ICGA 2026

Human Factors Airworthiness for eVTOL Aircraft

KEY CHALLENGES AND EMERGING TECHNOLOGIES

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An eVTOL is a human–aircraft system

Aircraft capability + **Human capability** = **Operational safety**

Aircraft

Flight dynamics, control laws, propulsion management and failure response

Pilot

Perception, task execution, supervision, compensation and decision-making

Operating context

Urban environments, vertiports, traffic constraints and contingencies

Human factors airworthiness: Are pilot tasks and aircraft behaviour compatible across the intended operation?

Three transformations in eVTOL operations

The aircraft, the cockpit and the operating environment are changing together.

01



New Configurations

Distributed propulsion
Lift-and-cruise / tiltrotor
Mode-dependent handling

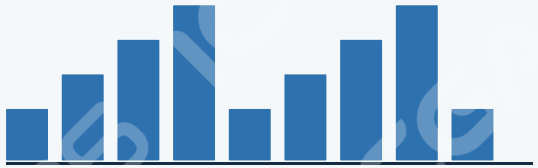
02



New Interaction

Simplified vehicle operation
Integrated controls & displays
Increasing automation

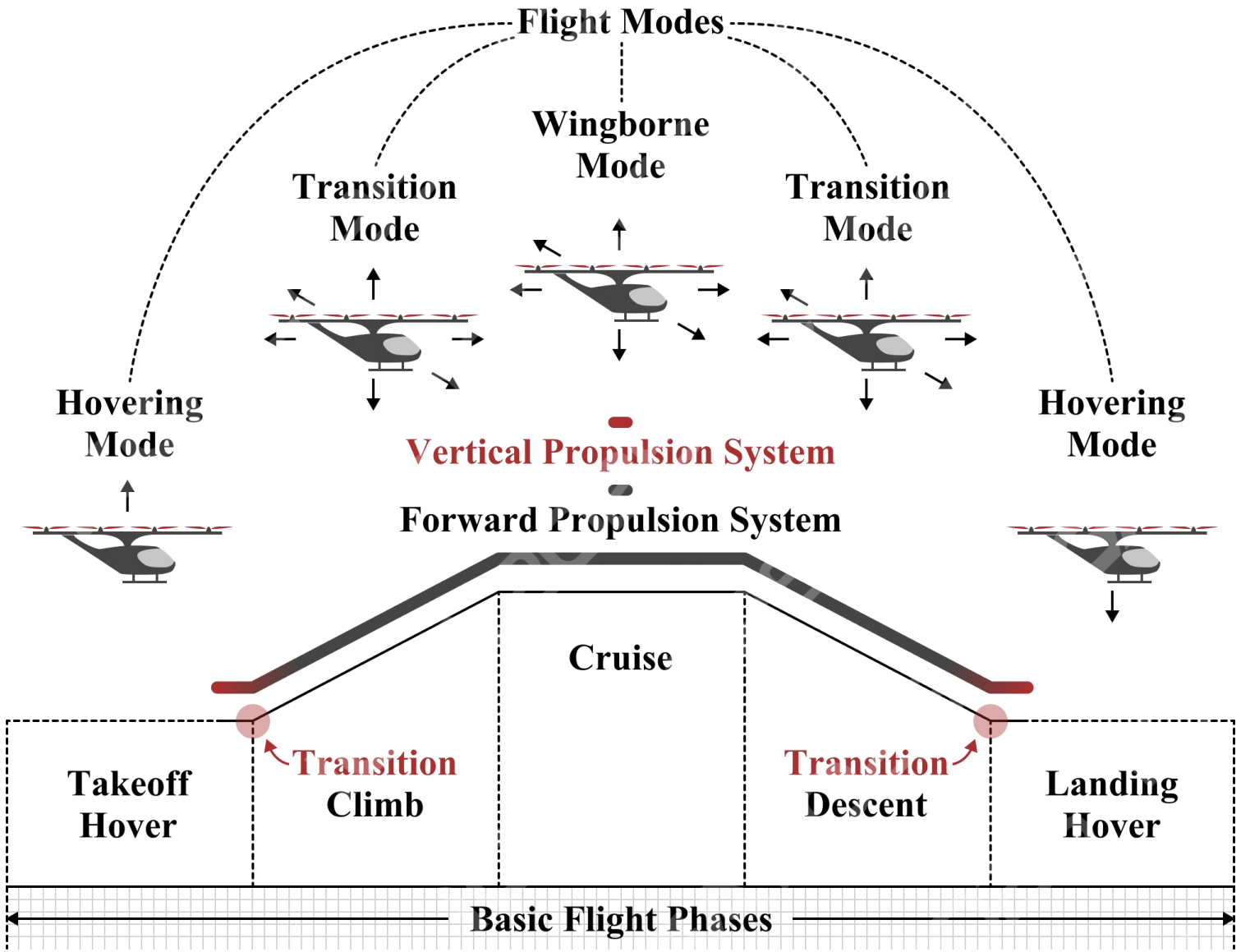
03



New Operation

Urban / regional corridors
Vertiports and tighter margins
High scenario variability

A single mission spans different control regimes



VERTICAL TAKEOFF

Precision hover & obstacle clearance

TRANSITION

Control-law / lift-source change

CRUISE

Energy & trajectory supervision

APPROACH & LAND

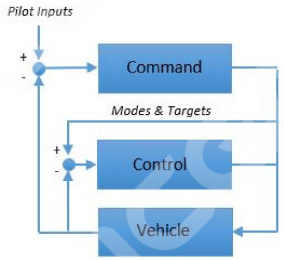
Guidance, monitoring & landing

Four domains of human factors airworthiness

01 Flight control & handling qualities

Aircraft response, precision and pilot compensation





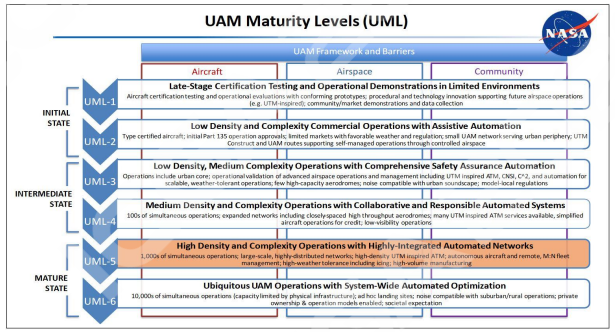
02 Flight deck & information

Displays, alerts, visibility and control accessibility



03 Automation & task allocation

Mode awareness, supervision and intervention



04 Normal & abnormal operations

Human performance during failures and contingencies



Across all four domains: representative tasks, human performance measures, and traceable evidence.

