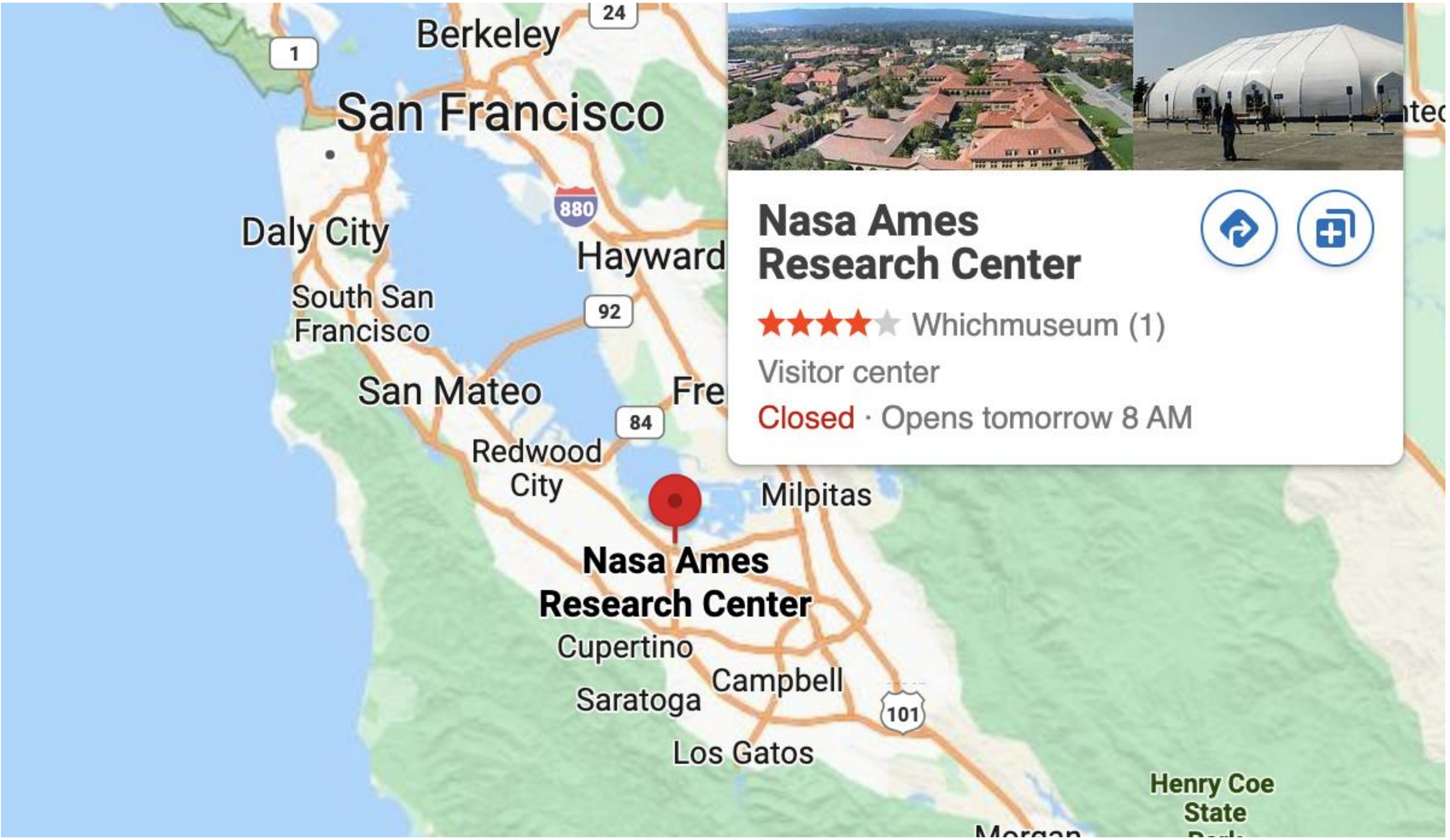
Training the Powered-Lift Evaluation Pilot

Loran Haworth*, Michael Feary[†], John Kaneshige[†*], Kimberlee Shish[†*], Thomas Lombaerts[‡], Kevin Monk[†], Amber Villa[†], Mieczyslaw Steglinski[‡], Nelson Iwai[‡*], and John Archdeacon[‡*]

[†]NASA Ames Human Systems Integration Division, [†*]NASA Ames Intelligent Systems Division, *SJSU Research Foundation, [‡]KBR Wyle Services LLC, [‡*]ASRC Federal

NASA Ames Research Center Location



nasa ames research center - Search (bing.com)

Ames Research Center

History - Early NASA-Ames/Army Vertical Flight Research

Ryan VZ-3RY Vertiplane

Bell X-14B (VTOL experimental aircraft)

Ryan XV-5B ("fan-in-wing")

Hawker P.1127

History – Early NASA-Ames/Army Indirect Flight Control Systems (IFCS)

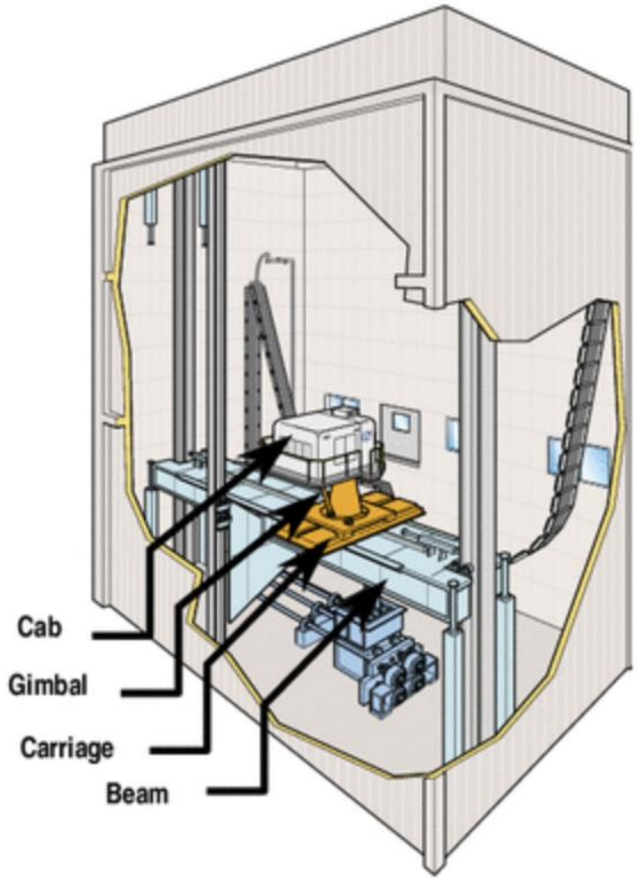
Comanche surrogate (Sikorsky)

RAH-66 Comanche prototype

Training the Powered-Lift Evaluation Pilot (Background)

This presentation regards the preparation and training of Fixed and Rotary wing pilots as pilot evaluators* for the Automation Enabled Pilot -2 (AEP-2) research study conducted on the NASA Vertical Motion Simulator (VMS) in June 2024.

