of differences among individuals and task conditions.

4. DATA ANALYSIS

4.1 Conditions and Boundary Thresholds

Different *conditions* were defined to distinguish different groups of situations the participants encountered during the tasks:

a. **Group 1**
   - *Approach*: the pointer is moving towards one of the boundaries;
   - *Leave*: the pointer is moving away from one of the boundaries;

b. **Group 2**
   - *Near*: the point is between one of the boundaries and its corresponding boundary threshold;
   - *Away*: the pointer is outside boundary thresholds.

c. **Group 3**
   - *Approach and Near*: both the *Approach* and *Near* conditions are simultaneously met;
   - *Leave or Away*: any of the *Leave* or *Away* conditions (or both) is met.

They are illustrated in Fig. 7.

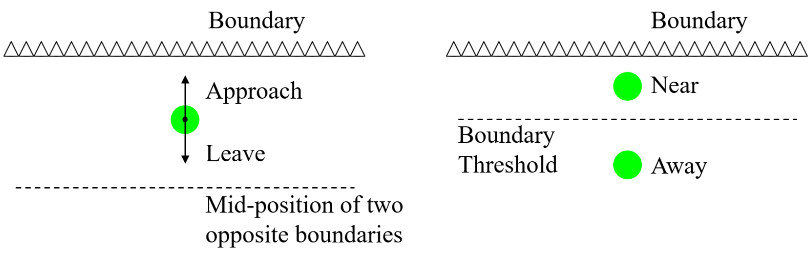

Figure 7: *Conditions* of Section 4.1.

The analysis presented in the following is based on a boundary threshold of 0.1.

DOI: 10.13009/EUCASS2023-426

4.2 Failing the Task

The existence of critical boundaries meant that participants could fail the task before the defined task duration of 120 s was reached. Statistical and regression analysis was done with task runs that did not fail, to extract data that fully represented participants' performances under pressure. Task runs that failed will be treated individually to analyze how the test developed leading to the failure of the task.

5. RESULTS

5.1 Individual Analysis

5.1.1 Baseline Performances

Baseline performances were extracted from the first 3 to 5 task runs where boundary avoidance tracking was not involved. The RMS values of the tracking error are shown in Fig. 8. The RMS values of the aggression are shown in Fig. 9.

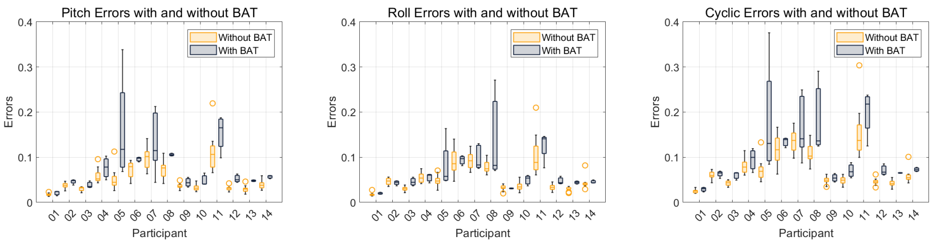

Figure 8: RMS values of tracking error.

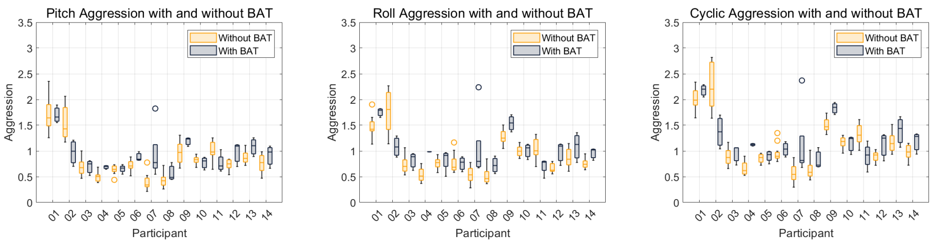

Figure 9: RMS values of input aggression.