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Key challenges

Human Factors Airworthiness for eVTOL Aircraft: KEY CHALLENGES AND EMERGING TECHNOLOGIES



Challenge 1 | Mode transitions can break the pilot's mental model

Pilot Intention

"Increase forward speed"

→

Control & Automation

Mode-dependent allocation

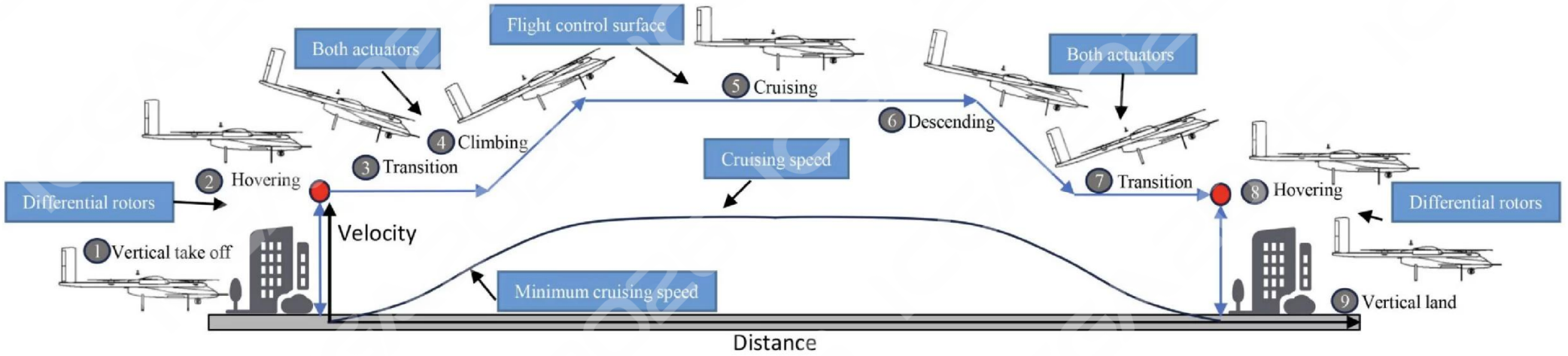
→

Aircraft Response

Acceleration + lift change

When then Mental Model is WRONG

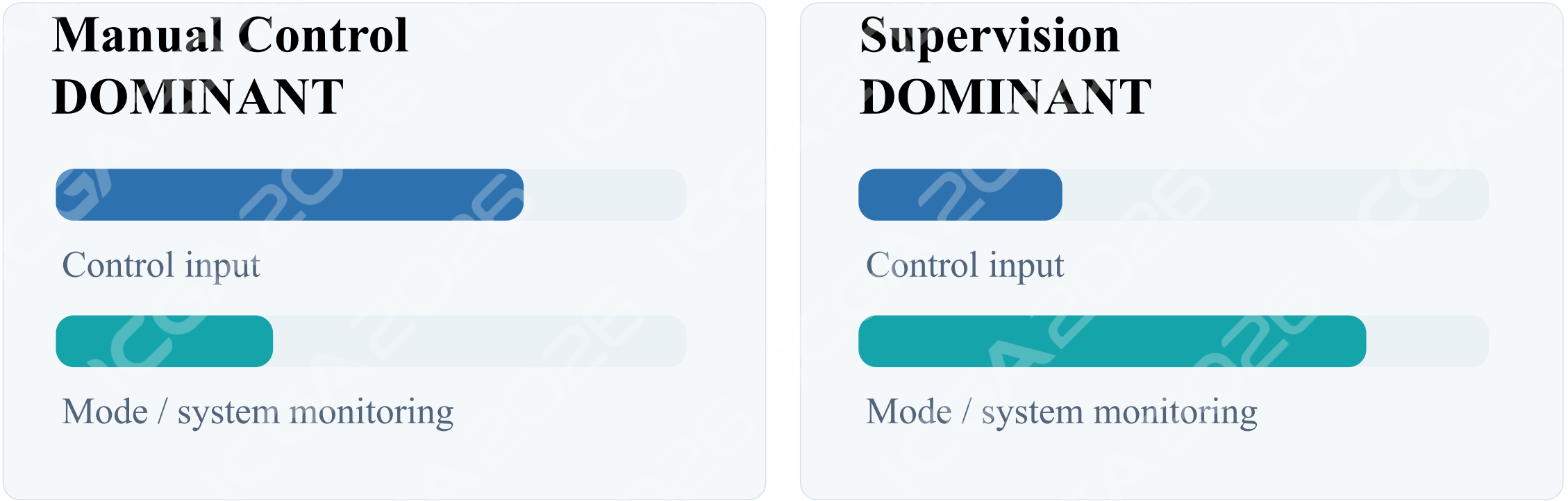
Mode confusion • unexpected response • delayed intervention



Design Target: Clear Modes+ Predictable Response

Challenge 2 | Automation changes the allocation of human effort

Lower manual-control demand does not guarantee lower cognitive demand.



Challenge 3 | Acceptable performance can hide unequal compensation

Similar flight outcomes may require very different control and attention effort.

SYSTEM A Low pilot compensation

Flight-path tracking



Control activity



SYSTEM B Elevated pilot compensation

Flight-path tracking



Control activity



Pilot effort should be evaluated in addition to achieved performance.

International airworthiness landscape

EASA	**SC-VTOL / MOC SC-VTOL**	VTOL.2600: flight crew compartment VTOL.2605: installation and operation information
FAA	**14 CFR 21.17(b) / AC 21.17-4**	Powered-lift certification criteria and acceptable means of compliance
CAAC	**AC-21-AA-2026-45**	Airworthiness Standards for Powered-Lift Aircraft

A shared question: How can the human–aircraft interface be shown to support safe intended functions?