* comprehensive pilot training is essential



NASA-Ames Vertical Motion Flight Simulator
(World's largest Motion Base Simulator)

Presentation Outline

- Goals of the AEP-2 Study on the VMS
- Training objectives and challenges
- Training procedures (classroom and fixed base simulator)
- Introduction to the Aerospace Cognitive Engineering Rapid Automation Test Environment (ACEL-RATE) "Training" Simulator
- Lift Plus Cruise (LPC) Concept Vehicle & equipment
- Maneuvers and Automation Tasks
- Subjective ratings
- Training Observations
- Study results are currently being collected and analyzed

Training the Powered-Lift Evaluation Pilot (AEP-2 study)

- **AEP-2 Study Goal**
  - Evaluate flight path information and automation requirements for expected Urban Air Mobility (UAM) operations using representative Powered Lift aircraft automation

UAM Operations

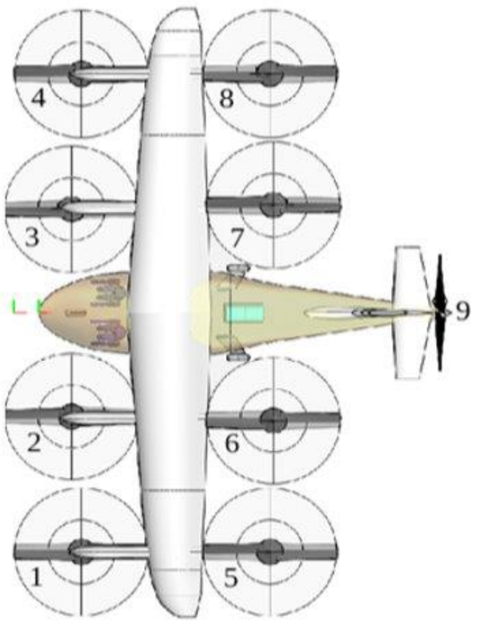
- **Objectives**
  - Evaluate challenges associated with transitioning from forward flight to a vertical landing with industry representative eVTOL aircraft
  - Explore challenges associated with safe and efficient operations when flying representative UAM approach procedures
  - Establish baseline for future automation studies
- **Approach**
  - Simulate Lift Plus Cruise (LPC) eVTOL vehicle design concept developed by NASA's Revolutionary Vertical Lift Technology (RVLT) project
  - Develop representative Simplified Vehicle Controls (SVC) and displays with advanced automation technologies
  - Evaluate using representative airspace procedures
    - Required Navigation Performance with Authorization Required (RNP-AR)
    - Localizer Performance with Vertical Guidance (LPV)

Training the Powered-Lift Evaluation Pilot (Training Objectives)

Training Objective:

Train the evaluation pilot with the knowledge and skill to complete and rate AEP-2 study maneuver requirements without overtraining.

- Pilot training included:
  - Lift-Plus-Cruise (LPC) eVTOL model
  - Indirect Flight Control System (IFCS)
  - Novel approach procedures
  - Three levels of approach automation
  - LPC Control interfaces and displays
  - Agnostic evaluation methods



Lift-Plus-Cruise

Training the Powered-Lift Evaluation Pilot (Training Challenges)

Notable Training Challenges:

- Limited training time (one day)
- Complex aircraft, transition modes and IFCS
- Diverse pilot backgrounds
- New and Novel
  - Maneuver concepts
  - Information displays and flight control
  - Automation concepts
- Scoping training elements to those required to fly and evaluate the maneuvers (Approach, hover & landing)
- Training subjective rating scales

Date	Time	Activity	Time (min)	Location
Day 1	0800	Collect NASA visitor badges	30	Main gate visitor badging office
Day 1	0830	Introductions	30	Building 262, room 283
Day 1	0930	AEP2 Study Briefing and Q & A	60	Building 262, room 283
Day 1	1030	ACELeRATE Session 1 (Vehicle Familiarization Flight)	90	Building 262, room 285
Day 1	1200	Lunch	60	
Day 1	1300	ACELeRATE Session 2 (Controller Familiarization Flights)	90	Building 262, room 285
Day 1	1430	Break	30	
Day 1	1500	ACELeRATE Session 3 (Flight Test Maneuvers)	90	Building 262, room 285
Day 1	1630	End of Day 1		
Day 2	0800	Arrive and VMS Briefing	30	Building 243
Day 2	0830	VMS Familiarization Flight	30	Building 243
Day 2	0900	VMS Session 1	90	Building 243
Day 2	1030	Break	30	
Day 2	1100	VMS Session 2	90	Building 243
Day 2	1230	Lunch	60	
Day 2	1330	VMS Session 3	90	Building 243
Day 2	1500	Break	30	
Day 2	1530	Post experiment discussion and out brief	60	Building 243
Day 2	1700	Depart		

Training Schedule

Training Procedures (See paper for details)

Procedures:

- Training Requirements Analysis
- Aircraft Flight Manual
- Training Schedule

- Classroom training
  - Establishing a positive training expectation*
  - Confirming pilot background
  - LPC description, controls and displays
  - Flight maneuvers and test conditions including environmental conditions, and aircraft traffic
  - Training and Performance objectives
  - Use of rating scales
  - Simulator familiarization (ACEL-RATE Simulator and VMS)
  - Conduct of the test/study

* Important for reducing pilot concerns

Aircraft Flight Manual

Training Procedures (Continued)

Continued

- In Simulator Training
  - Simulator familiarization (Inceptors, Grips, Buttons, displays, ergonomics, etc)
  - Safety protocols
  - Visual Environment including weather and FOV
  - Eye tracking glasses
  - Maneuver practice and training
    - Low-Speed Flight

      Hover (Control commands & Stabilization, Inceptor mapping & envelope limits)
    - Up and Away Flight

      Identify lift modes, transitions, Control commands & stabilization, Inceptor mapping, envelope limits, display information elements, and traffic
    - AEP-2 Study Maneuvers and use of subjective rating scales
  - Post simulation briefing and introduction to the VMS

ACEL-RATE Simulator

Aerospace Cognitive Engineering Rapid Automation Test Environment (ACEL-RATE) Simulator

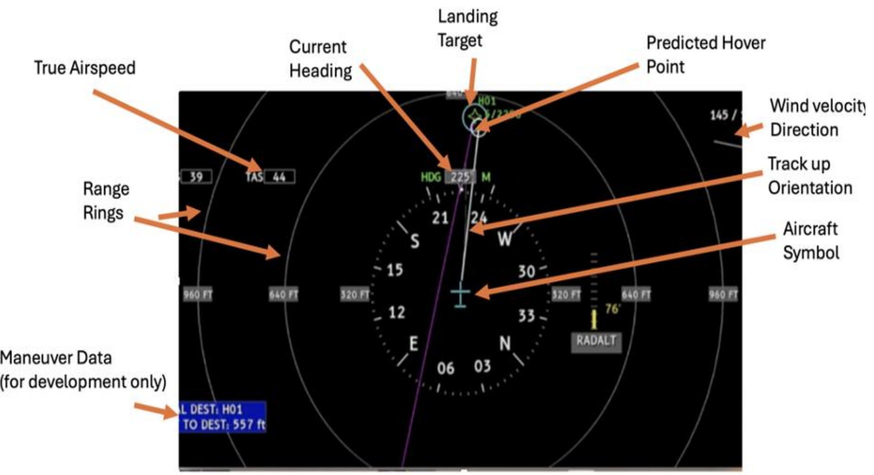
Large Field-Of-View Simulator

ACEL-RATE Simulator Comparison with the VMS

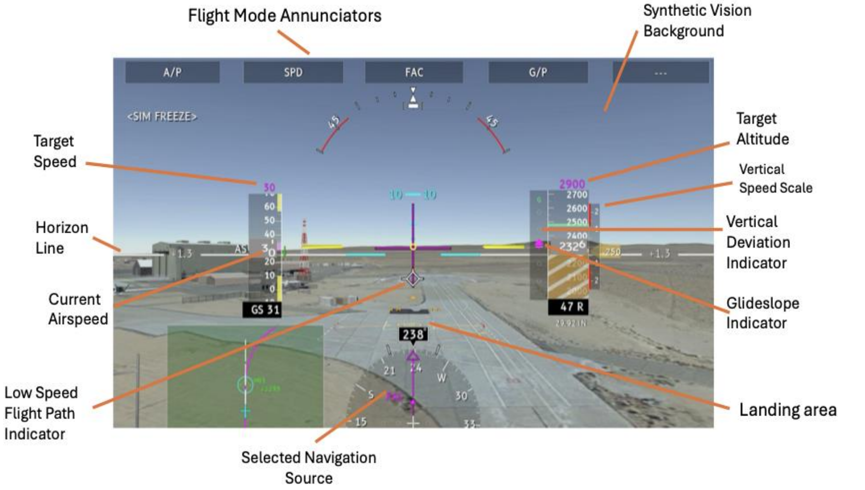
- The ACEL-RATE simulator replicated the displays, control laws (command & stabilization) and the outside visual environment of the VMS
- Major differences between the ACEL-RATE and VMS included the motion base, Field-Of View, use of twist for yaw on the right inceptor and minor differences in the grip design.

