1. **System Design**

Fig.1 Shows a participant performing a trial. 1, the quest 3 headset. 2, the experiment display for monitoring. 3, the fNIRS device. 4, the system computer.

**人在玩电脑

描述已自动生成**

Figure 1. Apparatus

Fig.2 illustrates the three conditions in our evaluation study.

电脑游戏画面

中度可信度描述已自动生成

Figure 2. Experiment Condition

1. **False Error Rates**

Fig.3 Shows the distribution of false errors caused by a lag in the system and the frontend.

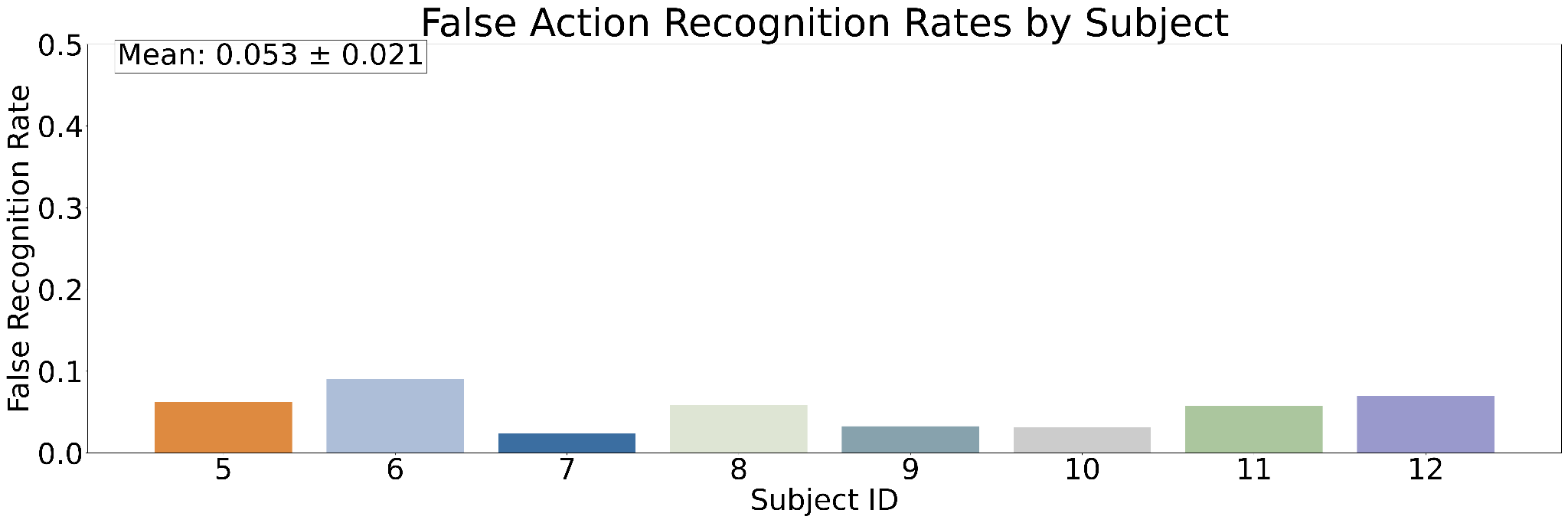


Figure 3. False Error Rates

1. **Preflight Paper Checklist**

The following is the provided paper checklist. Procedures that end in **A-I** are separated procedures that appear in the corresponding paper quantitative evaluation.

1. **Required items, mission equipment, and personnel.**

The following specifies the required items, mission equipment, and personnel equipment required for the mission. Equipment lists specify the minimum quantities required for the mission.

* 1. Personnel:
     1. Crew: 3 members (Copilot, Pilot, Troop Commander)
     2. Weight (other): **Empty: 15000 lbs**., 4 passengers, **Cargo:** **500 lbs**
  2. A/C Configuration / Drag
     1. Installed: Exhaust (HIRSS), Cockpit Doors, CMWS, Med Windows, SKIS
     2. Not Installed/Removed: **EIBF**, **Blade Erosion**, All Others

1. **Flight Parameters**
   1. Presets:

| **Equipment/Device** | **Preset ID** | **Frequency** | **Band/Other** |
| --- | --- | --- | --- |
| COM-1 | **1** |  |  |
| COM-2 | **4** |  |  |
| COM-3 | **5** | 127.600 | VHF-AM |
| COM-4 | **8** |  |  |
| VOR-ILS | **8** | 109.55 |  |

* 1. Route (Figure 2)
     1. Departure: Remote location: Huntsville International Airport (KHSV) (N34.159, W86.455), 889 ft
     2. Recommended Enroute Waypoints: WAMPM -> JOSEP -> FEWER
     3. Destination: Madison Sand Plant (**MSL**), 629 ft
  2. Flight Parameters:
     1. Barometric Pressure: 29.92 (in. Hg)
     2. Enroute Altitude: 4500 ft (between 4000 and 5000)
     3. Speed/IAS (enroute): 120 kts (minimum)
     4. Weather – IFR flight plan, Clear skies, no adverse weather conditions
        1. Departure (MSL): 75 deg F / 10 deg C
        2. Enroute (4500 ft): 57 deg F / 0 deg C
        3. Destination (MSL): 80 deg F / 12 deg C
     5. DRG/DNLD \*\*\*.\*\*\*
  3. Estimated Time Enroute (ETE):
     1. GS @ 125 kts is approx. 00:17:10, TOT: 01:28:00 (**0128**) hours from takeoff

**Cockpit Equipment Checks**

**Load mission data**. **- A**

* 1. CDU **INI** key — Press.
  2. **LSK R4 DTS CTRL** soft key — Press.
  3. Press **LSK L2 -- LOAD** MSN DATA
  4. Press **LSK L5** - **LOAD ALL**.
  5. **Press LSK L5** again (black screen) to **CONFIRM**.
     1. MSN data load is complete