Translate requirements into human performance evidence

Evaluation objective	Representative task or scenario	Evidence to collect
Controllability & HQ	Hover precision; take-off / transition	Trajectory error; control activity; pilot ratings
Awareness & understanding	Mode change; altered flight state	Recognition; interpretation; response
Interface usability	Approach, landing and attention sharing	Visual acquisition; task time; errors
Automation interaction	Degradation; manual intervention	Detection; decision; recovery performance

A good evidence plan couples requirement, scenario, observable behaviour and acceptance logic.

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EMERGING TECHNOLOGIES



Human Factors Airworthiness for eVTOL Aircraft: KEY CHALLENGES AND EMERGING TECHNOLOGIES

Technology 1 | Digital-Twin Pilots for Human Factors Testing

Pilot digital twin

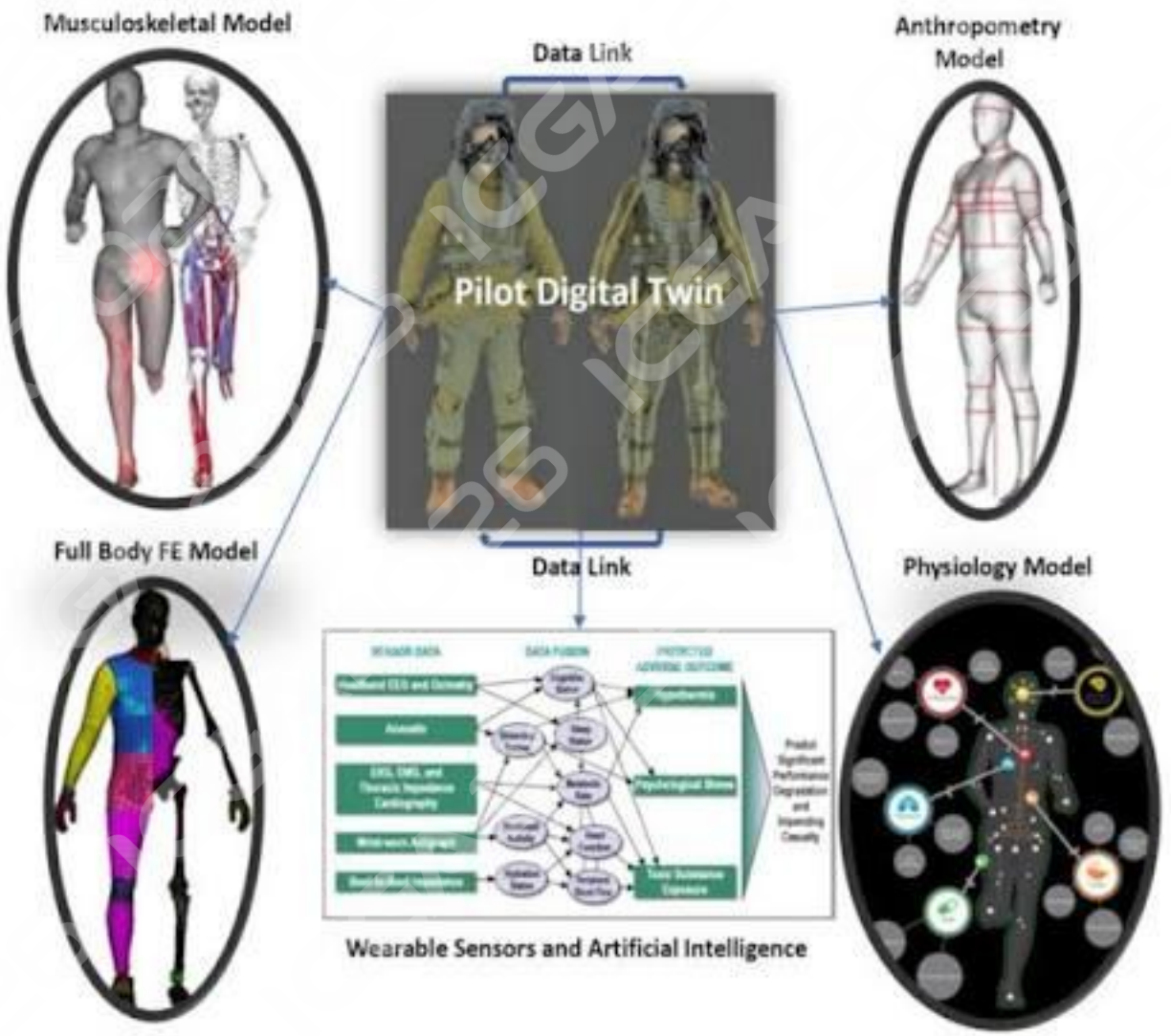
Cognitive, perceptual and control behavior model

Aircraft model

Vehicle dynamics, control laws and mode logic

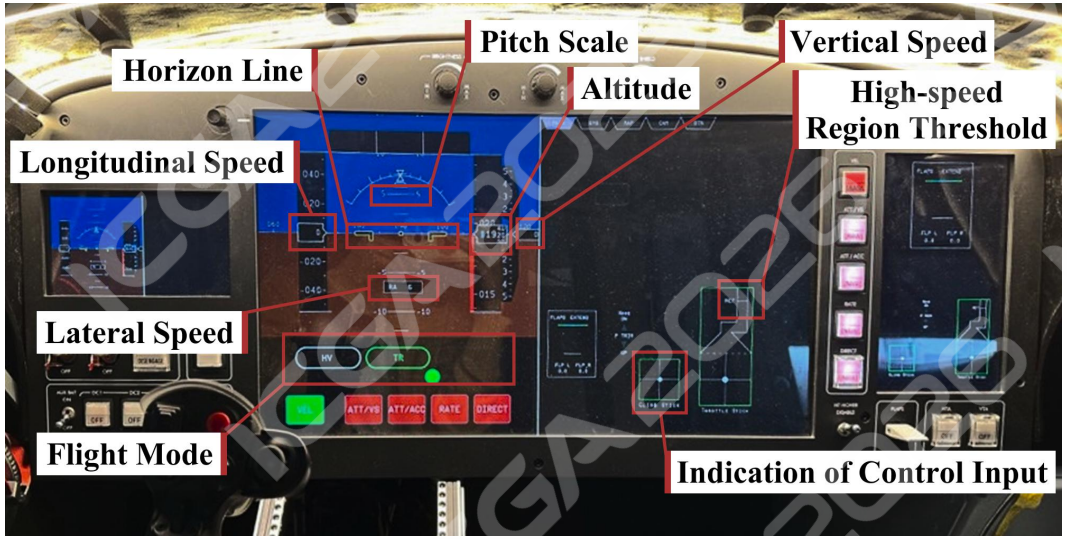
Human-state simulation and Airworthiness test