In terms of tracking errors, the following results can be observed:

1. in task runs with BAT, the tracking error of participants 4 and 7 was higher in the pitch than in the roll direction; the tracking error of participant 8 was higher in the roll than in the pitch direction; the tracking errors of all participants showed significant difference ($p < 0.01$) in the pitch direction, but not in the roll direction ($p > 0.05$);

2. for most participants, task runs with BAT showed a higher and more scattered tracking error than that of task runs without BAT; exceptions are participants 1, 2, 6, 11, 13, and 14, whose tracking errors were less scattered in task runs with BAT, and participant 9, whose tracking error showed no significant difference;

3. participant 11 is the only one whose tracking error in task runs without BAT was higher than that in task runs with BAT, but the largest error was treated as an outlier.

The above-discussed comparison showed that a larger tracking error occurred in BAT tasks, and this was desired since we tended to create harder tasks to trigger different input strategies of the participants. The more scattered tracking error in task runs with BAT also showed that additional difficulties were brought in by BAT tasks, and the participants had to sacrifice tracking performance to avoid critical boundaries.
The comparison of the aggression came to the following results:

DOI: 10.13009/EUCASS2023-426

1. only participants 2 and 11 had a lower aggression in task runs without BAT than that in task run with BAT, and other participants had a higher aggression in task runs without BAT. The difference in the input aggression is significant ($p < 0.001$);

2. scattered degree of aggression showed no significant difference for most cases except that participant 7 showed a larger scatter region (contributed by an outlier) in task runs with BAT. The changing of aggression for participants 2 and 11 was unique among other participants, indicating that they chose less aggressive input strategies for BAT tasks. While other participants utilized stronger input strategies for more difficult tasks.

5.1.2 Considering the Condition

a. **Group 1**

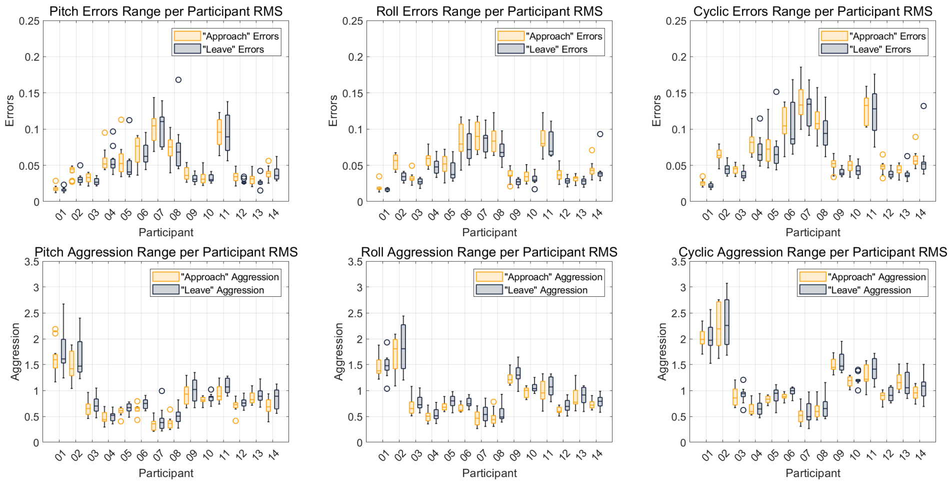

Figure 10: Error and Aggression under the *Approach* and *Leave* conditions.

The tracking errors under the *Approach* condition are slightly larger than those under *Leave* for most participants, but the results showed did not show sufficient statistical significance ($p > 0.05$). Furthermore, participants 5, 6, 8, 11, and 14 presented a larger scattered region for tracking errors. Combined with their behaviour during the test, a conclusion can be drawn that they tended to aggressively pull back the joystick when the target was leaving the boundary area, resulting in larger maximum tracking error values. The input aggression under the *Approach* condition was slightly larger than under *Leave*, though again no sufficient significance could be observed ($p > 0.05$).
The result shows that participants were more likely to control the stick less aggressively when they tried to follow the target getting close to the boundary, to avoid hitting it.

b. **Group 2**

The tracking errors under the *Near* condition are significantly lower than under *Away* ($p < 0.001$) for all participants. The analysis of the participants' behaviour during the test runs led to two possible conclusions:

1. the participants exerted greater effort to control the stick, achieving high accuracy for the point tracking task while preventing hitting the boundary;

2. when the target was in the threshold of the *Near* condition, it was stationary for a larger portion of time than outside the threshold, so point-tracking tasks were easier.