**FMS Initialization**

* 1. CDU **INI** key — Press. **- B**
  2. On the **INITIALIZATION 1/3** 
     1. Confirm SYS time is **-7 UTC** as required.
     2. Confirm that **WGS-84** is displayed.
  3. Press **NXT** to page down to the **INITIALIZATION 2/3** page. **- C**
     1. ConfirmEGI alignment is set to **NAV** (Navigate)
  4. Press **NXT** to page down to the **INITIALIZATION 3/3** page. **- D**
     1. A/C GWTchecks:
        1. Press **LSK L4** – **A/C GWT**
        2. Confirm empty weight as per checklist
        3. Press **LSK L3** – input passengers and press **ENT**
        4. Press **LSK R1**
        5. Input Cargo weight and press **ENT**
     2. BINGO caution checks: **- E**
        1. Press **CLC** key
        2. **LSK R1** – **BINGO**
        3. Confirm BW and BGW are equivalent and matched A/C GWT entries

**Set Up MFD/COM/FMS For Mission**

* 1. FMS FPLN — Check as required.
     1. CDU **FPN** key **- F**
     2. Confirm **WPT SEQ** — **AUTO** setting
     3. Press **LSK L3** - **FPLN LIST**
        1. Press **LSK** **L1** to **IMPORT TO ALTN**
        2. Press **LSK R1** – **REVIEW**
        3. Press **LSK L5** – **IMPORT TO ACTV**
        4. Press **LSK L5** – **CONFIRM**
     4. CDU **FPN** key **- G**
        1. **Press LSK R4 – PROCS**
        2. **Press LSK R2 - DEP/DEST AIRPORTS –** 
           1. Press **LSK L1** to select Destination
           2. Input destination acronym as per Checklist
           3. CDU ENT
  2. Input Frequency **Preset IDs** for **RADIO 1 & 2** as per checklist **- H**
     1. Repeat for Radio 1 and 2:
        1. Press CDU **COM** key
        2. Press **LSK key** for appropriate radio
        3. Input **preset ID** and Press CDU **ENT**
* **(Copilot) -** Confirm Pilot and Crew of GO/NGO ready for takeoff. **- I**

1. **Formative Study Questions**

* How do varying levels of cognitive load (e.g., low, moderate, and high stress) influence a pilot's ability to perform critical flight operations, such as preflight checklist execution?
* In your experience, during which flight phases (e.g., taxiing, takeoff, cruising, or landing) do pilots most frequently experience high load or low load, and how do these states affect their situational awareness?

**B1**

* In high-load scenarios, how should the system prioritize and limit non-critical information while ensuring that essential data is delivered effectively?
* Do you think real-time adjustments to the amount of presented information could help prevent cognitive fatigue during prolonged high-demand tasks? Why or why not?
* What criteria would you suggest for determining which information is non-critical versus essential during high-stress situations?

**B2**

* How should the system adapt the level of detail in the information provided during different tasks, such as routine navigation versus complex maneuvers in adverse conditions?"
* For tasks with high urgency or complexity, do you think combining detailed instructions with situational updates is more effective than focusing solely on actionable steps? Why?"
* What is your opinion on using minimal guidance during routine tasks? Could this approach inadvertently lead to disengagement or over-reliance on the system?"

**B3**

* When switching modalities (e.g., visual to auditory or text), what factors should the system consider to ensure the transition is seamless and does not disrupt the pilot’s focus?"
* In your experience, how can modality switching be optimized to align with a pilot’s cognitive state and the demands of the current task?"
* Do you think certain modalities (e.g., auditory prompts) are inherently better suited for specific cognitive loads or flight phases? Could you provide examples?

**B4**

* How should the system differentiate between novice and expert pilots when delivering guidance? For example, should novices receive step-by-step instructions while experts receive summaries?"
* What level of customization do you think is appropriate for pilots with varying experience levels, and how could this impact system scalability in operational environments?"
* Do you believe expert pilots might find adaptive feedback intrusive? If so, how can the system balance personalization without compromising usability?"

**Other questions**

* In your experience, what types of errors are most common during preflight checklists or similar routine tasks, and what specific feedback strategies (e.g., real-time prompts, error highlights) would you suggest to address them?
* How should an adaptive system prioritize errors? For example, should it focus on critical safety-related errors first, or address all errors equally regardless of their severity?
* What strategies do you recommend for maintaining pilot focus and engagement during routine tasks (e.g., taxiing, cruising), and how can adaptive systems assist in mitigating fatigue or boredom?"
* During repetitive or low-demand flight phases, what type of feedback would help maintain a balance between situational awareness and task engagement?

1. **Qualitative Evaluation Questions**

The following questions provided guidance to the interviewer but the interviews were semi-structured and as such the pilots were encouraged to share thoughts outside of these questions as well as expand on things they said during the interview.

* Have you noticed the adaptive systems changing the way information is presented based on your workload, attention, or perception?
* Have there been moments when the adaptive systems either alleviated or increased your cognitive load? If so, could you describe those moments?
* Do you find that either adaptive version’s transition between different modalities (e.g., audio to visual) feel more natural or manageable under high workload conditions?
* Based on your flight experience, how effective do you think managing information load (e.g., high, optimal, low) and switching between different modalities (visual, text, audio) is in enhancing flight performance?
* When using the adaptive versions, what specific advantages or disadvantages have you noticed compared to the traditional checklist (baseline)?
* In your current aviation system, how do you think these three versions of pilot-assist systems could be applied to your typical flight environment? Why?
* If you were the designer of the adaptive system: How would you envision it functioning during other flight phases (e.g., climb, cruise, or landing)? During these phases, what type of guidance or adaptive feedback would you like to see?
* Among the three conditions, which do you prefer? Why?

1. **Prompt Example**

The following is the prompt used for adaptivity. In addition to this prompt a tokenized UH-60 manual and procedure checklist was given to the PHI-3 model.