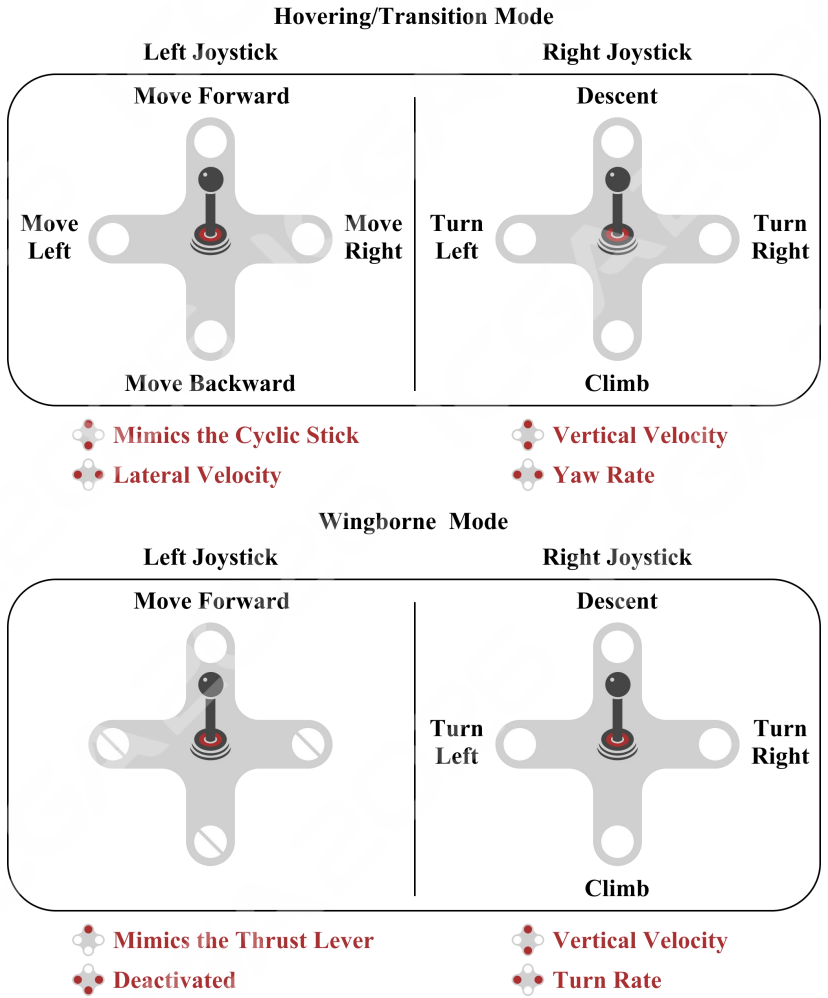
- Workload, compensation, attention and decision process
- Normal, off-nominal and failure cases for compliance evaluation



Technology 2 | Human-in-the-loop and mixed reality

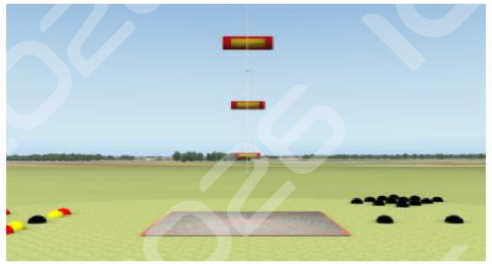






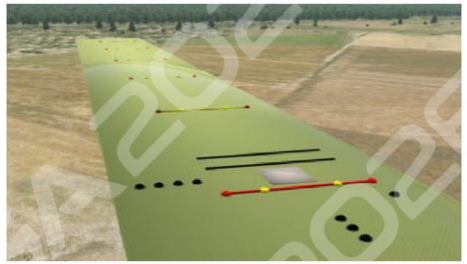
Repeatable scenarios • Controllable failures • Synchronized aircraft and human data

Technology 3 | eVTOL-specific mission task elements



Vertical maneuver

Vertical tracking accuracy; station-keeping effort



Acceleration / deceleration

Speed response; flight-path control; workload



Pirouette / yaw

Heading precision; cross-axis coupling



Obstacle avoidance

Trajectory deviation; visual attention; response



Take-off & transition

Mode awareness; climb-path control; compensation



Transition & landing

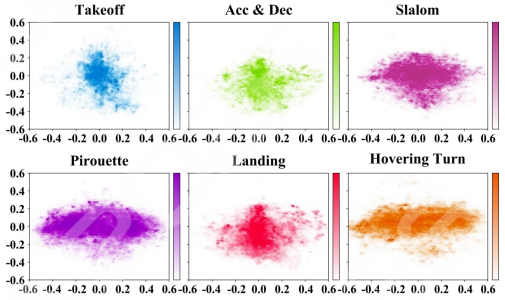
Deceleration; descent-path control; visual guidance

Representative MTEs test precision control, mode transitions, and pilot performance across the eVTOL mission.