The input aggression showed inconsistent results across participants. For some of them, the input aggression was higher under the *Near* condition, while for others it was lower. Participants 10 and 11 presented different input strategies for the pitch and roll direction. This might indicate that they tended to focus on one direction. For all participants, the difference in the input aggression was significant ($p < 0.05$).

c. **Group 3**

DOI: 10.13009/EUCASS2023-426

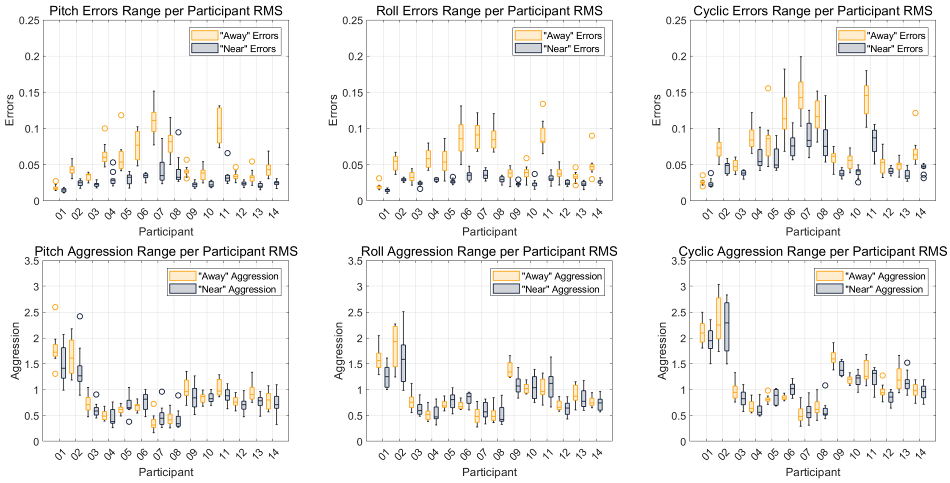

Figure 11: Error and Aggression under the *Near* and *Away* conditions.

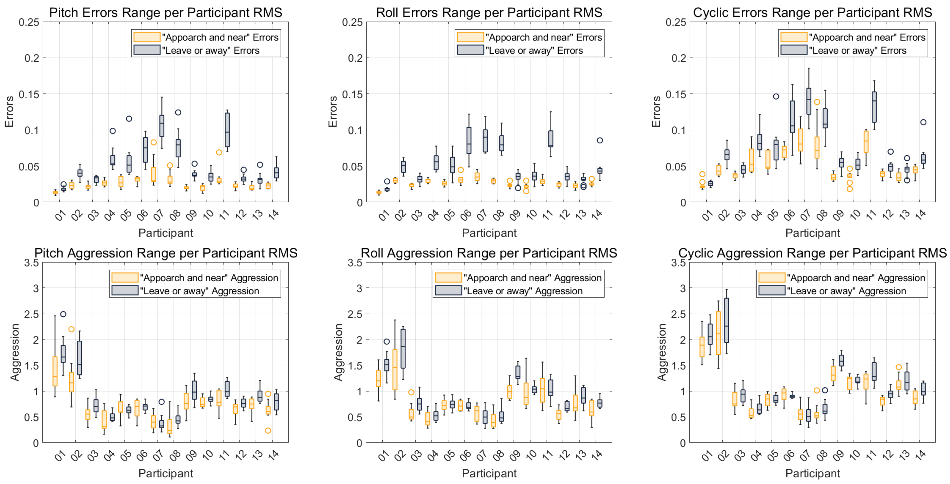

Figure 12: Error and Aggression under the *Approach and Near* and *Leave or Away* conditions.

The tracking errors under the *Approach and Near* and *Leave or Away* conditions showed a similar trend as under *Near* and *Away* mainly because tracking errors under *Approach* and *Leave* showed no significant difference. The difference in tracking error here also showed statistical relevance ($p < 0.001$). Inconsistent results were observed for aggression also under this group. The difference between conditions and participants is significant for pitch and roll axis ($p < 0.05$), but not the composed cyclic, i.e., the combination

$$\sqrt{\text{error}^2_{\text{longitudinal}} + \text{error}^2_{\text{lateral}}} \tag{6}$$

($p > 0.05$).
Different participants applied different input strategies under severe task conditions, resulting in different point-tracking performances.