ACEL-RATE Simulator

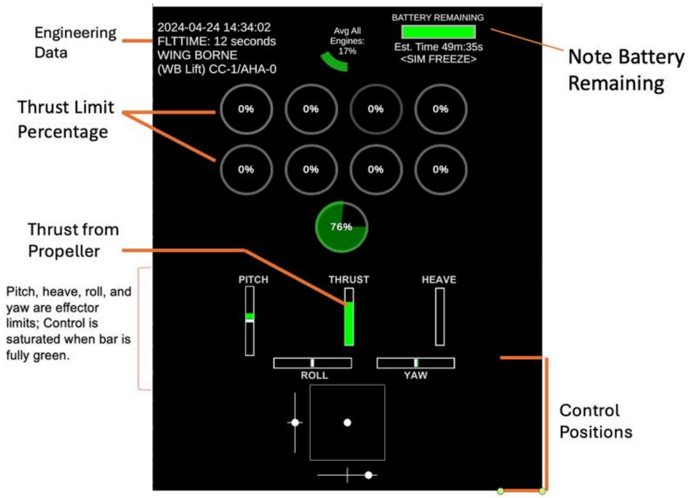
Information Displays and Controllers



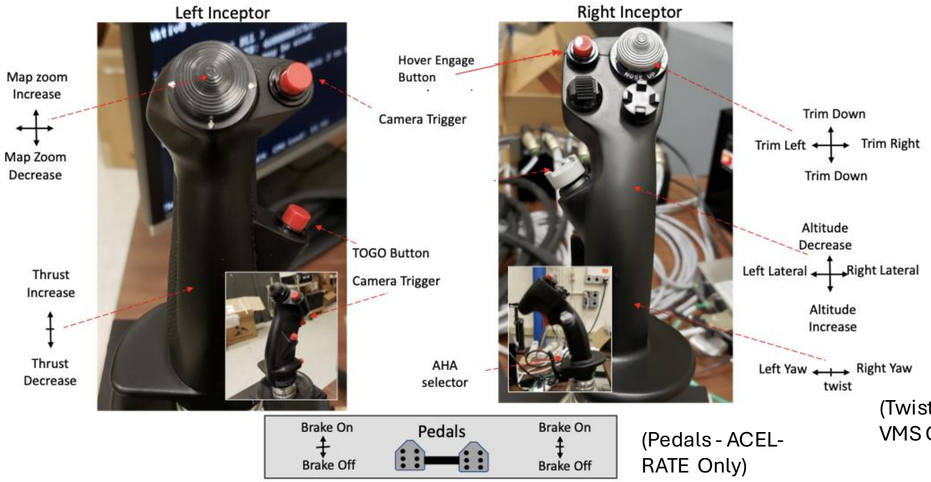
Map Display



Primary Flight Display
Edwards AFB imagery in background



System Health Display



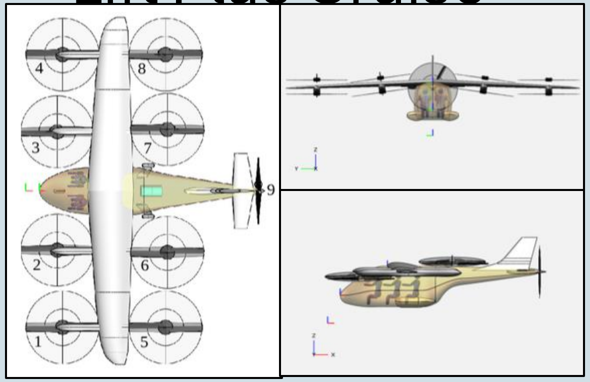
(Pedals - ACEL-RATE Only)

(Twist - VMS Only)

Inceptors

AEP-2 Study: Lift Plus Cruise (LPC) Concept Vehicle

Lift Plus Cruise

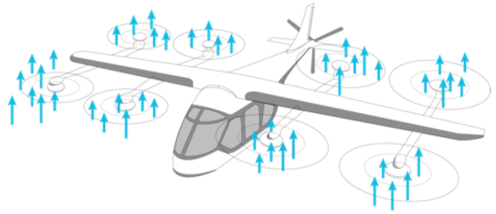


- Design Parameters
  - Gross Weight = 6013 lbs
  - Payload = 1000 lbs (5 passenger)
  - Wingspan = 47.42 ft
  - 8 collectively controlled rotors
  - 1 pusher propeller
  - 2 ailerons, 1 elevator, 1 rudder

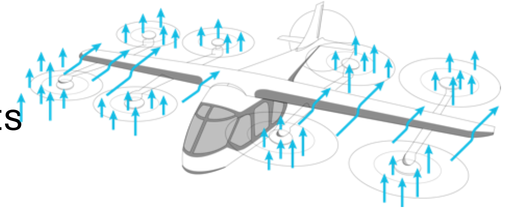
- Performance Parameters
  - Range = 50 nm
  - Best endurance speed = 90 kts
  - Maximum speed = 123 kts

LPC Winged eVTOL Taxonomy

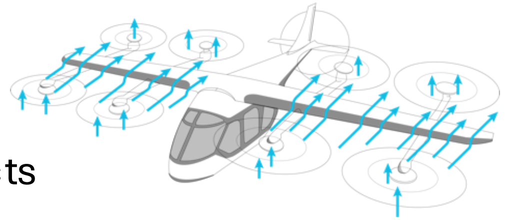
- Thrust Borne (TB) Lift (0-20 KIAS)
  - Rotors provide lift
  - Airframe produces minimal aerodynamic effects



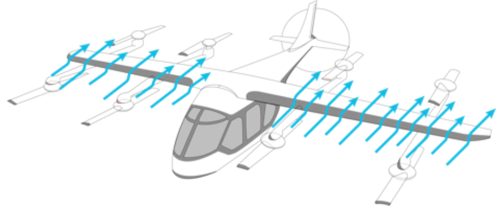
- Semi-Thrust Borne Lift (STB) (15-40 KIAS)
  - Rotors provide primary lift
  - Airframe produces moderate aerodynamic effects (i.e., requiring AoA and sideslip considerations)



- Semi-Wing Borne Lift (SWB) (30-100 KIAS)
  - Airframe provides primary lift
  - Rotors provide some lift (e.g., for AoA protection)
  - Airframe produces significant aerodynamic effects (i.e., requiring AoA and sideslip protection)