You are an expert in document analysis, expert flight instructor, and expert cognitive scientist. You have been provided a relevant portion of an operator's manual for a UH-60 Blackhawk Helicopter; measured cognitive workload on a flight trainees working memory, attention, and perception; and relevent behavioral metrics, such as currently gazed cockpit location, current next action, etc. You will use this provided data as context to help maintain a trainees optimal workload state by adjusting the next guidance provided to the trainee. Upon receiving metrics and a query, you will analyze the query. You will then deeply analyze the given context. You will then provide step-by-step reasoning about the response based on the query and context. Finally, you will compile and return a response based on the provided context, query, and your reasoning.

You can adjust guidance in 2 ways:

1. The information load:

- this represents the information that is provided to the trainee in for textual or audible (or both) guidance types.

2. The guidance type, one of the following:

0=Visual Only - display a look cue to the current action

1=Audio Only - audibly present information to user

2=Text Only - visually present information to user

3=Visual and Audio

4=Visual and Text

5=Audio and Text

6=Visual and audio and text

Each of the 3 types of cognitive workload can be classified into 1 of 3 types

- Underload

- Description: The workload facet is under the optimal mental processing threshold, potentially leading to distraction and wrong actions.

- Adaptive Strategy: Increase the information load and the variety of prompt modalities to

stimulate the pilot's cognition and prevent errors caused by low cognitive load.

- Overload:

- Description: The workload facet is over the optimal mental processing threshold, potentially leading to stress or wrong actions.

- Adaptive Strategy: Reduce the information load, especially during perception overload,

using concise visual prompts to avoid further cognitive burden.

- Optimal:

- Description: The workload facet is at the trainees optimal level

- Adaptive Strategy: Use an appropriate amount of visual and auditory prompts to ensure the

pilot can perform tasks efficiently without overly disrupting their attention and perception.

Input:

behavioral:

todo\_actions: Action list that the user should do next. Each element in this list is an action that needs to be performed. You only need to consider the first element of the action list in your answer, and be sure to include the action corresponding to that element. For example, if you get a list: ['Press LSK R4 DTS CTRL soft key.','Press LSK L2 LOAD MSN DATA.','Press LSK L5 LOAD ALL.',' Press LSK L5 CONFIRM.'], you should only consider 'Press LSK R4 DTS CTRL soft key.' and you must contain this action in the tip you give to the user. Although you can change its description level.

gaze\_location: Which panel the user is currently viewing.

Workload states:

memory\_state: Represents a pilot's cognitive capacity to process and manage the influx of information during flight operations. This state reflects the mental demand placed on the pilot, categorized into three levels: overload (when the pilot's cognitive capacity is exceeded by the demands of the task, potentially leading to errors or delayed reactions), optimal (when the pilot is operating within their cognitive capacity, allowing for efficient and accurate task execution), and underload (when the cognitive demands are too low, possibly leading to reduced alertness or attention).

attention\_state: Indicates a pilot's ability to maintain focused concentration on essential flight tasks and instruments. This state is crucial for prioritizing tasks and managing cockpit workload effectively. It is classified into overload (where the pilot struggles to maintain focus due to excessive distractions or a high number of concurrent tasks), optimal (where the pilot can effectively concentrate on the necessary tasks and maintain situational awareness), and underload (where a lack of challenging stimuli may cause the pilot's attention to drift, potentially leading to missed cues or delayed responses).

perception\_state: Refers to a pilot's ability to accurately perceive and interpret critical information from the cockpit environment and external conditions. This state influences the pilot's situational awareness and decision-making. It is categorized into overload (when the pilot is bombarded with too much information, causing difficulty in distinguishing relevant details from irrelevant ones), optimal (when the pilot can effectively perceive and interpret all necessary information, leading to accurate situational assessment), and underload (when there is insufficient sensory input or stimuli, potentially causing the pilot to overlook important cues or misjudge the situation).

Adaptive Strategy:

Information Load:

- Three information load levels.

- low: Only operation button names such as "INI", "ENT", "LSK R4", "MFD L2" or "confirm/verify", etc.

- medium: can include complete operation of action such as "Press LSK R4 DTS CTRL soft key", etc.

- high: can include complete operations of action and its function. Such as "Press CDU INI to INITIALIZATION", "Visually and Verbally acknowledge TAC DB & NAV DB (DTS) are on correct dates", etc.

The adaptive rules are designed to adjust the modality and information load presented to the pilot based on their cognitive workload. These rules provide a dynamic system for delivering appropriate feedback depending on the pilot's current state. Here's a summary of the rules:

General Adaptive rules

Memory Underload

General Condition: The pilot's cognitive demand is low, leading to potential disengagement, missed cues, or inattention.

Adaptive Strategy: Increase information load and use multiple modalities (e.g., Visual, Audio, Text) to stimulate engagement and maintain focus on critical tasks.

Typical Modality: Visual, Audio, and Text combined, or Visual with Text for highlighting key tasks.

Information Load: Medium to High depending on attention and perception levels.

Memory Optimal

General Condition: The pilot is managing tasks effectively, but attention or perception may fluctuate.

Adaptive Strategy: Maintain moderate information load and use multimodal feedback to reinforce task performance, while avoiding cognitive overload.

Typical Modality: Visual and Audio, or Audio and Text, depending on attention and perception levels.

Information Load: Medium to Low to prevent overwhelming the pilot.

Memory Overload

General Condition: The pilot is under high stress and may be struggling to manage tasks due to excessive information or demands.

Adaptive Strategy: Reduce information load and provide concise, essential feedback to avoid overwhelming the pilot. Focus on simplifying task execution.

Typical Modality: Visual and Text, or Audio and Text, with minimal distractions.

Information Load: Low to Medium to reduce cognitive burden.

Attention and Perception States:

Underload: Increase engagement through multimodal feedback and additional prompts to enhance awareness and task focus.

Optimal: Maintain steady information flow using moderate multimodal prompts to support task execution without introducing unnecessary complexity.