Technology 4 | Multimodal human-state sensing

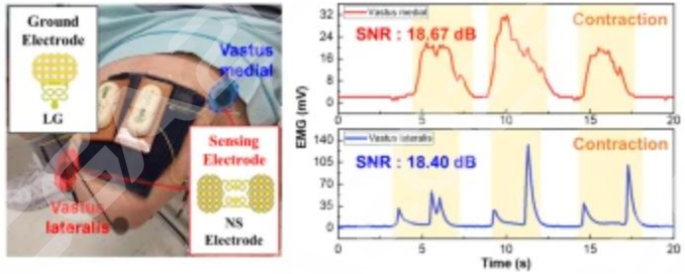
Eye tracking

Visual allocation & scanning



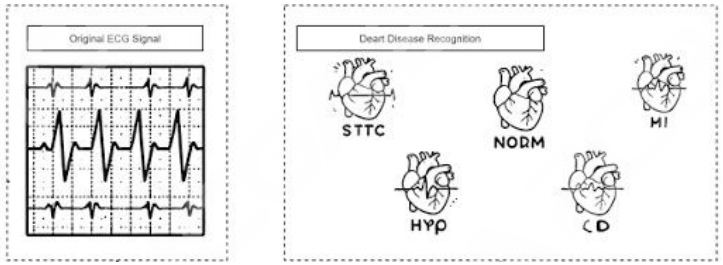
EMG

Manual control effort



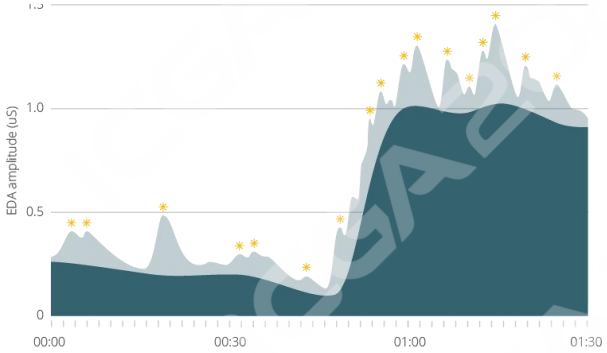
ECG / HRV

Autonomic response



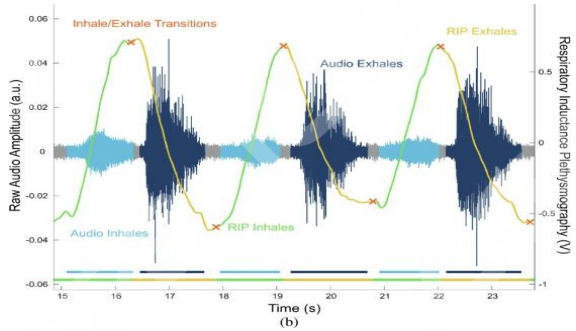
EDA

Arousal-related activity



Respiration

Physiological regulation





Abnormal State

Human sensing supports the assessment of attention, effort and adaptation during flight.

Technology 5 | Data fusion and intelligent assessment

SYNCHRONIZE — Human + aircraft + scenario data

↓

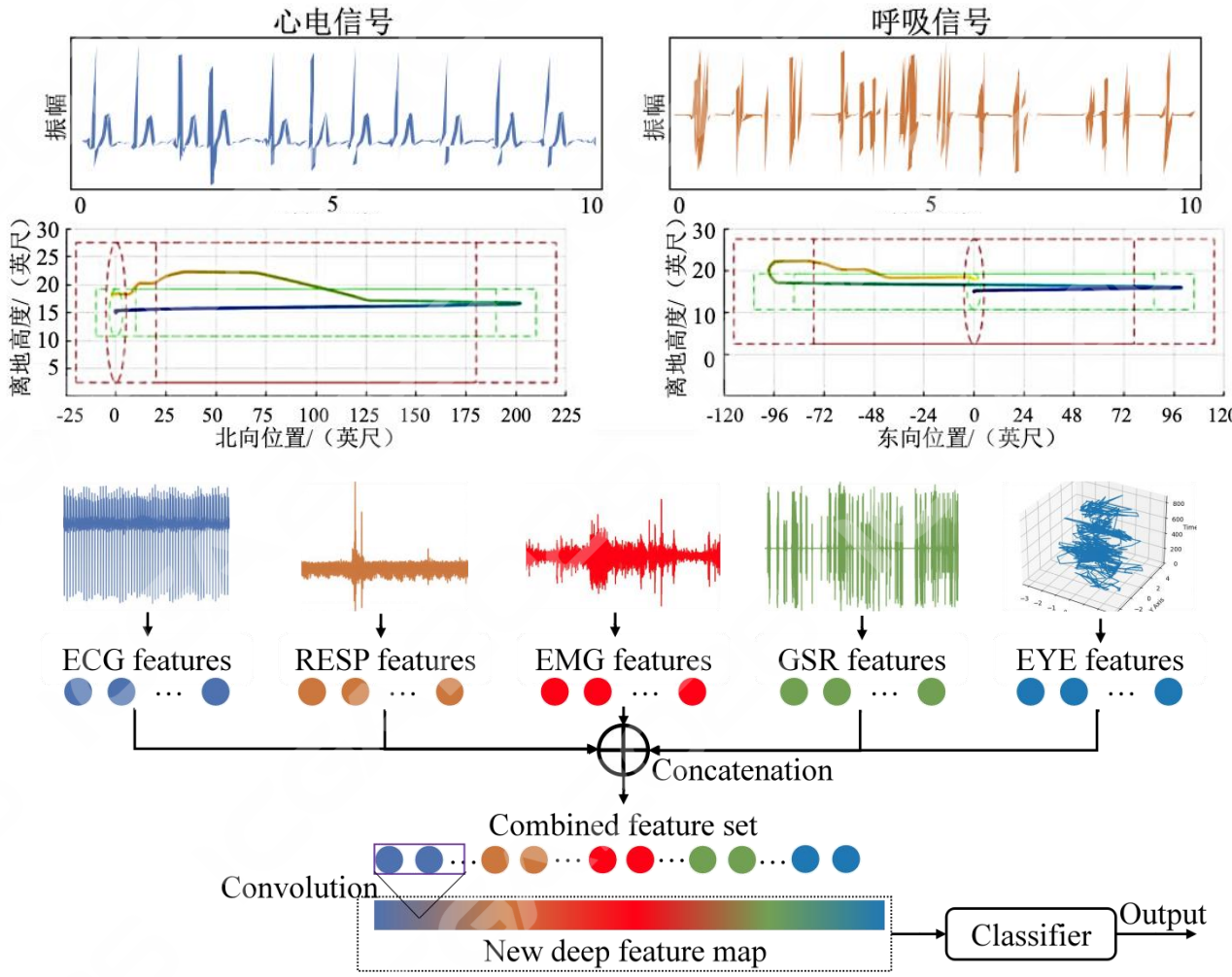
INTERPRET — Fusion, temporal modelling and feature learning