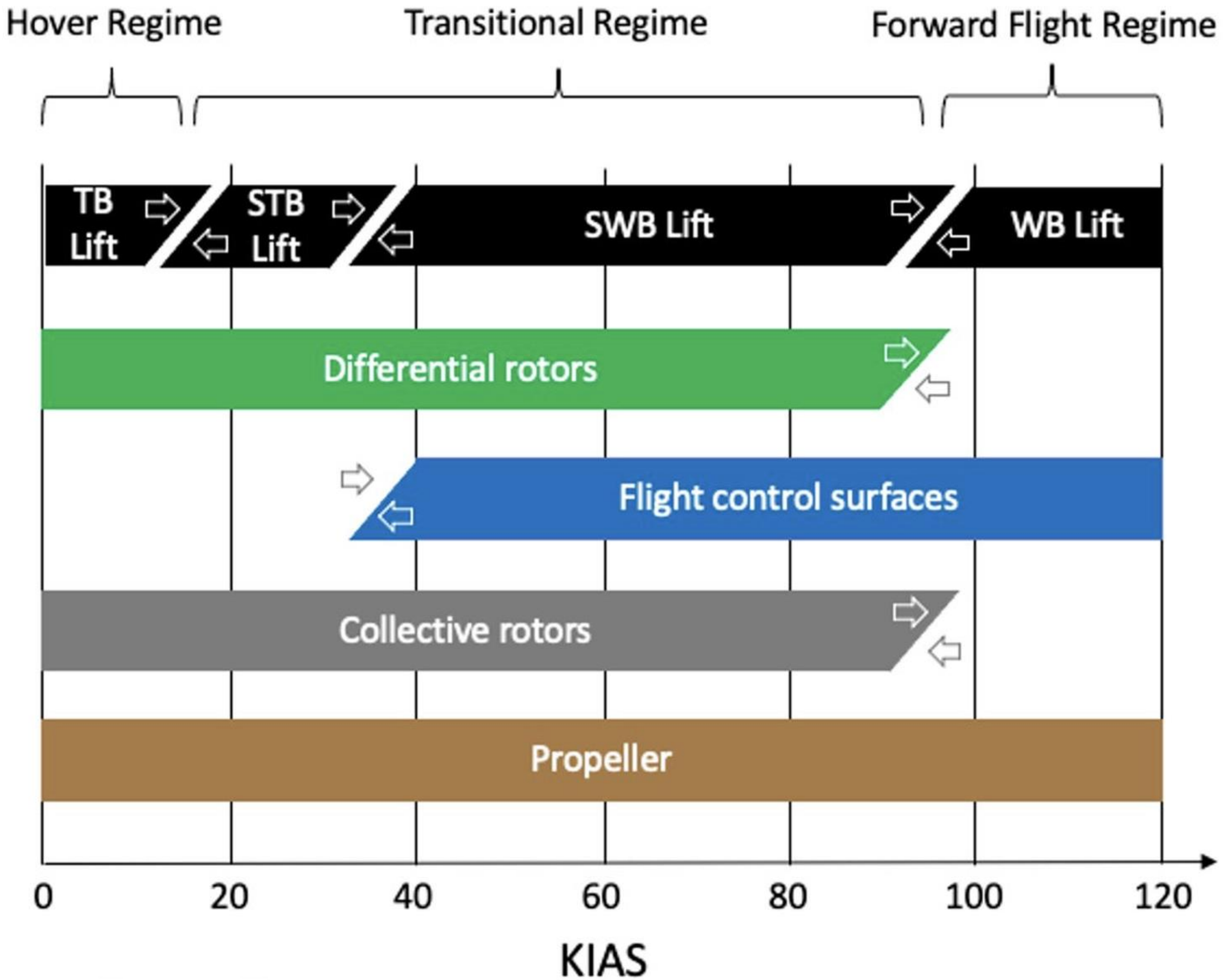


- Wing Borne Lift (WB) (90-120 KIAS)
  - Airframe provides lift
  - Rotors are stopped



Silva, C., Johnson, W., Antcliff, K., and Patterson, M., "VTOL Urban Air Mobility Concept Vehicles for Technology Development", AIAA 2018-3847, June 2018.
Advanced Rotorcraft Technology, Inc., "Improved Fidelity Simulation Models for VTOL Concept Vehicles", SBIR Phase III 80NSSC21C0610 Progress Report No. 3, May 2022.

LPC-COL Control Allocation Schedule



Thrust Borne (TB) Lift
Semi-Thrust Borne Lift (STB)
Semi-Wing Borne Lift (SWB)
Wing Borne Lift (WB)

LIFT MODES, CONTROL COMMANDS, STICK INCEPTOR MAPPING

<table>
<tr><th rowspan="2">Lifting Modes
f(KIAS)</th><th>Left Stick</th><th colspan="3">Right Stick</th><th rowspan="2">Groundspeed</th></tr>
<tr><th>Speed
Accelerate
Decelerate</th><th>Vertical
Descend
Climb</th><th>Lateral
Go Left *Go Right*</th><th>Directional
Yaw Left *Yaw Right*</th></tr>
<tr><td>Hover Engaged</td><td>Forward Groundspeed</td><td>Vertical Speed</td><td>Lateral Groundspeed</td><td>Heading Rate</td><td>(0-20 KGS)</td></tr>
<tr><td>TB Lift
(0-20 KIAS)</td><td rowspan="2">Acceleration[1]</td><td>Vertical Acceleration</td><td rowspan="2">Bank Angle</td><td rowspan="2">Heading Rate</td><td>(0-34 KGS)</td></tr>
<tr><td>STB Lift
(15-40 KIAS)</td><td rowspan="3">FPA Rate</td><td rowspan="3">(34+ KGS)</td></tr>
<tr><td>SWB Lift
(30-100 KIAS)</td><td rowspan="2">Acceleration[2]</td><td rowspan="2">Roll Rate</td><td rowspan="2">Sideslip Angle</td></tr>
<tr><td>WB Lift
(90-120 KIAS)</td></tr>
</table>