Overload: Reduce unnecessary information and streamline the task by prioritizing essential instructions. Avoid overloading the pilot's perceptual channels.

Five Example Scenarios

Example 1:

Memory: Underload

Attention: Underload

Perception: Underload

Workload Situation: The pilot is experiencing low cognitive demand, leading to disengagement from the task.

Flight Situation: During preflight, the pilot may be performing tasks mechanically, missing critical procedures.

Response Type: 6 = Visual, Audio, and Text

Information Load: High

Example 2:

Memory: Optimal

Attention: Optimal

Perception: Optimal

Workload Situation: The pilot is managing tasks efficiently with high attention and perception, performing well under optimal conditions.

Flight Situation: The pilot is executing preflight tasks with precision and accuracy.

Response Type: 3 = Visual and Audio

Information Load: Medium

Example 3:

Memory: Overload

Attention: Underload

Perception: Optimal

Workload Situation: The pilot is overwhelmed in Memory but is under-focused, risking missed steps.

Flight Situation: The pilot may be struggling to balance tasks, potentially leading to errors.

Response Type: 6 = Visual, Audio, and Text

Information Load: High

Example 4:

Memory: Optimal

Attention: Overload

Perception: Underload

Workload Situation: The pilot is overly focused, possibly leading to tunnel vision, missing environmental cues.

Flight Situation: The pilot is focused on specific tasks but might overlook important external factors.

Response Type: 6 = Visual, Audio, and Text

Information Load: High

Example 5:

Memory: Overload

Attention: Overload

Perception: Overload

Workload Situation: The pilot is overwhelmed in all aspects, with excessive information creating high cognitive strain.

Flight Situation: The pilot is likely experiencing difficulty in processing information and maintaining task focus, leading to errors.

Response Type: 4 = Visual and Text

Information Load: Low

Please infer the user's current task to provide a tip to help them complete the current step based on current cognitive load.

There exist seven potential combinations by incorporating visual, audio, and textual modalities in a tip.

The input cognitive states can be classified into Overload, Optimal, and Optimal categories, influencing the tip provided for each step.

Only generate one type of tip at once.

Avoid giving tips that are too far ahead or behind the user's current action.

The tip should be based on the current todo action.

Based on the user's current step in a task and current cognitive states, provide tips that could help them progress efficiently.

Your response tip should help guide the user towards completing the step they are on

Your tips can offer guidance on efficiency, caution, answer direct queries from the user, or suggest moving to the next step if it seems the current one has been completed based on the user confirmation.

However, the advice should be flexible enough to be valuable even if the current cognitive load does not perfectly align with the user's stated step.

Output :

Your response should be based on the input, query, and adaptive strategies.

Give your response in the following format with each field:

reasoning: Why you are giving this tip.

response\_type: Display type to present tip.

response\_text: Adapted action for the trainee. LIMIT response text to 20 words.

Reasoning:

1.Analyze Pilot Mental State: Begin by assessing the current mental state of the pilot. This involves understanding factors such as attention, working memory, perception, and overall cognitive load.

2.Determine Pilot Actions: Based on the pilot's current actions, determine what they are trying to accomplish and their immediate goals within the flight phase.

3.Derive Recommended Information Load and Modality Type:Based on the analysis of the pilot's mental state and the current action, recommend an appropriate level of information load (low, medium, high) and select the optimal modality type from 0-6

4.Determine Final Information to Relay: based on the derived information load and modality, decide what specific information needs to be conveyed to the pilot. This might include commands, alerts, or additional context.

Reasoning should limit to 20 words

Examples:

input:

behavioral:

Todo Actions: ['Press CDU INI key', 'Press LSK R4 DTS CTRL soft key', 'Press LSK L2 LOAD MSN DATA','Press LSK L5 LOAD ALL', 'Press LSK L5 CONFIRM']

Gaze Location: 'CDU'

cognitive states:

Memory State: overload

Attention State: optimal

Perception State: overload

query: "Give me the helicopter operational tip."

output:

reasoning: The pilot is experiencing cognitive overload in both memory and perception, which may hinder their ability to remember the sequence of steps; therefore, a high information load with modality 6 ( 6=Visual and audio and text) is recommended such as Press CDU INI key to Initialize

response\_type: 6

response\_text: "Press CDU INI key to initialize."

input:

behavioral:

Todo Actions: []

Gaze Location: 'CDU'

cognitive states:

Memory State: underload

Attention State: optimal

Perception State: overload

query: "Keep me motivated!"

output:

reasoning: The pilot has perception overload but maintains optimal attention. They have just finished a procedure, since there todo\_actions are empty. They should be encouraged audibly (1), since there perception is overloaded.

response\_type: 1

response\_text: "Keep up the great work!"

input:

behavioral:

Todo Actions: ['Press LSK L2 LOAD MSN DATA','Press LSK L5 LOAD ALL','Press LSK L5 CONFIRM']

Gaze Location: 'CDU'

cognitive states:

Memory State: optimal

Attention State: overload

Perception State: overload

query: "Give me the helicopter operational tip."

output:

reasoning: The pilot has optimal memory but is overloaded in both perception and attention, requiring a low information load audio modalities such as "LSK L2" to clearly guide them to the correct action.

response\_type: 1

response\_text: "LSK L2."

1. **Adaptive Rules**

### General Summary of Adaptive Rules:

1. **Underload Scenarios**: Provide more information and use diverse modalities (visual, audio, text) to stimulate engagement and prevent errors due to a lack of focus.
2. **Overload Scenarios**: Reduce the information load and rely primarily on visual cues to help reduce cognitive overload and keep pilots calm and focused.
3. **Optimal Scenarios**: Use a balanced mix of visual and audio prompts, providing enough information to assist the pilot while avoiding unnecessary distractions.

### Adaptive Rules for Workload, Attention, and Perception in Flight Scenarios

The adaptive system is designed to adjust the content and modality of guidance based on pilots’ cognitive load, dynamically adapting to the demands of various flight scenarios. This approach ensures that pilots receive the right level of support depending on their current workload, attention, and perception levels.

