ULI: Robust and Resilient Autonomy for Advanced Urban Aerial Mobility

Andy J. Smith, PhD
Principal Systems Engineer
SNC - Mission Solutions and Technologies

Sierra Nevada Corporation

PRIVATELY OWNED & OPERATED

- Est. 1963, co-owned by Fatih (CEO) & Eren Ozmen (Chairwoman & Pres) since 1994
- Continuous profitability; current projected revenue of +$2.6B
- Capabilities in Space, Aviation and National Security
- 20 strategic acquisitions

CORPORATE HEADQUARTERS: SPARKS, NEVADA

- Three business areas plus subsidiaries & affiliates; ~5,000 personnel
- 40+ facilities in 19 U.S. states, England, Germany and Turkey
- Virtual enterprise with cross-pollination to leverage technologies

COMMITMENT TO EXCEED CUSTOMER EXPECTATIONS

- Culture of driving innovative technological solutions in rapid & agile production environment
- Best-of-breed prime integrator (80% from U.S. government direct)
- Responsiveness, professionalism, discipline, highest standards of character & integrity

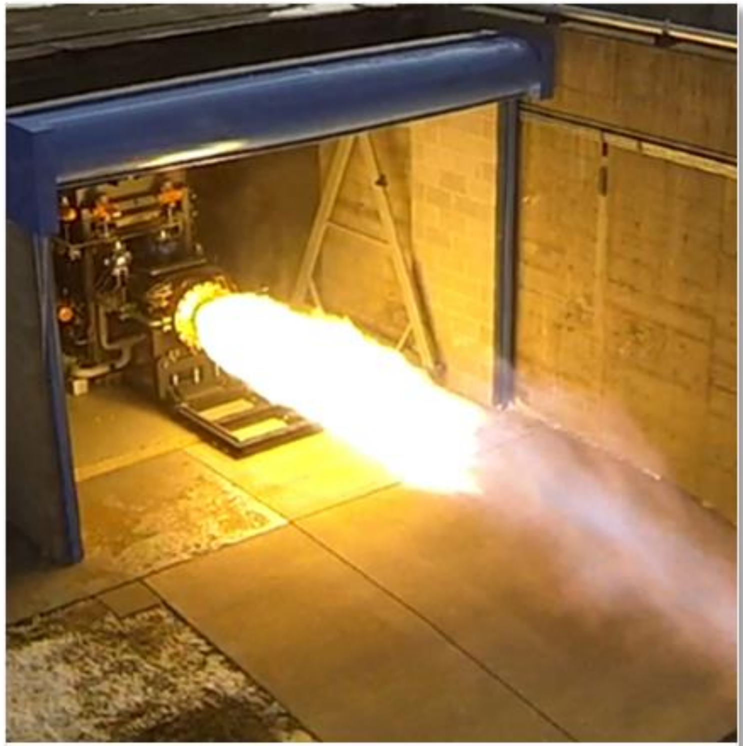
Sierra Nevada Corporation

NATIONAL SECURITY & DEFENSE

We continually redefine the standards of defense and special operations contracting through an innovative and customer-centric approach.

SPACE SYSTEMS

We provide high performance, innovative space components and systems that are changing how we reach, explore and utilize space.



COMMERCIAL SOLUTIONS

We develop technology that disrupts the status quo by anticipating market needs and delivering flexible, innovative solutions.

MISSION SOLUTIONS & TECHNOLOGIES (MST)

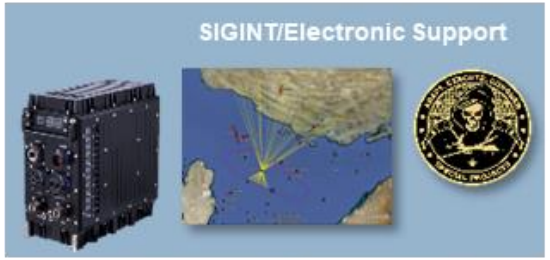
Aircraft system design, engineering, modification, integration, & sustainment