5.2 Failed Task Runs Analysis

In this Section, failed task runs that were representative are plotted and analyzed.
In the test run shown in Fig. 13, the participant failed the task at about 65 s. Between 42 s and 50 s, the roll direction target was approaching the right boundary. While the participant tried to track the target, they pulled the stick back periodically to avoid exceeding the boundary. As a consequence, the pointer also approached the boundary periodically, but with some delay with respect to the participant's input. Right before the pointer hit the boundary, while approaching it, the participant tried to slow down or stop the pointer by pulling the stick backwards. Because of the lag caused by the transfer function, the response was delayed, resulting in hitting the target, and thus failing the task.

DOI: 10.13009/EUCASS2023-426

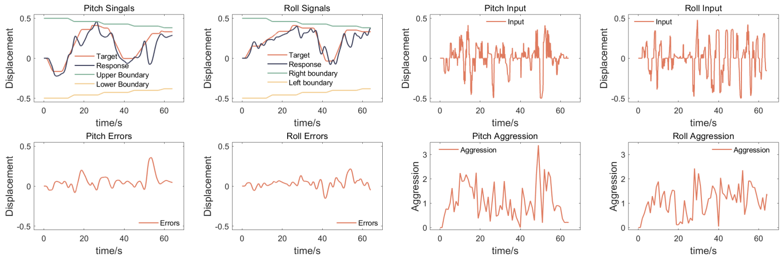

Figure 13: Task failed while trying to track the target near the boundary.

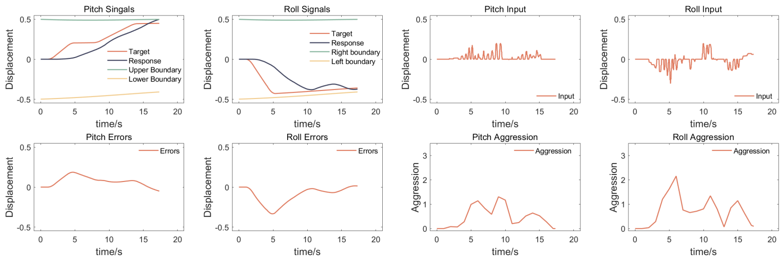

Figure 14: Task failed while ignoring one axis.

Another failed task run is shown in Fig. 14. The task failed at around 17 s. Comparing the input signal in both pitch and roll directions, one can observe that the participant was trying to control the stick to follow the target in the roll direction, where the target underwent a sudden stop close to the boundary. In the meanwhile, in the pitch direction, the target was also moving towards the boundary, but the participant seemed to ignore this axis and focused their attention on the roll axis, consequently failing the task with respect to the pitch axis.

5.3 Regression Analysis

During data processing, it was observed that participants who exhibited higher levels of input aggression presented lower tracking errors. Conversely, participants who had higher tracking error and task failure count exhibited lower input aggression. In order to provide a more comprehensive analysis of the data, all data points were plotted in Fig. 15, including failed trials. The Figure indicates that although there is considerable variation in the data points, they tend to be concentrated in the lower-left corner of the graph. This pattern suggests that tracking error and input aggression may negatively correlate.

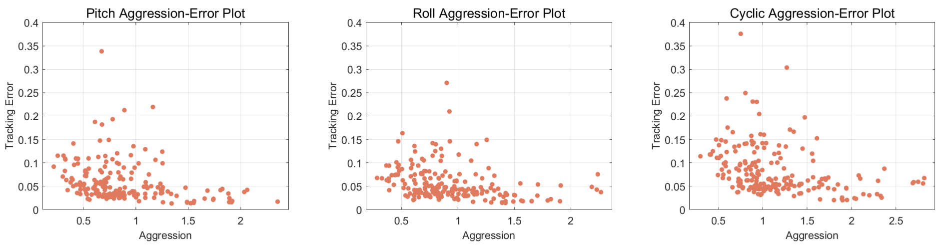

Figure 15: Aggression-Error plot.