#### Underload Scenarios

In situations where pilots experience cognitive underload, the system increases engagement by providing more detailed information and introducing diverse modalities. Visual, audio, and text prompts are used to stimulate the pilot’s focus and ensure they remain attentive during less demanding phases of flight. As cognitive demand is low, introducing additional complexity helps prevent errors due to a lack of attention. The system uses frequent prompts and reminders to maintain engagement and prevent lapses in concentration, thus ensuring that the pilot remains fully aware of the aircraft's status and environmental factors.

#### Optimal Scenarios

When the pilot’s cognitive load is in an optimal range, the system focuses on maintaining balance by providing a mixture of visual and audio prompts that are tailored to the task at hand. In these scenarios, the system aims to deliver just-in-time feedback, giving enough information to assist the pilot without causing distraction. This balance allows the pilot to maintain situational awareness while efficiently completing tasks without being overwhelmed by excessive data or prompts. Attention and perception are aligned with the current demands, ensuring smooth task execution.

#### Overload Scenarios

In high-pressure, overload scenarios where the pilot’s cognitive load is at its peak, the system reduces complexity by minimizing the amount of information delivered. Here, visual cues become the primary modality to prevent overloading the pilot with auditory or text-based distractions. The system focuses on essential tasks, providing only the most critical information to guide the pilot through urgent decision-making processes. This approach allows the pilot to focus on immediate priorities, reducing the risk of errors caused by cognitive overload, and ensuring their attention remains fixed on critical tasks.

Detailed

Hard code：

Workload: Underload | Attention: Underload | Perception: Optimal

Preflight:

Preflight Situation: Low workload and attention lead to the pilot becoming mechanical during checklist procedures. Although perception is normal, the lack of attention may still cause some details to be overlooked.

Preflight Potential Consequences: The pilot might miss certain checklist items, and despite normal perception, key steps could be neglected due to insufficient attention.

Modality: 5 = Visual and Text

Information Load: Medium

Additional Information: Provide visual and text prompts that highlight important information and critical operational steps to maintain the pilot’s attention. Regular reminders and status updates can be added.

Workload: Overload | Attention: Underload | Perception: Overload

Preflight Situation: Before takeoff, the pilot may feel stressed due to heavy task demands, but with insufficient attention, they may not focus adequately on each checklist item, despite an overload of perception information.

Preflight Potential Consequences: The pilot may fail to process the overloaded perception information in time, leading to missed items or errors in operation.

Modality: 7 = Visual, Audio, and Text

Information Load: High

Additional Information: Use comprehensive multimodal prompts, providing detailed operational steps and background information to help the pilot correctly execute tasks despite perception overload and insufficient attention.

Adaptive Strategies:

The 27 adaptive rules are designed to optimize the delivery of information to pilots based on their cognitive states—workload, attention, and perception—across various phases of flight, particularly during preflight procedures. These rules focus on adjusting the modality (visual, audio, text, or combinations thereof) and the information load (low, medium, or high) to match the pilot's current cognitive state. The primary goal is to enhance the pilot's performance by ensuring that the right amount of information is provided through the most effective channels without overwhelming or under-stimulating them.

1

"workload\_state": "underload",

"attention\_state": "underload",

"perception\_state": "underload",

"Workload Situation": "The pilot is experiencing low cognitive demand across workload, attention, and perception, indicating a lack of engagement or challenge.",

"Flight Situation": "During preflight, the pilot may be going through the motions of task completion without fully engaging, leading to potential neglect of important procedures.",

"Potential Consequences": "This can result in missed checks or errors that may compromise safety during later stages of the flight.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load with multi-modal prompts can help re-engage the pilot, ensuring they focus on critical tasks and procedures."

2

"workload\_state": "underload",

"attention\_state": "underload",

"perception\_state": "optimal",

"Workload Situation": "While the pilot’s perception remains optimal, the low workload and attention levels indicate a potential disengagement from the task at hand.",

"Flight Situation": "The pilot might be performing routine checks without full attention, potentially overlooking subtle but important cues in the environment.",

"Potential Consequences": "This can lead to missed or incomplete checks, with potential risks during the flight.",

"Modality": "5 = Visual and Text",

"Information Load": "Medium",

"Reasoning": "Visual and text prompts can help focus the pilot’s attention on critical tasks, ensuring important details are not overlooked."

3

"workload\_state": "underload",

"attention\_state": "underload",

"perception\_state": "overload",

"Workload Situation": "The pilot is underloaded in terms of workload and attention but is overwhelmed by the amount of information perceived.",

"Flight Situation": "In preflight, the pilot may struggle to prioritize tasks due to the overwhelming amount of sensory input, despite having low workload and attention.",

"Potential Consequences": "The overload in perception, combined with underload in workload and attention, can lead to confusion and errors in task execution.",

"Modality": "6 = Audio and Text",

"Information Load": "Low",

"Reasoning": "Simplified audio and text prompts can help reduce the cognitive load by filtering out unnecessary information, allowing the pilot to focus on critical tasks."

4

"workload\_state": "underload",

"attention\_state": "optimal",

"perception\_state": "underload",

"Workload Situation": "The pilot is under-stimulated and perceives less than required, but their attention to the task at hand is optimal.",

"Flight Situation": "The pilot is correctly focusing on preflight tasks, but their perception of the surrounding environment and external factors may be lacking. This can lead to missing important cues or failing to notice potential issues in the cockpit.",

"Potential Consequences": "External or less obvious issues might go unnoticed, leading to potential problems during later flight phases if not addressed during preflight.",

"Modality": "6 = Audio and Text",

"Information Load": "Medium",

"Reasoning": "Audio and text prompts can help ensure that the pilot’s perception is aligned with their attention, helping them to consider overlooked external factors."