1. Acceleration is relative to forward groundspeed
2. Acceleration is relative to indicated airspeed

Study Sessions and approaches

Simulation Session One

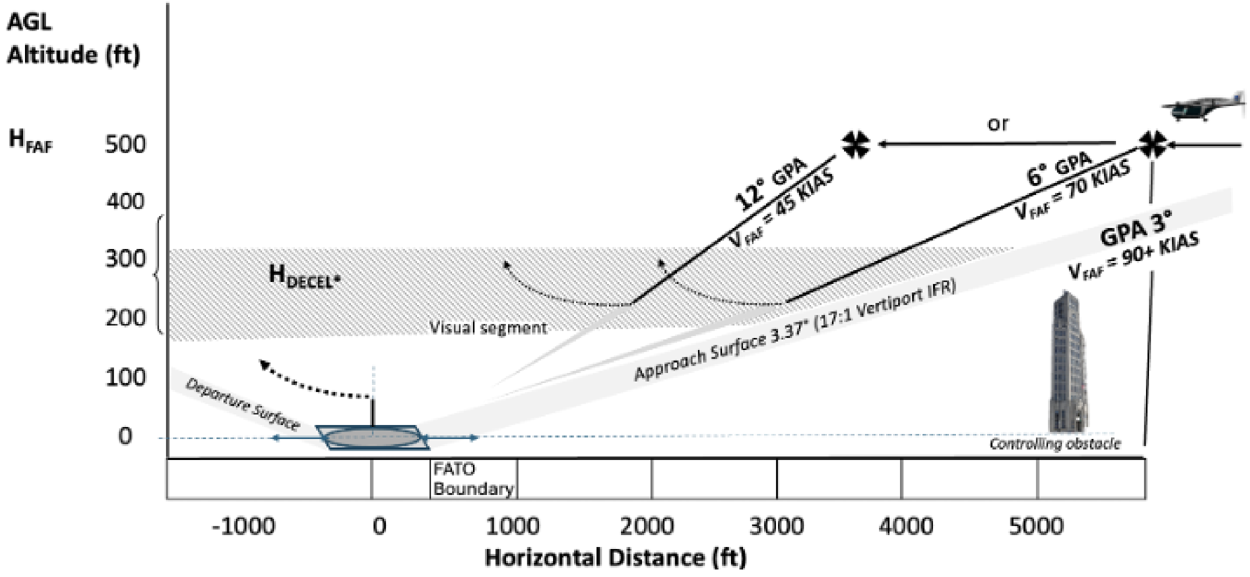
- Full 6-degree approach

Simulation Session Two

- 6-degree approach from intercept
- 12-degree approach from intercept

Simulation Session Three

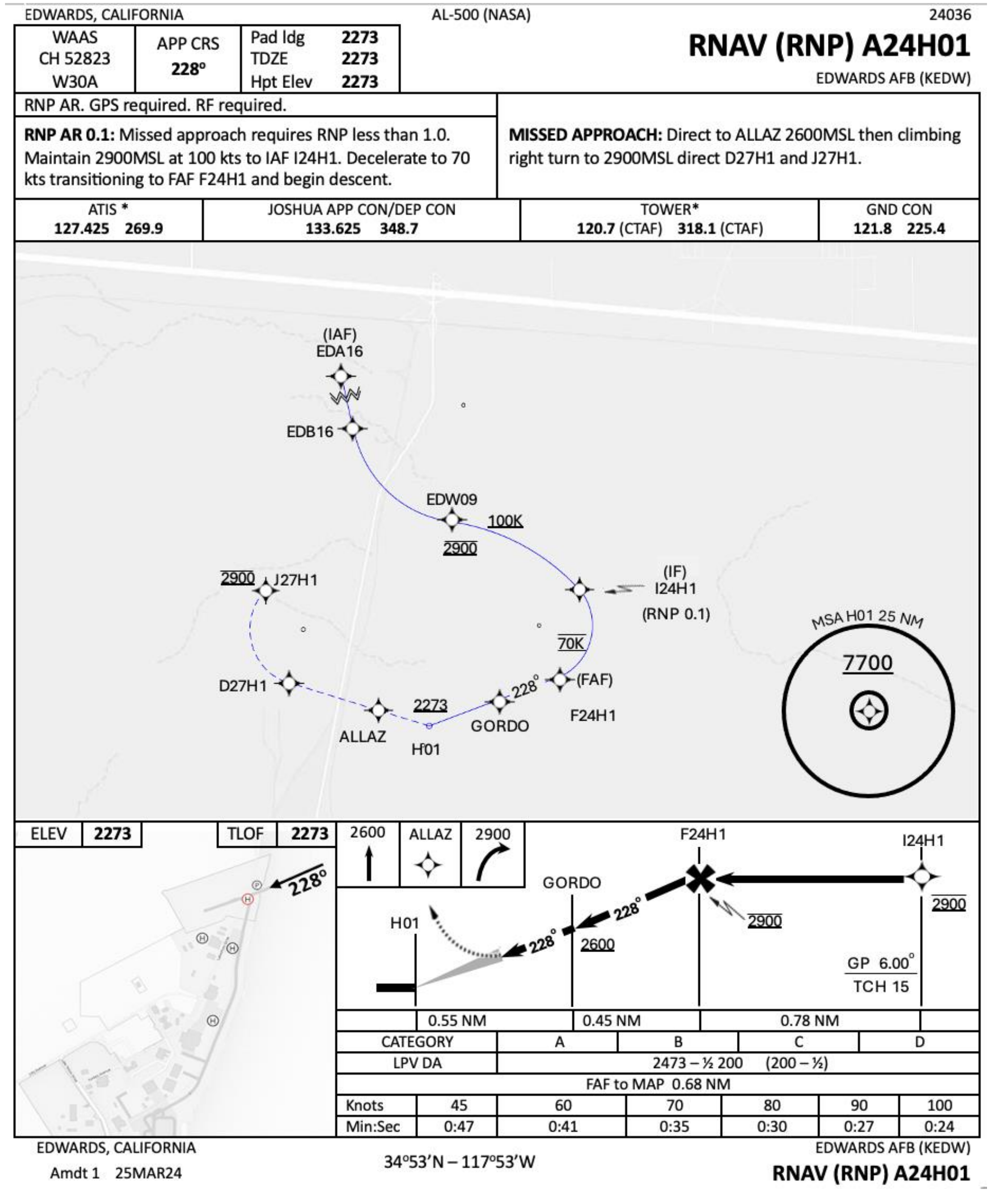
- 6-degree final approach



RNAV (RNP) Approach Plate

Example of 6-Degree Arrival Approach

Session one - Maneuver Description
RNP-AR: Initiate the on the arrival path (0.4 NM) prior to EDA16.
Fly the arrival procedure maintaining the lateral, vertical and speed profile.
Note the speed limitations of 100K and 70K.



Bird on the wire approach & Landing

1. **Bird on the Wire Approach**: This approach involves a fast approach followed by deceleration and touchdown, aiming to minimize the time spent in hovering flight.
2. **Energy Efficiency**: The approach is designed to reduce aircraft energy use by staying on the wing (using lift from the wing) as long as possible during the approach, before transitioning to hovering flight for landing. Hovering flight (using lift from thrusters) consumes more energy compared to lift on the wing.
3. **AEP-1 Findings**: During AEP-1, it was found that pilots struggled to land accurately and reliably at the intended landing spot.
4. **Proposed Solution for AEP-2**: To address this issue, the deceleration and decrab process was automated in AEP-2.

Even Birds have difficulty landing

Study Hover Modes

Assistive Hover Automation Behavior and Interface

- **Assistive Hover Automation (AHA – 0)**
  - Hover Button arms Hover mode
  - Predicted hover point is not displayed
  - Hover mode engages below 10 KFGS
    - RHI lateral movement transitions from bank angle to lateral groundspeed
    - RHI twist adjusts aircraft direction (yaw). Pedals for yaw In ACEL-RATE sim.
- **Assistive Hover Automation (AHA – 1)**
  - Hover Button engages Transition to Hover
    - Automatically commands a 2.5 knot/sec deceleration rate[1]
    - Automatically commands a decrab maneuver[2]
  - Hover Mode engages below 10 KFGS
    - RHI response transitions from bank angle to vector-based track angle
- **Assistive Hover Automation (AHA – 2)**
  - Hover Button engaged Transition to a Hover Point
    - Automatically commands a deceleration to the hover point[1]
    - Automatically latches to helipad if "close enough" when transition is engaged
    - Automatically commands a decrab maneuver[2]
  - Hover Mode engages below 10KFGS
    - RHI response transitions to command a hover target[3]

(1) Can be modified with Left Hand Inceptor (LHI) inputs
(2) Can be modified with Right Hand Inceptor (RHI) twist inputs. Pedals input In ACEL-RATE sim.
(3) Can be modified with Right Hand Inceptor (RHI) lateral inputs

