NASA University Leadership Initiative (ULI) Advanced Air Mobility:
Navigating the Road to Flight Certification of Complex Systems

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AVIATE SPEAKER SERIES
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A Little Bit About Me (Ramsey)

Educational Background

- Ph.D. Physics, Washington University, St. Louis, MO
  - -Nonlinear Control and Synchronization
    - (Advisor: **Dr. C.I. Byrnes (Deceased)**, Collaborator **Dr. Alberto Isidori**)
  - -Discovered a new nonlinear harmonic oscillator (Universal Oscillator)
- - M.S. Electrical Engineering, Washington University, St. Louis, MO
  - -Magnetics Lab: Noise Properties of Recordable Magnetic Media
- - M.A. Physics, Washington University, St. Louis, MO
  - -Condensed Matter Physics Lab: Transmission Electron Microscopy (TEM) of Quasi-crystalline Materials
  - -Rapid quenching, chemical etching, ion-beam milling, differential thermal calorimetry, x-ray diffraction
- -B.A. Physics, The American University, Washington, D.C.

Industry Experience/Interests

- Morphing Vehicle Flight Control
- Plasma Fusion Control
- Advanced Control Design and Flight Testing (NNs)
- Legacy Program Flight Control Support
- Automated Aerial Refueling
- Ground Vehicle Advanced Control Design
- Novel Guidance Method, Confirmed in Test Flight
- Flight Control Design and Linear Analysis Tool Dev
- Research Funding Recipient (AFOSR, ONR)
- Gain schedule stability research
- L1-Adaptive Control Research, Flight Tests (2022,2023)
- Application of Novel PID Method in flight test
- Invariant Manifolds in Control Systems

AMERICAN UNIVERSITY WASHINGTON, DC

Washington University in St. Louis

A circuitous route to nonlinear control.

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A Little Bit About Me (Niestroy)

Educational Background

Ph.D. Aerospace Engineering, The University of Texas at Austin
- Neural and Fuzzy Neural Networks for Optimal Control

Advisor: **Dr. David G. Hull**

M.S. Aerospace Engineering, Texas A&M University
- Handling Qualities Evaluation of Simple Control Input Devices

Advisor: **Dr. Donald T. Ward**

B.S. Aerospace Engineering, Texas A&M University.

Industry Experience/Interests

- Aero Stability & Control, simulation model development, wind tunnel testing, conceptual design support
- Civilian employee at AFRL/Dayton OH, Palace Knight Program
- Developed a tool to implement (shallow) neural networks with specialized activation functions
- Used to create neural networks that were integrated in a safety critical application for a piloted aircraft

Industry Experience/Interests (continued)

27 years with LM Aero - In that time, worked/pursued/shaped/led/captured 26 CRAD programs, mostly 6.2 R&D from NASA, DARPA, NAVAIR, ONR, and AFRL

- Recent 5 years at LM Aero the Integrated Product Team (IPT) lead for Flight Control/VMS/Avionics on major ADP program
- Starting 11th year as Adjunct Professor of Electrical Engineering at The University of Texas at Arlington, graduate courses in
  - spring - Optimal Control; fall - System Identification & Estimation
- On various project, applied neural networks, fuzzy logic, adaptive control, optimal control, classical control methodologies
- Engaged in NATO S&T projects on formation flight for fuel efficiency and active flow control for advanced aircraft application
- Several other activities, including industry advisor for NASA ULI and JHTO UCAH projects

Experience a Mile Wide and Deep in a Few

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The Path to Demonstrating Airworthiness of Complex Systems

The path to certification of complex systems can seem just as complex as the systems themselves.

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Q: Air Mobility Challenges?