5

"workload\_state": "underload",

"attention\_state": "optimal",

"perception\_state": "optimal",

"Workload Situation": "The pilot is experiencing low workload, with optimal attention and perception, indicating an efficient but potentially complacent state.",

"Flight Situation": "The pilot is managing preflight tasks efficiently but may be at risk of overlooking non-routine issues due to the low workload.",

"Potential Consequences": "Complacency can lead to missed checks or unanticipated issues not being addressed.",

"Modality": "4 = Visual and Audio",

"Information Load": "Medium",

"Reasoning": "Balanced visual and audio prompts can help maintain the pilot’s engagement, ensuring that they remain vigilant and attentive to any unexpected situations."

6

"workload\_state": "underload",

"attention\_state": "optimal",

"perception\_state": "overload",

"Workload Situation": "The pilot is underloaded in terms of workload, optimally attentive, but overwhelmed by the sensory input.",

"Flight Situation": "During preflight, the pilot may be dealing with an overload of information while trying to remain focused on the tasks at hand.",

"Potential Consequences": "This situation could lead to errors or missed steps due to an overwhelming amount of information, despite the pilot's optimal attention.",

"Modality": "6 = Audio and Text",

"Information Load": "Low",

"Reasoning": "Simplified audio and text prompts with a reduced information load can help mitigate the overload, allowing the pilot to complete tasks efficiently."

7

"workload\_state": "underload",

"attention\_state": "overload",

"perception\_state": "underload",

"Workload Situation": "The pilot is underloaded in terms of workload but overly focused, potentially leading to tunnel vision and missing peripheral details.",

"Flight Situation": "During preflight, the pilot may become fixated on specific tasks while neglecting other important elements due to the lack of workload and overstated attention.",

"Potential Consequences": "This can lead to missed checks or errors as the pilot may not be considering the full scope of the preflight procedures.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load with multi-modal prompts can help broaden the pilot's focus, ensuring they consider all necessary tasks and checks."

8

"workload\_state": "underload",

"attention\_state": "overload",

"perception\_state": "optimal",

"Workload Situation": "The pilot is underloaded in terms of workload, overly focused, with optimal perception, indicating a potential risk of over-focusing on specific tasks.",

"Flight Situation": "During preflight, the pilot might be concentrating too much on certain procedures while neglecting others, despite having optimal perception.",

"Potential Consequences": "This could result in important tasks being overlooked or delayed, impacting the overall safety and efficiency of the flight preparation.",

"Modality": "6 = Audio and Text",

"Information Load": "Medium",

"Reasoning": "Moderate information load with audio and text prompts can help the pilot distribute their attention more evenly across all necessary tasks."

9

"workload\_state": "underload",

"attention\_state": "overload",

"perception\_state": "overload",

"Workload Situation": "The pilot is underloaded in workload but experiencing overload in both attention and perception, creating a complex situation where they might feel overwhelmed despite the low workload.",

"Flight Situation": "In preflight, the pilot might struggle to manage the influx of information and attention demands, potentially leading to confusion or errors.",

"Potential Consequences": "This situation could lead to important steps being missed or performed incorrectly due to the overwhelming nature of the sensory and attentional load.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Visual and text prompts with a low information load can help reduce the cognitive strain, allowing the pilot to focus on completing the essential tasks efficiently."

10

"workload\_state": "optimal",

"attention\_state": "underload",

"perception\_state": "underload",

"Workload Situation": "The pilot is in an optimal workload state, but their attention and perception are underloaded, indicating potential disengagement.",

"Flight Situation": "The pilot is adequately handling preflight tasks, but may be missing subtle details or cues due to reduced attention and perception.",

"Potential Consequences": "Important checks could be overlooked, leading to potential issues during later flight phases.",

"Modality": "4 = Visual and Audio",

"Information Load": "Medium",

"Reasoning": "Visual and audio prompts can help re-engage the pilot, ensuring they pay attention to critical tasks and external factors."

11

"workload\_state": "optimal",

"attention\_state": "underload",

"perception\_state": "optimal",

"Workload Situation": "The pilot is in an optimal workload state, with sufficient perception, but their attention is underloaded, suggesting a risk of disengagement.",

"Flight Situation": "The pilot might be effectively processing the preflight tasks, but may not be fully attentive to details, potentially leading to errors.",

"Potential Consequences": "This can result in missed or incomplete tasks, affecting the overall safety and efficiency of the flight preparation.",

"Modality": "4 = Visual and Audio",

"Information Load": "Medium",

"Reasoning": "Balanced visual and audio prompts can help the pilot maintain focus on important tasks, ensuring they do not overlook critical details."

12

"workload\_state": "optimal",

"attention\_state": "underload",

"perception\_state": "overload",

"Workload Situation": "The pilot is in an optimal workload state, but their attention is underloaded while perception is overloaded, indicating a risk of becoming overwhelmed.",

"Flight Situation": "During preflight, the pilot may struggle with an overload of sensory information, leading to potential distractions from the necessary tasks.",

"Potential Consequences": "This can lead to errors or missed checks, as the pilot may be distracted by the overwhelming amount of information.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Visual and text prompts with a low information load can help the pilot filter out unnecessary information, maintaining focus on essential tasks."

13

"workload\_state": "optimal",

"attention\_state": "optimal",

"perception\_state": "underload",

"Workload Situation": "The pilot is in an optimal workload and attention state, but their perception is underloaded, potentially leading to missed cues.",

"Flight Situation": "The pilot is handling preflight tasks well but may not be fully aware of all environmental or system factors, leading to potential oversights.",

"Potential Consequences": "Critical cues or information might go unnoticed, which could result in safety issues during the flight.",

"Modality": "4 = Visual and Audio",

"Information Load": "Medium",

"Reasoning": "Balanced visual and audio prompts can help enhance the pilot’s perception, ensuring they do not miss important information."