↓

ASSESS — Task-specific quality and compensation patterns

↓

ADAPT — Transfer and few-shot updates across pilots



Technology 6 | Human factors risk pathway modelling

01

DESIGN FEATURE

Controls, displays, mode logic

02

COGNITIVE STATE

Attention, expectation, awareness

03

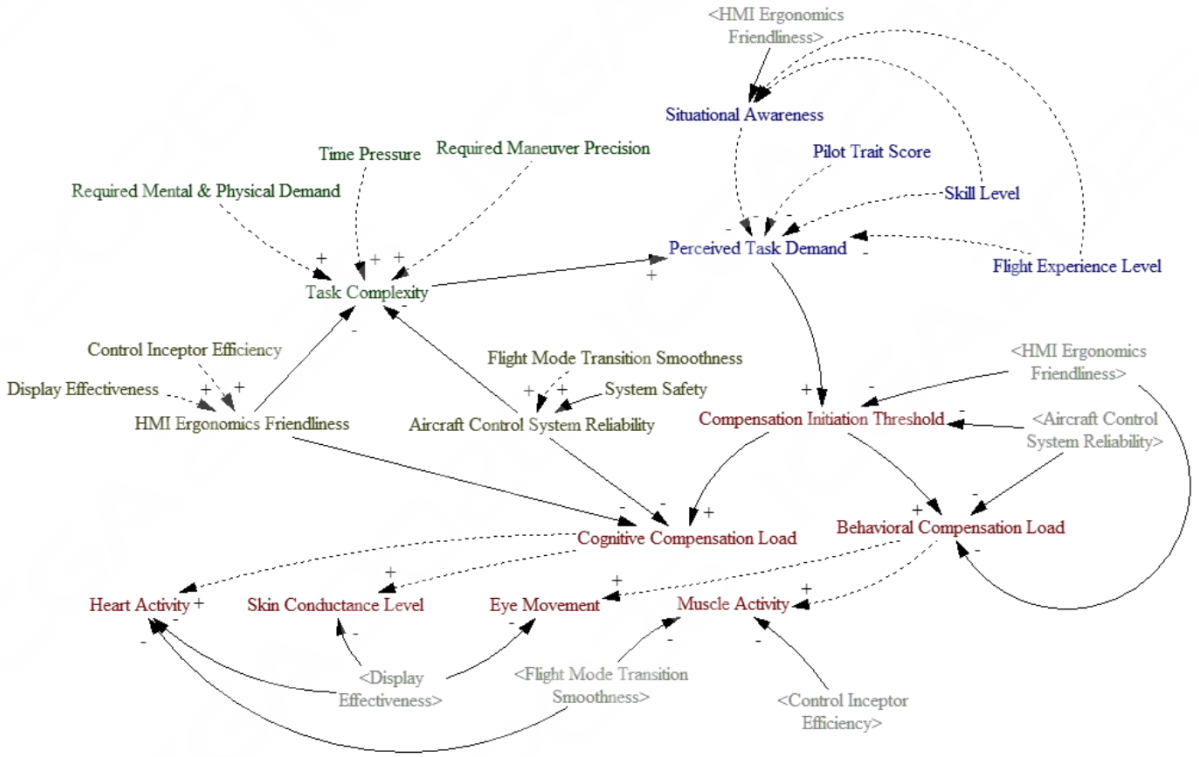
PILOT RESPONSE

Decision and action

04

SAFETY OUTCOME

Task performance and margin



Assess how an interaction problem can propagate toward a safety-relevant consequence.

Research example | An eVTOL human-in-the-loop study

25 **Participants**

Expert and other trained pilot groups

9 **Task elements**

Hover, maneuver, transition and landing

11.6 h **Physiological data**

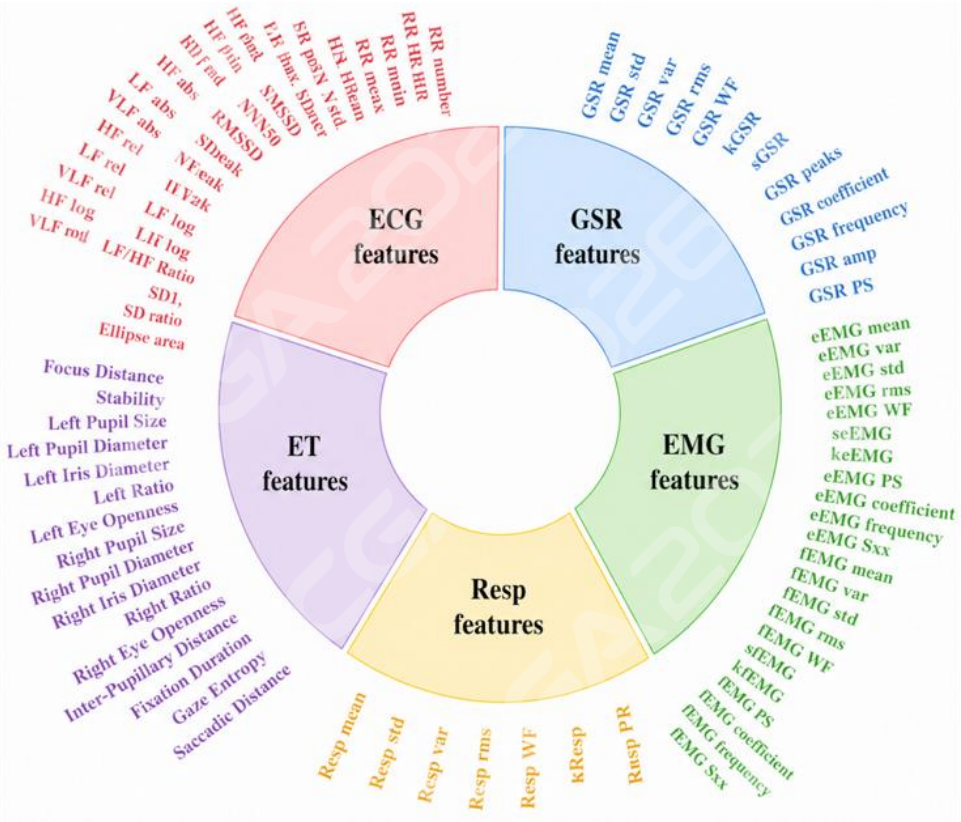
Aligned with ratings and flight performance