Air Mobility based V&V extends beyond the vehicle

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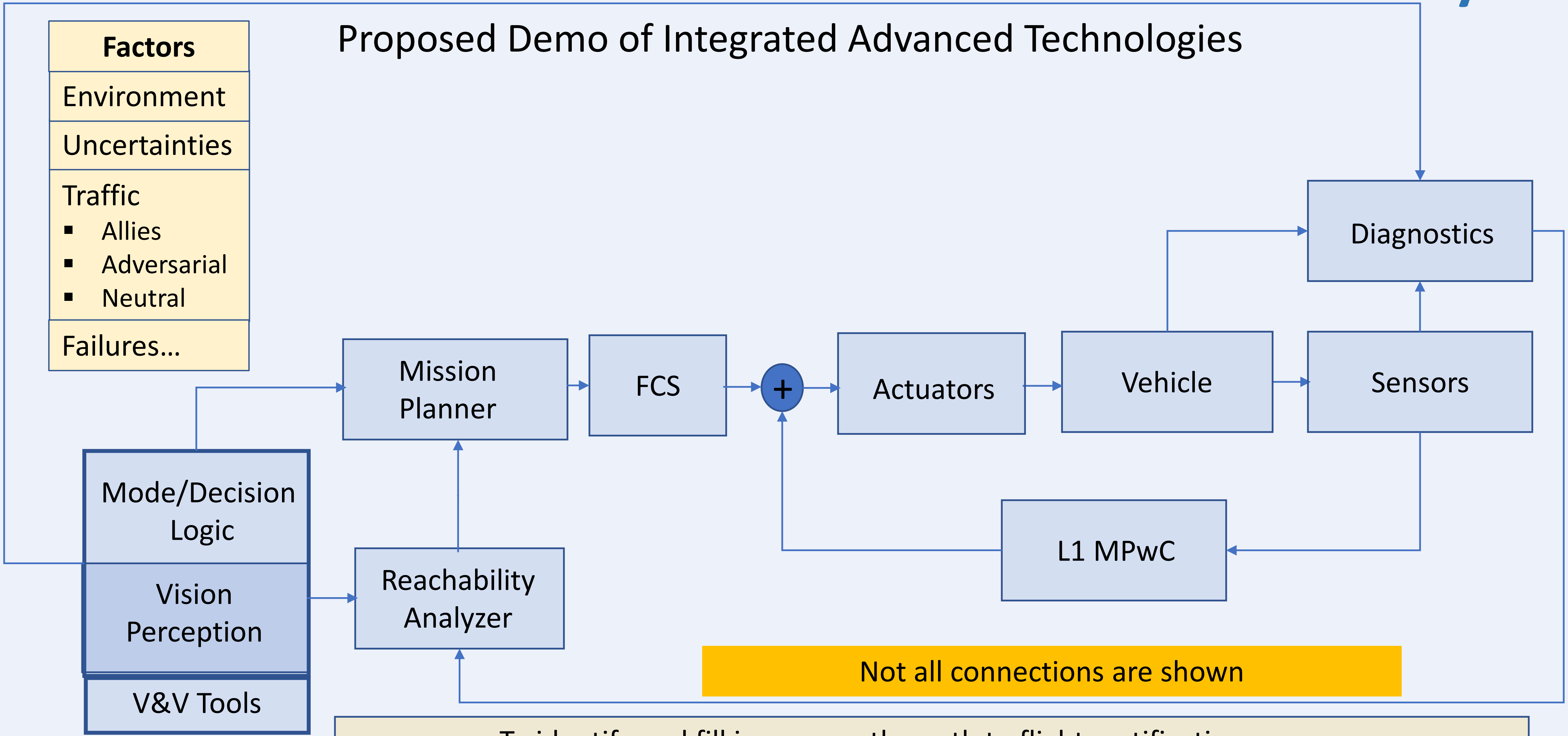
Borrowed from Sikorsky Chart Deck ("Urban Air Mobility Barriers")

Contribution of the ULI Team Toward Urban Air Mobility



To identify and fill in gaps on the path to flight certification process.

Q: What Can Industry Offer?

Help define and shape what successful V&V processes:

- clear and concise system and subsystem requirements
- adherence to coding standards
- processes that lead to confidence in the modeling, software (code), and hardware-in-the-loop test results
- establishment of system/subsystem integrity guarantees
    - Bounded-Input-Bounded-Output (BIBO)
    - Input-to-State Stability (ISS)
    - Seek the minimal set of test vectors that exercises all paths through each subsystem
    - Understand all limitations
    - Uncertainty/Failure analysis
        - What if ?
        - Likelihood of violation
        - Plan B, Plan C strategies confirmed
        - Vulnerability mitigation
    - Ground Station
        - Communication Links
        - Contingency Plans
- And More….