14

"workload\_state": "optimal",

"attention\_state": "optimal",

"perception\_state": "optimal",

"Workload Situation": "The pilot is in an ideal state with optimal workload, attention, and perception, indicating high efficiency and effectiveness.",

"Flight Situation": "The pilot is likely performing preflight tasks with high accuracy and awareness, managing all aspects of the operation well.",

"Potential Consequences": "This is the most desirable state, with minimal risk of errors or missed steps.",

"Modality": "4 = Visual and Audio",

"Information Load": "Medium",

"Reasoning": "Visual and audio prompts are sufficient to support the pilot’s tasks without overwhelming or underloading them, maintaining peak performance."

15

"workload\_state": "optimal",

"attention\_state": "optimal",

"perception\_state": "overload",

"Workload Situation": "The pilot is in an optimal workload and attention state, but their perception is overloaded, indicating a risk of becoming overwhelmed by information.",

"Flight Situation": "During preflight, the pilot may find it challenging to filter through excessive sensory input, potentially leading to confusion or errors.",

"Potential Consequences": "An overload in perception can lead to critical mistakes or missed steps, as the pilot may struggle to manage the information overload.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Visual and text prompts with a low information load can help reduce cognitive strain, allowing the pilot to maintain focus on essential tasks."

16

"workload\_state": "optimal",

"attention\_state": "overload",

"perception\_state": "underload",

"Workload Situation": "The pilot is in an optimal workload state but is overly focused, leading to potential tunnel vision, and their perception is underloaded.",

"Flight Situation": "The pilot may be too focused on specific tasks, neglecting other important aspects of the preflight process due to reduced perception.",

"Potential Consequences": "This can lead to errors or oversights in tasks that are not within the pilot’s immediate focus, compromising overall flight safety.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load with multi-modal prompts can help broaden the pilot’s focus, ensuring all critical tasks are considered."

17

"workload\_state": "optimal",

"attention\_state": "overload",

"perception\_state": "optimal",

"Workload Situation": "The pilot is in an optimal workload state with overloaded attention but optimal perception, potentially leading to over-focusing on specific tasks.",

"Flight Situation": "The pilot may become fixated on certain procedures, risking the neglect of other important tasks during preflight.",

"Potential Consequences": "This could result in missed steps or delays in task completion, impacting the overall safety and efficiency of the flight preparation.",

"Modality": "6 = Audio and Text",

"Information Load": "Medium",

"Reasoning": "Moderate information load with audio and text prompts can help the pilot distribute their attention more evenly across all necessary tasks."

18

"workload\_state": "optimal",

"attention\_state": "overload",

"perception\_state": "overload",

"Workload Situation": "The pilot is in an optimal workload state but is overloaded in both attention and perception, indicating a complex situation where they might feel overwhelmed.",

"Flight Situation": "In preflight, the pilot might struggle to manage the influx of information and attention demands, potentially leading to confusion or errors.",

"Potential Consequences": "This situation could lead to important steps being missed or performed incorrectly due to the overwhelming nature of the sensory and attentional load.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Visual and text prompts with a low information load can help reduce the cognitive strain, allowing the pilot to focus on completing the essential tasks efficiently."

19

"workload\_state": "overload",

"attention\_state": "underload",

"perception\_state": "underload",

"Workload Situation": "The pilot is facing an overload in workload, but their attention and perception are underloaded, leading to potential lapses in critical task management.",

"Flight Situation": "During preflight, the pilot may be overwhelmed by the number of tasks but may also become disengaged, missing critical steps due to underloaded attention and perception.",

"Potential Consequences": "This can result in critical errors or missed steps, severely compromising the safety and effectiveness of the preflight process.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load using multiple modalities is necessary to engage the pilot’s attention and perception, ensuring all tasks are completed."

20

"workload\_state": "overload",

"attention\_state": "underload",

"perception\_state": "optimal",

"Workload Situation": "The pilot is experiencing an overload in workload with underloaded attention but optimal perception, potentially leading to neglect in task management.",

"Flight Situation": "The pilot might be overwhelmed by the workload, leading to disengagement or errors in the preflight process, despite optimal perception of the environment.",

"Potential Consequences": "This could lead to missed steps or errors, as the pilot may not be fully focused on the tasks at hand, impacting overall flight safety.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A combination of modalities with a high information load is recommended to re-engage the pilot’s attention while leveraging their optimal perception."

21

"workload\_state": "overload",

"attention\_state": "underload",

"perception\_state": "overload",

"Workload Situation": "The pilot is dealing with an overload in both workload and perception, while their attention is underloaded, creating a situation where they might miss important details.",

"Flight Situation": "During preflight, the pilot might be struggling to manage the overwhelming amount of information and tasks, leading to a lack of focus and potential errors.",

"Potential Consequences": "Critical steps could be missed, or errors could occur due to the pilot’s inability to effectively manage the overload in workload and perception.",

"Modality": "6 = Audio and Text",

"Information Load": "Medium",

"Reasoning": "Audio and text prompts with a moderate information load can help manage the overload while ensuring the pilot stays focused on essential tasks."

22

"workload\_state": "overload",

"attention\_state": "optimal",

"perception\_state": "underload",

"Workload Situation": "The pilot is experiencing an overload in workload, with optimal attention but underloaded perception, leading to potential tunnel vision.",

"Flight Situation": "The pilot might be focusing well on specific preflight tasks, but their reduced perception might cause them to miss broader environmental or system cues.",

"Potential Consequences": "This could lead to missed or incomplete checks, potentially compromising the safety of the flight.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load across multiple modalities can help broaden the pilot’s focus, ensuring they do not miss critical environmental or system cues."

23

"workload\_state": "overload",

"attention\_state": "optimal",

"perception\_state": "optimal",

"Workload Situation": "The pilot is managing an overload in workload with optimal attention and perception, indicating a high level of stress but effective task management.",

"Flight Situation": "During preflight, the pilot is likely under significant pressure but is managing the tasks well, although the risk of fatigue is high.",

"Potential Consequences": "While the pilot may complete all necessary tasks, the high workload could lead to fatigue, affecting later stages of the flight.",

"Modality": "6 = Audio and Text",

"Information Load": "Medium",

"Reasoning": "Moderate information load through audio and text prompts can support the pilot’s task management while minimizing the risk of overload."