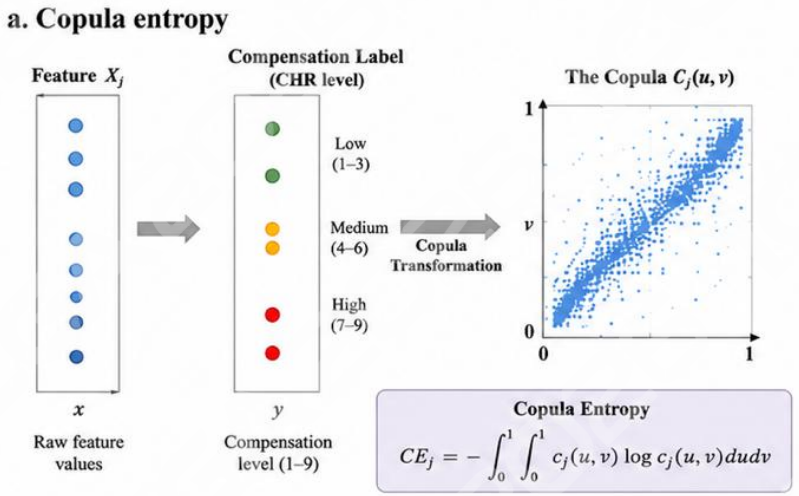
Stage 1 Briefing → **Stage 2** Preparation → **Stage 3** Experiment → **Stage 4** Interview