Flight Path Vector

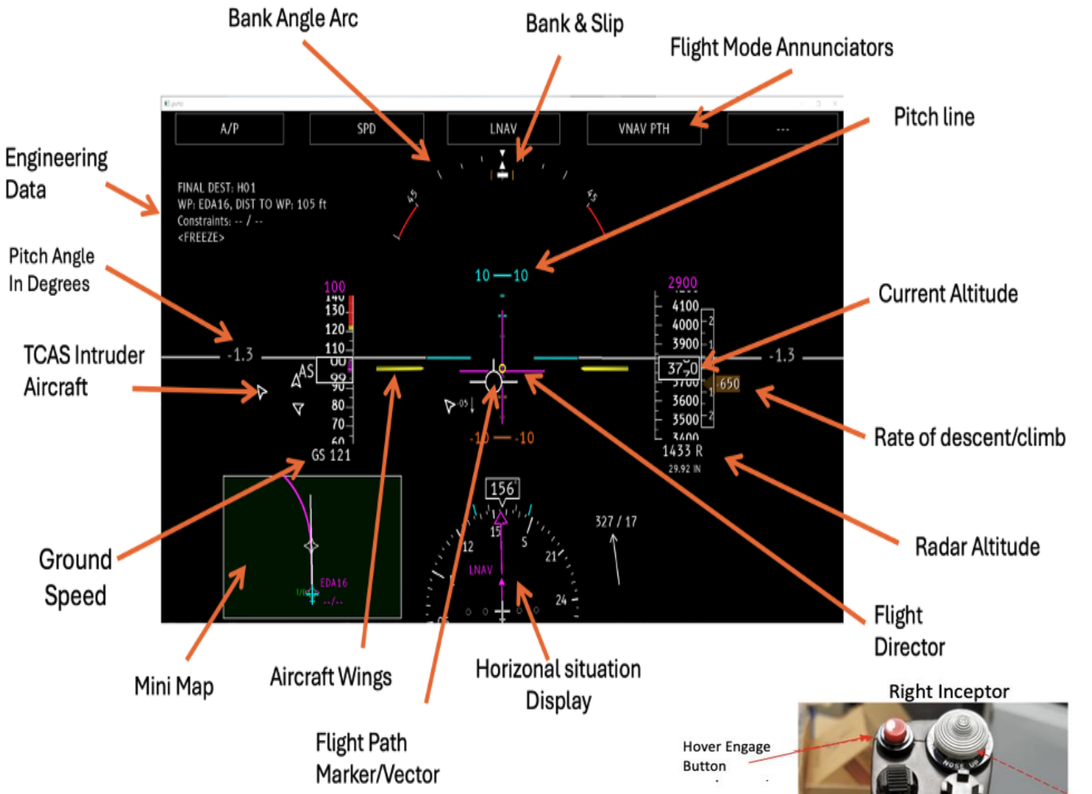
Predicted Hover Point Along Current Track