Ans. Industry can offer guidance toward achieving flight readiness.

Extension to interconnected subsystems

Successful V&V must include:

- well-defined interfaces with sufficient redundancy/auxiliary support
- protections against error/fault propagation (i.e., containment)
- robustness for the composite system under adverse conditions (uncertainty, failures, attacks, environment, etc.)
- mode logic verification
- a test plan that demonstrates the key elements of advanced air mobility
- documentation
    - Requirements checklist
    - Subsystems and Interfaces with limits on inputs and outputs
    - Functionality (what the system can and cannot do)
    - Composite system test results
- flight test results match simulation, SIL, and HIL.

Safe, stable flight that meets or exceeds mission and performance requirements in an uncertain and dynamically changing environment…

Understanding and addressing coverage gaps in complex systems are key to successful V&V.

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Some specific criteria (Federal Register/Vol 85, No 226)

- **Concept of Operations**
  - Intended Operation (UAV, operators, personnel responsibilities)
  - Operational Parameters (population density, geographic boundaries, etc.)
    - Proposed operating area, launch and recovery, traffic (ground/air/sea)
- **Design and Construction**
  - Control Station (equipment, information inflow and outflow)
  - Software (Documentation: Testing, Configuration Management, Problem-Reporting)
  - Cybersecurity
  - Contingency Planning
  - Lightning Protection/Weather Conditions
  - Critical Parts analysis
  - Flight Manual
- **Operating Limitations and Information**
  - Flight Manual (operating limits, safety, performance, loading, etc.)

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Some specific criteria (Federal Register/Vol 85, No 226) Cont'd

- **Probable Failures**
    - Failure should not result in a loss of containment or control of the UAV.
  - Propulsion (Electric or otherwise)
  - C2 Link
  - GPS
  - Critical Flight Components with a single point failure
  - Control station and any equipment used in flight
  - And more…
- **Capabilities and Functions**
  - Regaining command if the C2 Link is lost
  - Return to base plan in case of emergencies
  - Take-off, landing, and go-around
  - Reroute plan (reachability and path planning working harmoniously)
  - And more…

UAV certification involves meeting a set of rigorous requirements. We can do it!

Some specific criteria (Federal Register/Vol 85, No 226) Cont'd

- **Durability and Reliability (Flight Test Demo)**
  - Test evaluation must include the entire flight envelope across all phases of flight
    - To be completed with no failures that result in a loss of flight, loss of control, loss of containment, or emergency landing outside the operator's recovery area
- **Flight Test report must include (at minimum)**
  - a minimum, the following:
  - (1) Flight distances;
  - (2) Flight durations;
  - (3) Route complexity;
  - (4) Weight;
  - (5) Center of gravity;
  - (6) Density altitude;
  - (7) Outside air temperature;
  - (8) Airspeed;
  - (9) Wind;
  - (10) Weather;
  - (11) Operation at night, if requested;
  - (12) Energy storage system capacity
  - And more…

Excerpts

Comments Invited: The FAA invites interested people to take part in the development of these airworthiness criteria by sending written comments, data, or views. The most helpful comments reference a specific portion of the airworthiness criteria, explain the reason for any recommended change, and include supporting data. Comments on operational, pilot certification, and maintenance requirements would address issues that are beyond the scope of this document.

Verification Limits: The performance, maneuverability, stability, and control of the UA within the flight envelope described in the UAS Flight Manual must be demonstrated at a minimum of 5% over maximum gross weight with no loss of control or loss of flight.

The UAS must be designed to safeguard against inadvertent discontinuation of the flight and inadvertent release of cargo or external load.

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Airworthiness Criteria (UAV/UAS Examples)

https://www.federalregister.gov/documents/2022/03/28/2022-06378/airworthiness-criteria-special-class-airworthiness-criteria-for-the-percepto-robotics-ltd-percepto

https://www.govinfo.gov/content/pkg/FR-2020-11-23/pdf/2020-25659.pdf

Airworthiness Criteria: Special Class Airworthiness Criteria for the 3DRobotics Government Services 3DR-GS H520-G Unmanned Aircraft

https://www.federalregister.gov/documents/2022/03/17/2022-05611/airworthiness-criteria-special-class-airworthiness-criteria-for-the-3drobotics-government-services

General

https://www.federalregister.gov/

Search “FAA” for specific details on past and present regulations including amendments.