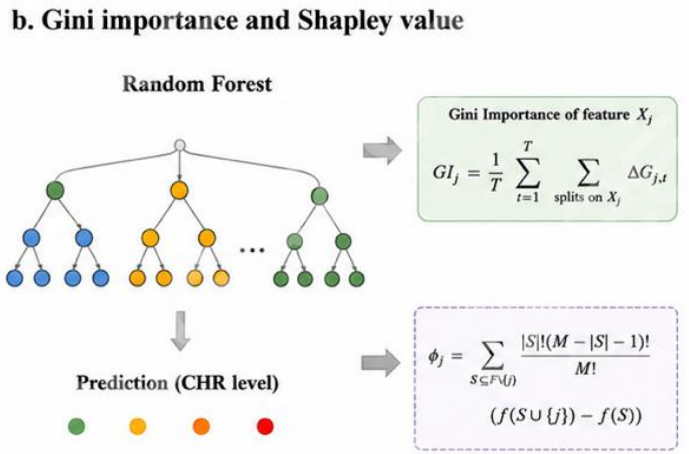


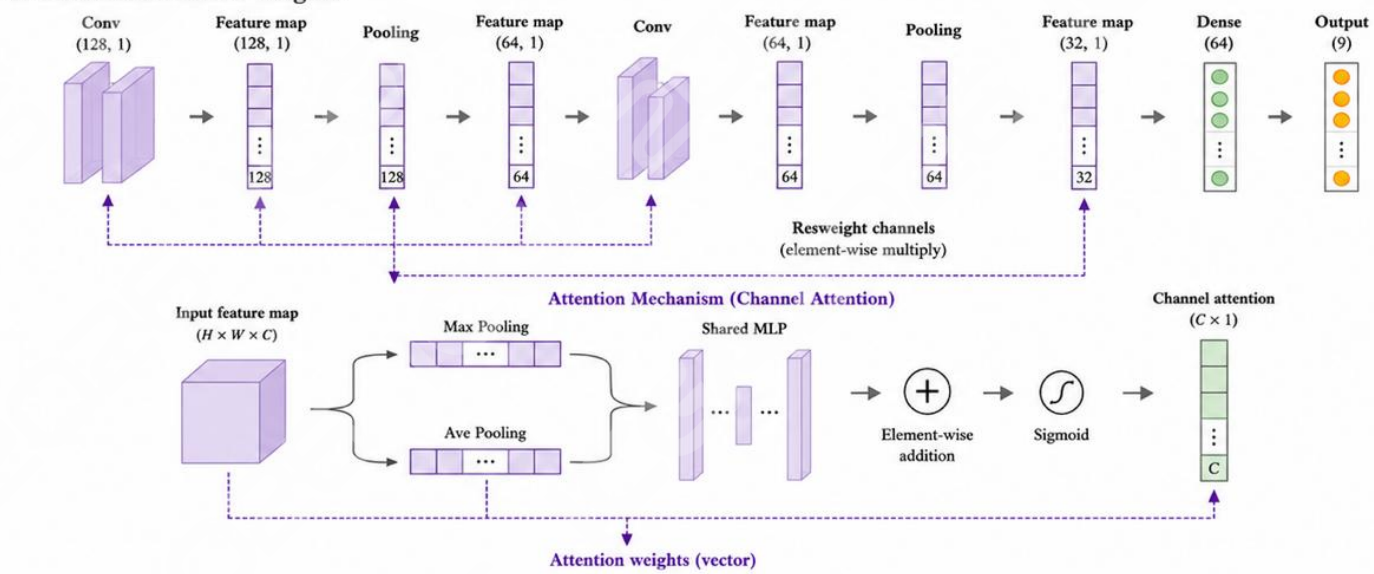


Research example | Multi-Method Analysis of Human Response Patterns



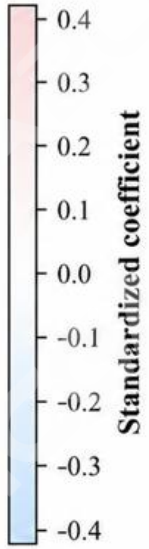


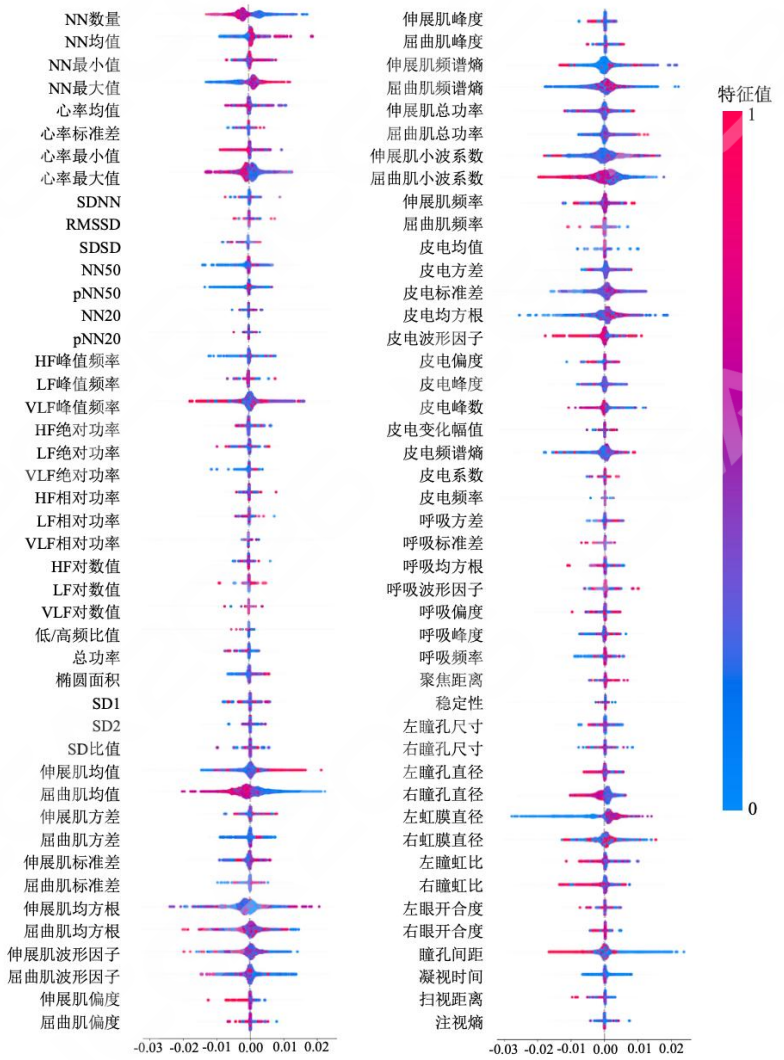




Research example | Physiological features reflect pilot compensation

	CHR	NASA-TLX
RR number	0.08	**0.30***
GSR std	0.18	0.12
GSR rms	**0.27***	0.17
GSR WF	**0.23***	0.15
kGSR	0.16	0.19
GSR PS	0.15	0.18
eEMG WF	0.15	0.08
fEMG coefficient	0.20	0.12
eEMG coefficient	**0.26***	0.09
fEMG PS	**0.28***	0.15
fEMG rms	**0.37****	0.13
eEMG rms	**0.40****	0.12
fEMG mean	0.18	0.11
eEMG mean	0.20	0.10
eEMG PS	**0.32***	0.14
Right Iris Diameter	0.12	0.16
Left Pupil Diameter	**0.24***	0.18
Right Pupil Diameter	0.21	0.19
Left Iris Diameter	0.13	0.17
Inter-Pupillary Distance	0.17	0.15





Research example | Pilot feedback becomes design action

Control Surface

Locking Mechanism
- ⚠ The locking mechanism lacks smoothness.
- 🔧 Adopt an alternative trigger method (e.g., a dedicated button) or integrate this operation into the training program for better familiarity.

Side Drift
- ⚠ Aircraft drifts forward and experiences unintended rotations during vertical maneuvers.
- 🔧 Introduce a dead zone design to minimize unintentional movements and reduce small, inadvertent inputs.

Joystick Sensitivity
- ⚠ High joystick sensitivity and asymmetrical responses.
- 🔧 Adjust joystick sensitivity or reduce control gain to achieve more consistent and linear control inputs across different axes.

Turning Control
- ⚠ Some users find the side-pulling method for turning, rather than rotating the joystick, counterintuitive.
- 🔧 Incorporate this turning operation into the training program to improve user familiarity and comfort.

Control Systems

Altitude Loss
- ⚠ Slight altitude loss after switching flight modes.
- 🔧 Improve the unified control system to better manage mode transitions and mitigate altitude loss during the changeover.

Altitude Perception
- ⚠ The aircraft's nose pitches up during deceleration, leading to misjudgments in altitude.
- 🔧 Implement a compensation mechanism to counteract the effects of pitch-up during deceleration, improving altitude control accuracy.

Cockpit Display

Limited Visibility
- ⚠ Lack of downward visibility hinders certain maneuvers.
- 🔧 Add a bottom camera view to the cockpit display to enhance situational awareness and provide better visibility during relevant maneuvers.

Flight Mode and Rate Indicators
- ⚠ Difficulty in observing deceleration, descent rates, and flight modes.
- 🔧 Improve the layout and clarity of the display to enhance the visibility of flight mode indicators and rate information.

Design learning from representative tasks is a central value of human factors assessment.

Future directions: from human data to safer operations

01

Human-centred autonomy

Automation that communicates intent, state and control authority

02

Predictive assessment

Human factors risk linked to scenario, pilot response and recovery

03

Evidence-driven certification

Consistent evaluation through models, simulators and flight tests

Human factors will increasingly shape both eVTOL design and airworthiness evidence.

Key takeaways

01 eVTOL alters the pilot's role across flight modes and operations.

02 Human factors assessment must integrate controls, interfaces, automation and operational scenarios.

03 Emerging technologies can connect pilot-in-the-loop evidence to design improvement and airworthiness verification.



Thank you.

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