Table 1: Regression Training Results

	Pitch	Roll	Cyclic
RMSE	0.027	0.025	0.033
R-Squared	0.59	0.53	0.62
MAE	0.015	0.014	0.019

DOI: 10.13009/EUCASS2023-426

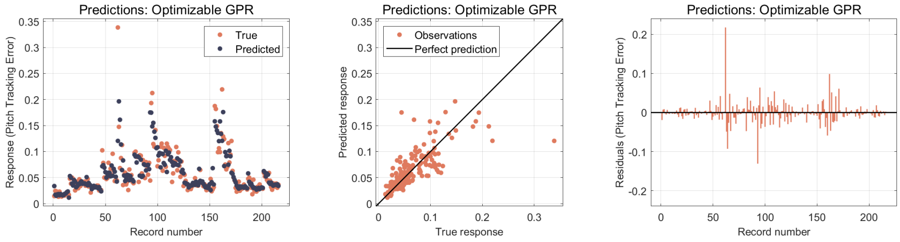

Figure 16: Gaussian Process Regression in the Pitch Axis.

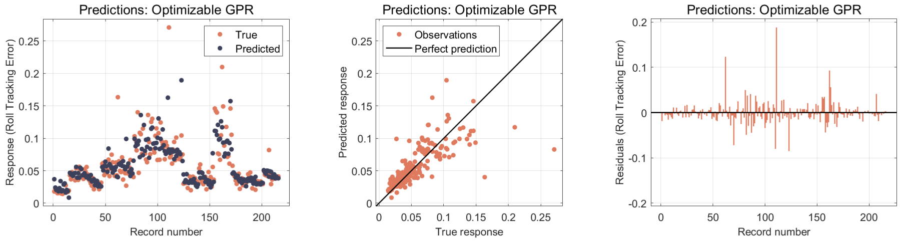

Figure 17: Gaussian Process Regression in the Roll Axis.

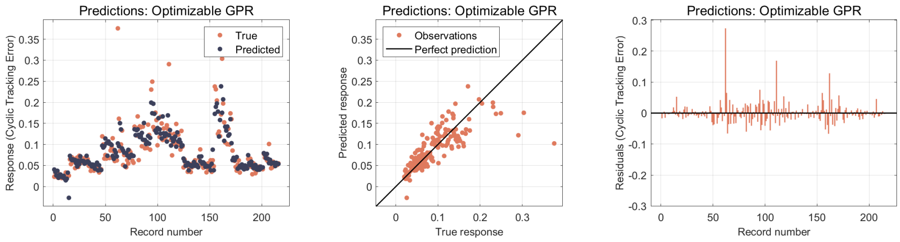

Figure 18: Gaussian Process Regression in the Cyclic Axis.

6. CONCLUSIONS

This paper featured a simulation task design based on the concepts of point tracking and boundary avoidance tracking, and a data analysis method to investigate pilots' point tracking performance and input aggression. Several results could be drawn from this study. First, during the whole experiment, participants had a learning curve for the joystick and task pattern, reflected in a significantly reduced tracking error from the task without boundary to tasks with boundary. Then, after the boundary avoidance tracking was introduced in the task, participants presented different input strategies, detected through aggression, resulting in different levels of tracking error. When the target was near the boundary, the participants presented significantly lower tracking errors ($p < 0.001$), and the levels of input aggression were also lower for the pitch and roll axis ($p < 0.05$). While the tracking error was not significantly affected by task patterns ($p > 0.05$), the input aggression showed a significant difference ($p < 0.001$). During the experiment, task failures were sometimes caused by two types of situations: a) the delay between the manual input signal and the motion of the pointer, and b) the distribution of the participants' attention. Regression analysis showed that tracking errors can be predicted to a certain extent, giving useful indications for pilot training and input strategy advising in future experiments. This research demonstrated the relationship between task condition, input strategy, and task performance. Task design, data analysis method, and results could inspire related research in pilot's biodynamic feedthrough, human-machine interaction and rotorcraft-pilot coupling. Future work will focus on implementing a more realistic experimental environment, with real helicopter control inceptors, establishing a pilot model, and exploring the full potential of the measured data.