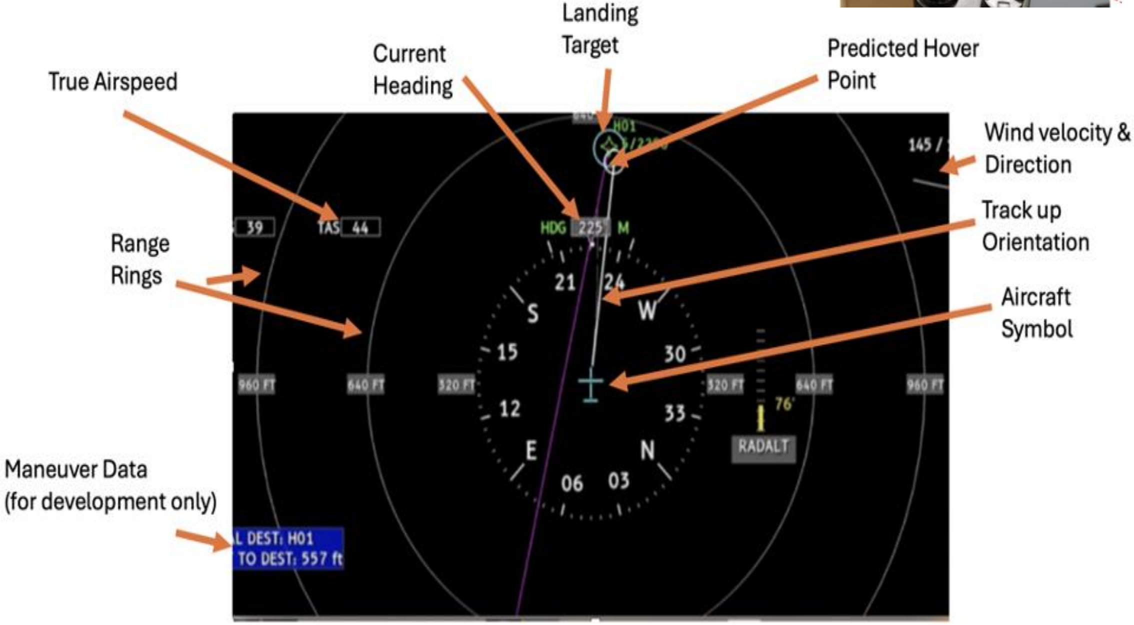
Commanded Flight Path Vector

Predicted Hover Point Along Commanded Track

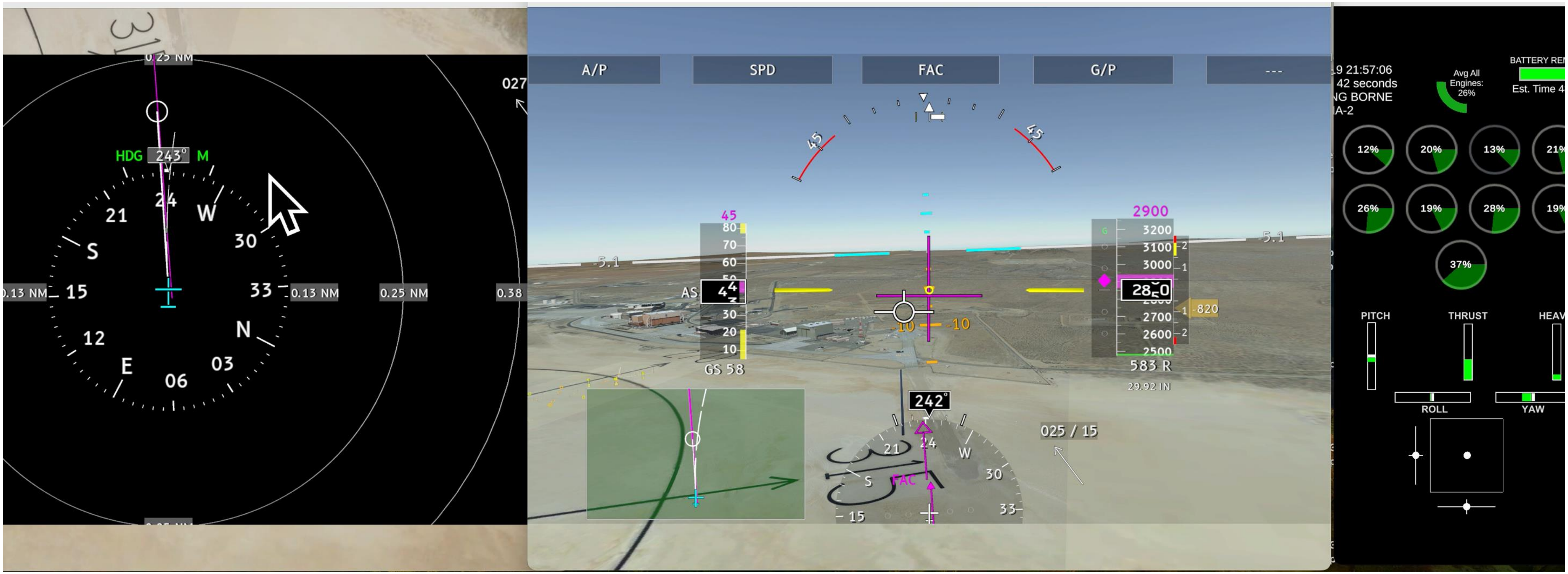
Commanded/Computed Flight Path Vector

Commanded Hover Point Along Computed Track



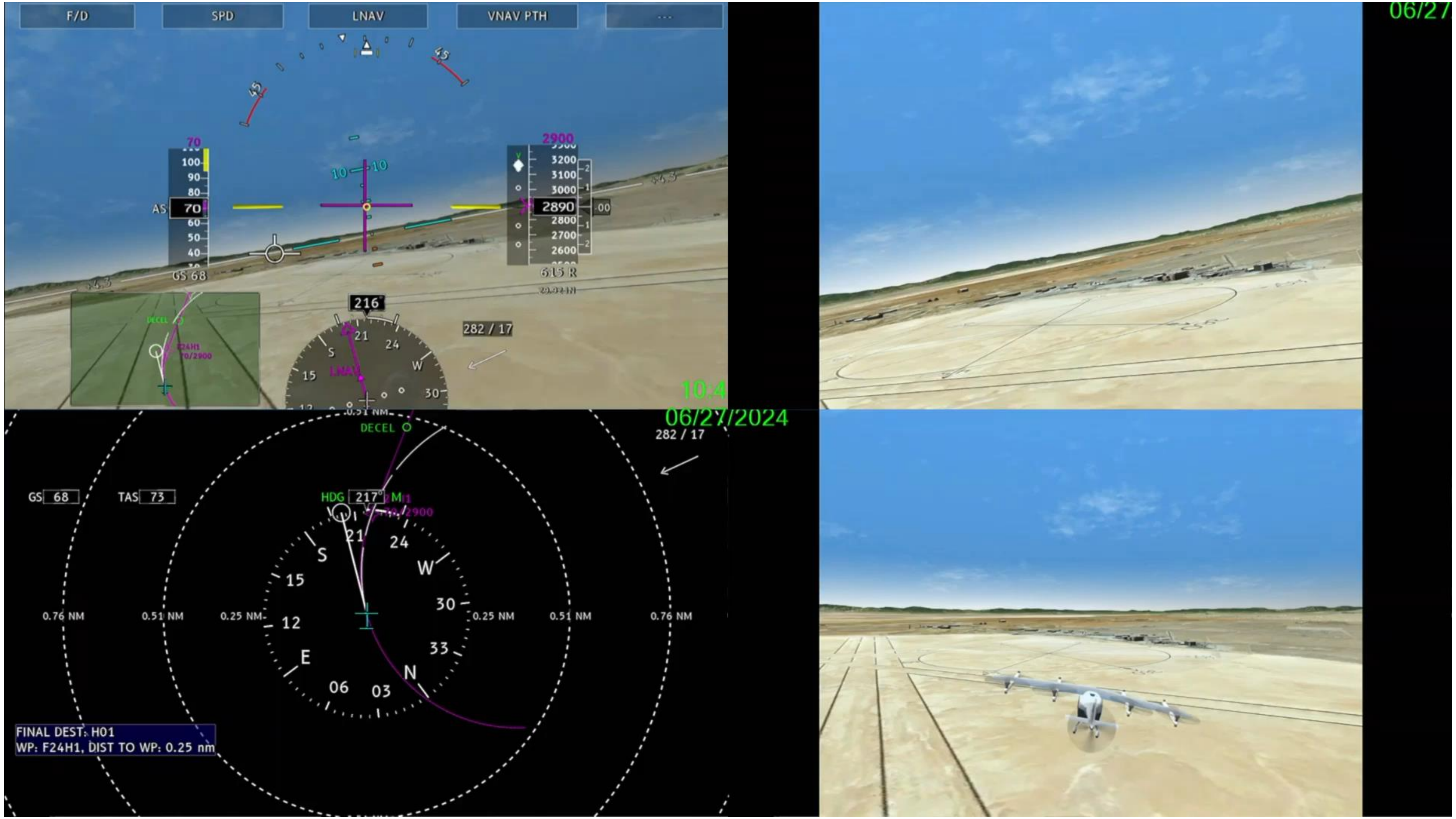


12-degree approach, AHA-2, No Wind

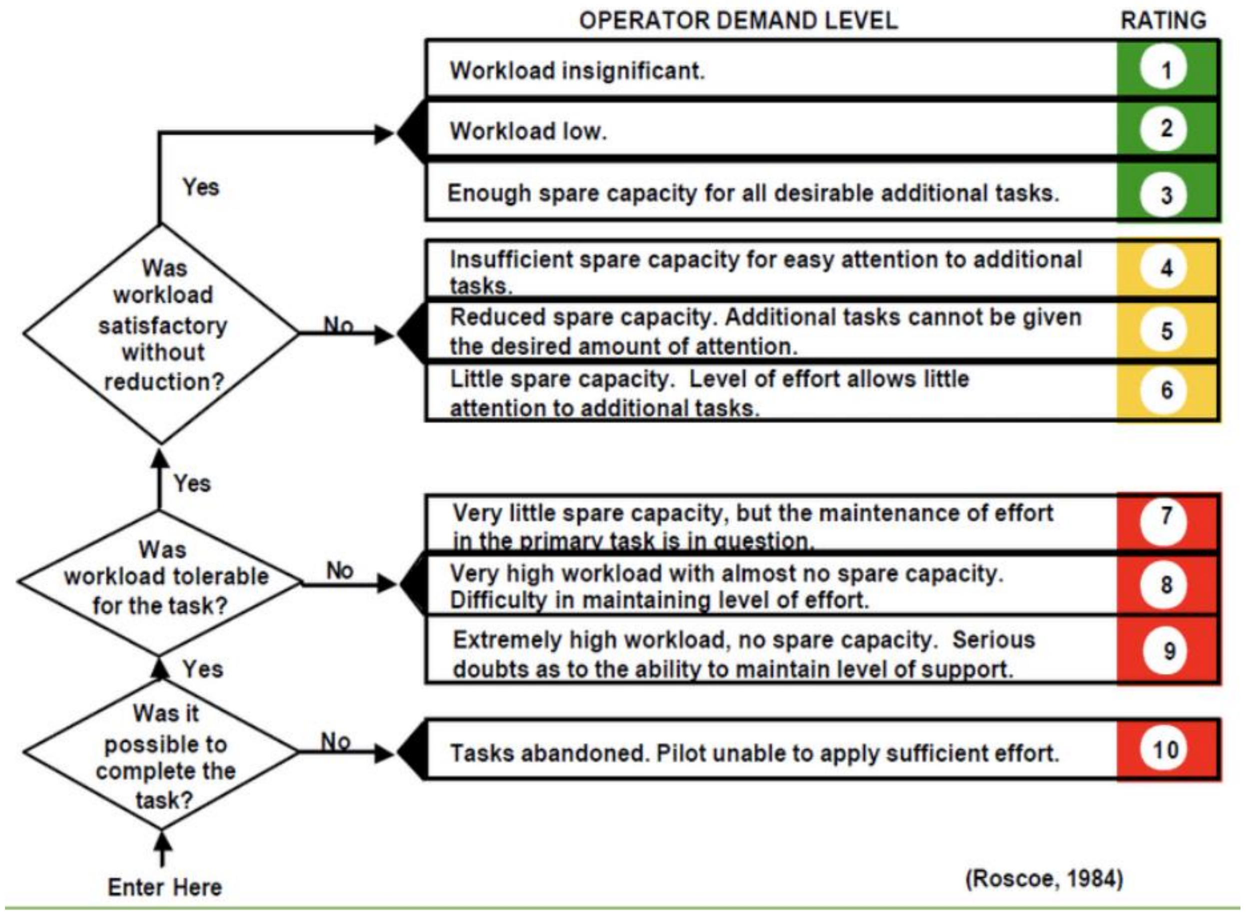


Example of a 12-degree training video – watch the predicted hover point circle as it overlays the landing target point circle