24

"workload\_state": "overload",

"attention\_state": "optimal",

"perception\_state": "overload",

"Workload Situation": "The pilot is overloaded in both workload and perception but is maintaining optimal attention, potentially leading to high stress and errors.",

"Flight Situation": "The pilot may be effectively managing tasks but is at risk of being overwhelmed by the amount of information and tasks during preflight.",

"Potential Consequences": "This could lead to critical mistakes or omissions, as the pilot might struggle to manage the overwhelming information load.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Low information load through visual and text prompts can help the pilot manage their tasks without adding to their cognitive burden."

25

"workload\_state": "overload",

"attention\_state": "overload",

"perception\_state": "underload",

"Workload Situation": "The pilot is experiencing an overload in workload and attention, with underloaded perception, leading to a narrow focus and potential for missed cues.",

"Flight Situation": "The pilot may be too focused on specific tasks, neglecting other important aspects of the preflight process due to underloaded perception.",

"Potential Consequences": "This can result in errors or oversights, compromising the overall safety of the flight preparation.",

"Modality": "7 = Visual, Audio, and Text",

"Information Load": "High",

"Reasoning": "A high information load across multiple modalities can help broaden the pilot’s focus and ensure all critical tasks are addressed."

26

"workload\_state": "overload",

"attention\_state": "overload",

"perception\_state": "optimal",

"Workload Situation": "The pilot is overloaded in both workload and attention but maintains optimal perception, indicating a high-stress situation with potential for errors.",

"Flight Situation": "During preflight, the pilot might be struggling to manage the heavy workload and attention demands, leading to possible mistakes or omissions.",

"Potential Consequences": "This could result in missed steps or errors, affecting the overall safety and efficiency of the flight preparation.",

"Modality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "Visual and text prompts with a low information load can help reduce cognitive strain, allowing the pilot to focus on completing the essential tasks."

27

"workload\_state": "overload",

"attention\_state": "overload",

"perception\_state": "overload",

"Workload Situation": "The pilot is overloaded in workload, attention, and perception, creating a highly stressful and potentially overwhelming situation.",

"Flight Situation": "The pilot might be overwhelmed by the sheer amount of information and tasks, leading to confusion and errors during preflight.",

"Potential Consequences": "This situation could lead to critical errors or missed steps, severely compromising flight safety.",

"M odality": "5 = Visual and Text",

"Information Load": "Low",

"Reasoning": "A low information load with visual and text prompts can help manage the overload, ensuring the pilot remains focused on completing essential tasks without further cognitive strain."

**Multiple Resource Theory (MRT)**

* **Paper**: Wickens, C. D. (2002). Multiple resources and performance prediction. *Theoretical Issues in Ergonomics Science, 3*(2), 159-177.
* **Content**: This paper explores Multiple Resource Theory (MRT), which is a framework for understanding how different sensory channels (visual, auditory) and cognitive tasks allocate resources. According to MRT, the use of multiple modalities (such as the combination of visual and auditory cues) under different workloads can better distribute cognitive resources and reduce the risk of overload.

**Cognitive Load Theory**

* **Paper**: Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12*(2), 257-285.
* **Content**: Sweller's Cognitive Load Theory examines how cognitive load is managed and distributed during learning and task execution. The theory suggests that under high cognitive load, using multimodal cues (such as combining visual and auditory cues) can help distribute the load and reduce the risk of overloading a single sensory channel.

**Human Factors and Ergonomics in Aviation**

* **Book**: Wickens, C. D., & Hollands, J. G. (2000). *Engineering Psychology and Human Performance*. Prentice Hall.
* **Content**: This book delves into human performance under various workload and attention conditions, particularly in aviation environments. It discusses how adjusting cue modalities (such as visual, auditory, or textual) can optimize pilot performance under different cognitive load conditions.

**Eye-Tracking Studies in Aviation**

* **Paper**: Van Orden, K. F., Limbert, W., Makeig, S., & Jung, T. P. (2001). Eye activity correlates with workload during a visuospatial memory task. *Human Factors, 43*(1), 111-121.
* **Content**: This paper uses eye-tracking research to examine pilots' visual behavior under different workload and attention conditions. The study shows that under high workload conditions, visual cues help focus attention, while under low workload conditions, auditory cues can reduce visual distractions.

**Attention and Modality Interaction in Task Performance**

* **Paper**: Spence, C., & Driver, J. (1997). Audiovisual links in endogenous covert spatial attention. *Journal of Experimental Psychology: Human Perception and Performance, 23*(5), 1333-1350.
* **Content**: This paper investigates the interaction between attention and perception with multimodal cues (such as audiovisual combinations). The research demonstrates that using multimodal cues can improve task performance under different levels of attention, particularly in situations of perceptual overload.

**Adaptive Interfaces in Aviation**

* **Paper**: Parasuraman, R., & Hancock, P. A. (2008). Mitigating the adverse effects of cognitive aging on flight performance: Adaptive task allocation strategies. *The International Journal of Aviation Psychology, 18*(2), 154-183.
* **Content**: This paper discusses how adaptive interfaces can adjust task allocation and cue modalities for pilots under different cognitive conditions. The research emphasizes that using combined visual and auditory cues under high workload and attention overload conditions can effectively reduce error rates.

**Modality Effects on Cognitive Load in Aviation**

* **Book**: Wickens, C. D., & McCarley, J. S. (2008). *Applied attention theory*. CRC Press.
* **Content**: This book explores how the use of different sensory channels (such as visual and auditory) affects cognitive load in aviation environments. The authors suggest that under high workload conditions, multimodal cues should be prioritized to distribute cognitive load more effectively.