References

[1] Marilena D. Pavel, Michael Jump, Binh Dang-Vu, Pierangelo Masarati, Massimo Gennaretti, Achim Ionita, Larisa Zaichik, Hafid Smaili, Giuseppe Quaranta, Deniz Yilmaz, Michael Jones, Jacopo Serafini, and Jacek Malecki. Adverse rotorcraft pilot couplings—Past, present and future challenges. *Progress in Aerospace Sciences*, 62:1–51, October 2013.

DOI: 10.13009/EUCASS2023-426

[2] Military Specification. Flying qualities of piloted airplanes. Technical report, MIL-F-8785C, 1980.

[3] Military Standard. Flying qualities of piloted aircraft. Technical report, US Dept. of Defense MIL-STD-1797A, 1990.

[4] William Gray. Boundary-escape tracking: A new conception of hazardous PIO. Technical report, Air Force Flight Test Center Edwards AFB, CA, USA, 2004.

[5] William Gray. Boundary Avoidance Tracking: A New Pilot Tracking Model. In *AIAA Atmospheric Flight Mechanics Conference and Exhibit*, page 5810, San Francisco, CA, USA, August 2005.

[6] Linghai Lu and Michael Jump. Multiloop Pilot Model for Boundary-Triggered Pilot-Induced Oscillation Investigations. *Journal of Guidance, Control, and Dynamics*, 37(6):1863–1879, November 2014.

[7] Chuanyan Feng, Xiaoru Wanyan, Kun Yang, Damin Zhuang, and Xu Wu. A comprehensive prediction and evaluation method of pilot workload. *Technology and Health Care*, 26(S1):65–78, January 2018.

[8] Chuanyan Feng, Xiaoru Wanyan, Shuang Liu, Hao Chen, and Damin Zhuang. An approach to situation awareness (SA) assessment in flight simulation: SA dynamic circulation (SADC) model. *Human Factors and Ergonomics in Manufacturing & Service Industries*, 31(5):559–569, 2021.

[9] Chuanyan Feng, Shuang Liu, Xiaoru Wanyan, Hao Chen, Yuchen Min, and Yilan Ma. EEG Feature Analysis Related to Situation Awareness Assessment and Discrimination. *Aerospace*, 9(10):546, October 2022.

[10] Andrea Zanoni, Alessandro Cocco, and Pierangelo Masarati. Multibody dynamics analysis of the human upper body for rotorcraft–pilot interaction. *Nonlinear Dynamics*, 102(3):1517–1539, November 2020.

[11] Matteo Daniele, Giuseppe Quaranta, Pierangelo Masarati, and Andrea Zanoni. Pilot in the loop simulation of helicopter-ship operations using virtual reality. *l'Aerotecnica, Missili & Spazio*, 99(1):53–62, 2020.

[12] Andrea Zanoni, Matteo Zago, Rita Paolini, Giuseppe Quaranta, Manuela Galli, and Pierangelo Masarati. On Task Dependence of Helicopter Pilot Biodynamic Feedthrough and Neuromuscular Admittance: An Experimental and Numerical Study. *IEEE Transactions on Human-Machine Systems*, 51(5):421–431, October 2021.

[13] L. Lu and M. Jump. Pilot modelling for boundary hazard perception and reaction study. In *43rd European Rotorcraft Forum, ERF 2017*, volume 1, pages 640–652, Milano, Italy, September 2017.

[14] Honglei Ji, Linghai Lu, Mark D. White, and Renliang Chen. Advanced pilot modeling for prediction of rotorcraft handling qualities in turbulent wind. *Aerospace Science and Technology*, 123:107501, April 2022.

[15] V. Muscarello, G. Quaranta, and P. Masarati. The role of rotor coning in helicopter proneness to collective bounce. *Aerospace Science and Technology*, 36:103–113, 2014.

[16] William Gray. A Generalized Handling Qualities Flight Test Technique Utilizing Boundary Avoidance Tracking. In *2008 U.S. Air Force T&E Days*, Los Angeles, CA, USA, February 2008.