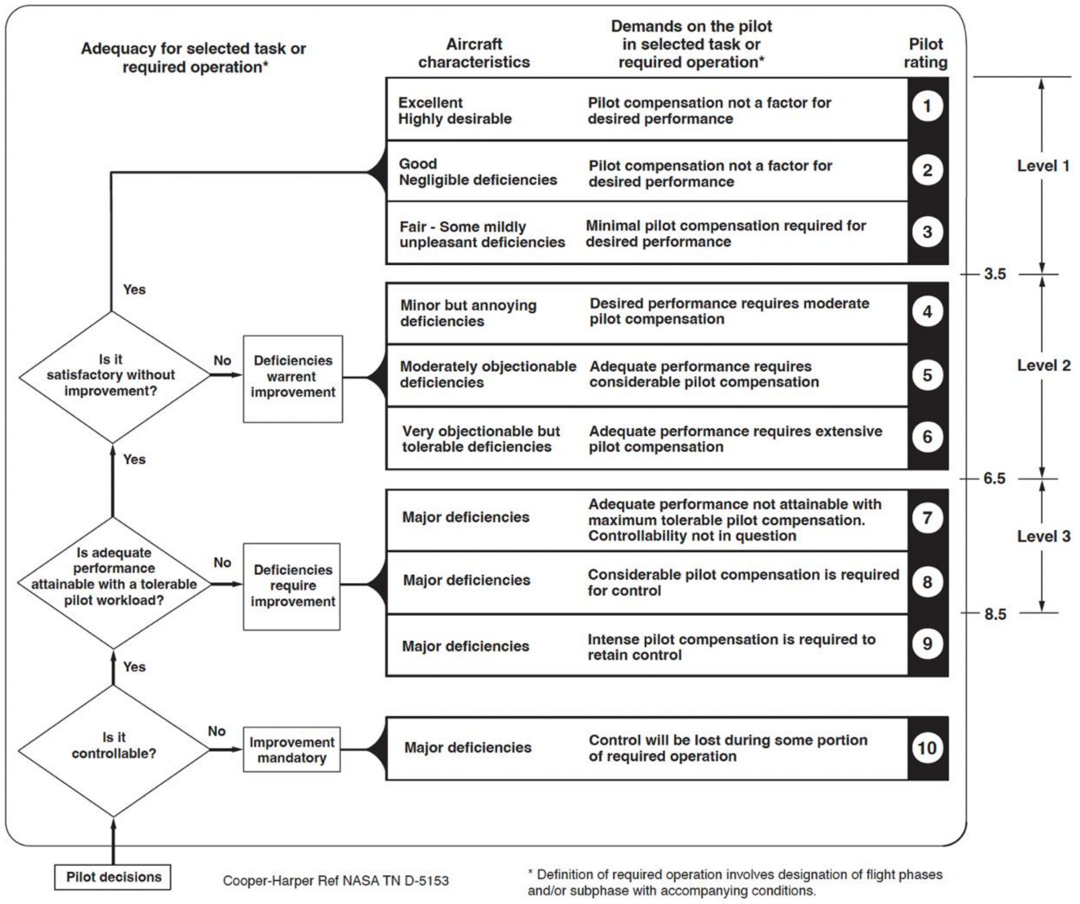
12-degree approach with Wind



Subjective Rating Scale Training

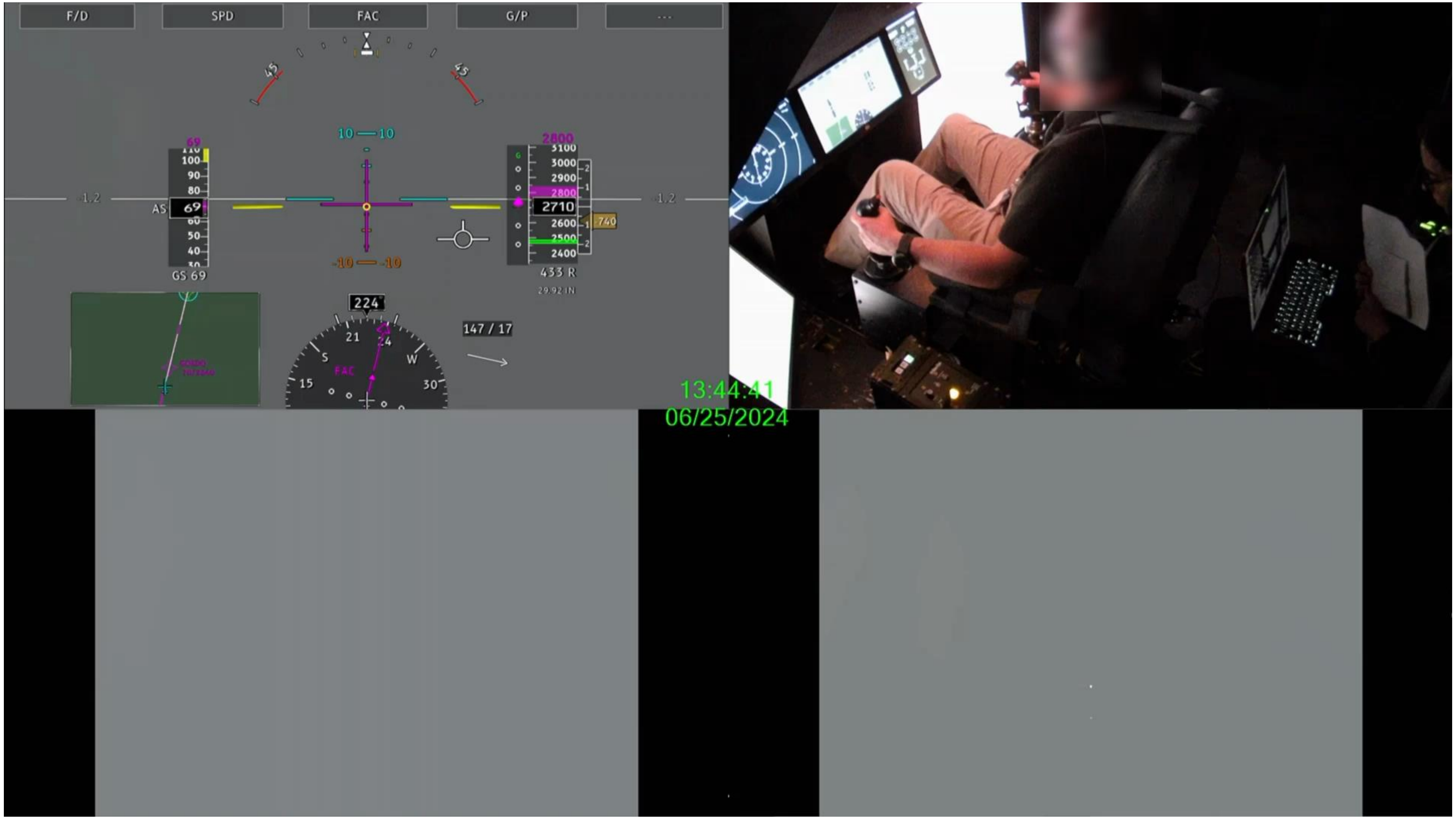


Cooper Harper Rating Scale



Bedford Rating Scale

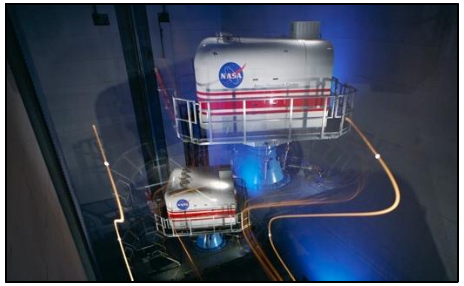
6-degree approach with ceiling and conflicts



Training Observations

1. **ACEL-RATE Simulator** was used successfully for meeting training objectives.
2. **Training requirements analysis** – Establishing specific training needs for the research study are important.
3. **The Aircraft Flight Manual** – Very important for pilot and researcher in building awareness of the LPC model and system.
4. **Training Schedule** – Helpful for coordinating training and study activities on both simulators (ACEL-RATE & VMS).
5. **Establishing a positive training expectation** – Instructing pilots that they will be able to complete the test maneuvers when their training is completed.
6. **Pilot background and flight experience** – Tailor training based on the pilot background.
7. **Habit transfer** was observed – Pilots were asked to report each incident.
8. **IFCS Deceleration to hover automation** was observed to reduce pilot workload, reduce energy use and increase accuracy.
9. **Study results** are still being analyzed.

Aerospace Cognitive Engineering Rapid Automation Test Environment (ACEL-RATE)



Vertical Motion Simulator (VMS)

The End

Thank you