There is a wealth of public information available on the certification process.

The Future Path to Air Worthiness of Complex Systems

From the Perspective of an Optimist.

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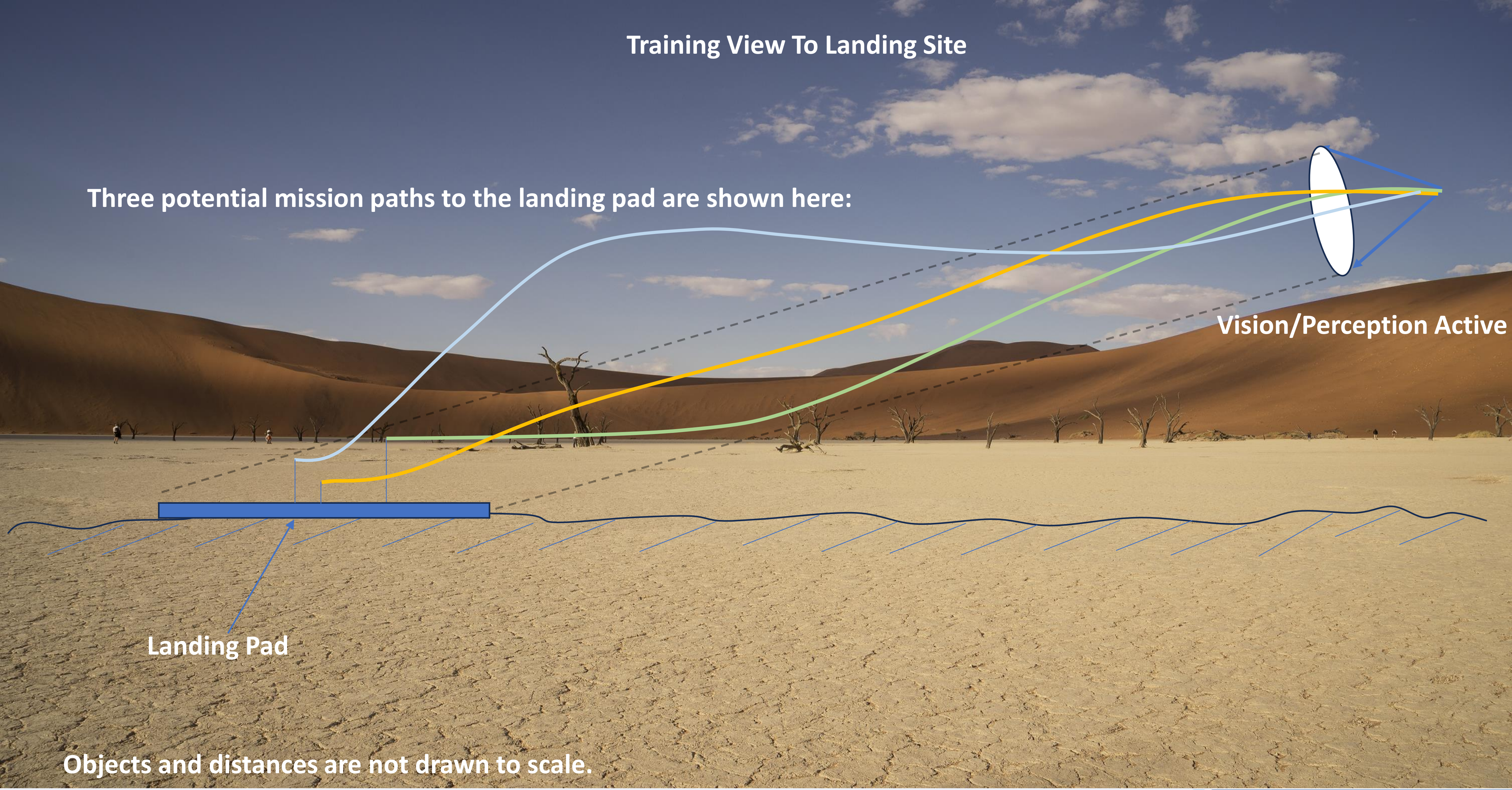
Training View To Landing Site



Off-Nominal View To Landing Site