Mission Solutions

- Airborne
  - Advanced ISR Platforms
  - Unmanned Systems
  - Air Launched Effects
  - Airborne Command & Control
  - Enhanced Vision Systems / DVE
- Threat Defeat
  - Counter UAS
  - Cyber Effects (Offensive & Defensive)
  - Mounted/Dismounted EW
- Networked Effects
  - Robust Interoperability (e.g. *SNC TRAX®*)
  - Net Enabled Operations
  - Key Management Systems
  - Long Range Precision Fires Support

Technologies

- RF Technologies
  - Signals Intelligence/Electronic Support
  - Electronic Warfare & Cyber
  - Aircraft Survivability Equipment
- Information Based Technologies
  - AI/ML Data Analytics
  - Fused & Integrated Sensor Systems
- Network Technologies
  - Tactical Mesh Networking
  - Secure Cryptography
  - Ultra-wideband Networking
- Aircraft Operational Support Technologies
  - Global logistics management
  - FAA Major/Minor Modifications & Avionics Upgrades under Part 145 Repair Station



Andy Smith

- Education
  - Undergraduate and Masters at University of Nevada, Reno in Mechanical Engineering
  - PhD in Robotics from Oregon State University
    - Emphasis on Distributed Multiagent Coordination
- Army Guard
  - 13 years with time on the Abrams Tank, Bradley IFV, Infantry, and Sniper
  - Deployed for OEF 2009/2010
- Joined SNC in 2018
  - Principal Systems Engineer
  - Member of the MST Technology Team and MST Systems Architecture Group
  - Lead internal and external S&T efforts related to robotics and sensor fusion across multiple domains/product lines

TC4: Testing, Evaluation, and Integration Toward Technology Transfer

- SNC's emphasis is on developing a photorealistic simulation:
  - Environment
  - Platform
  - Sensors
  - Flight model
  - Relevant ConOp

- Ongoing discussion to expand into flight tests on SNC's Voly-10 UAS

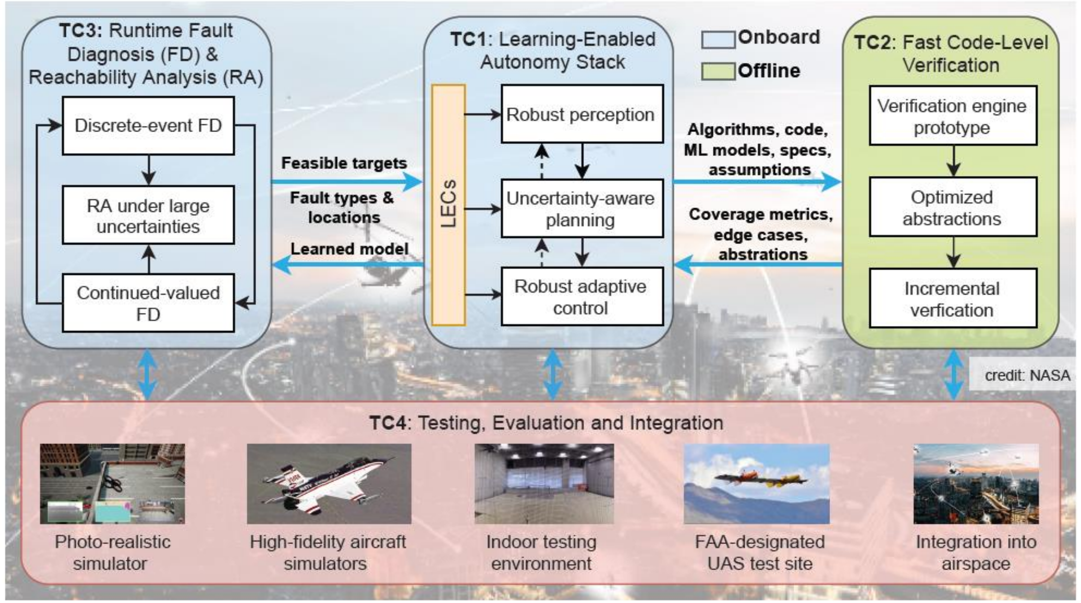


Figure 1: Proposed RRA framework

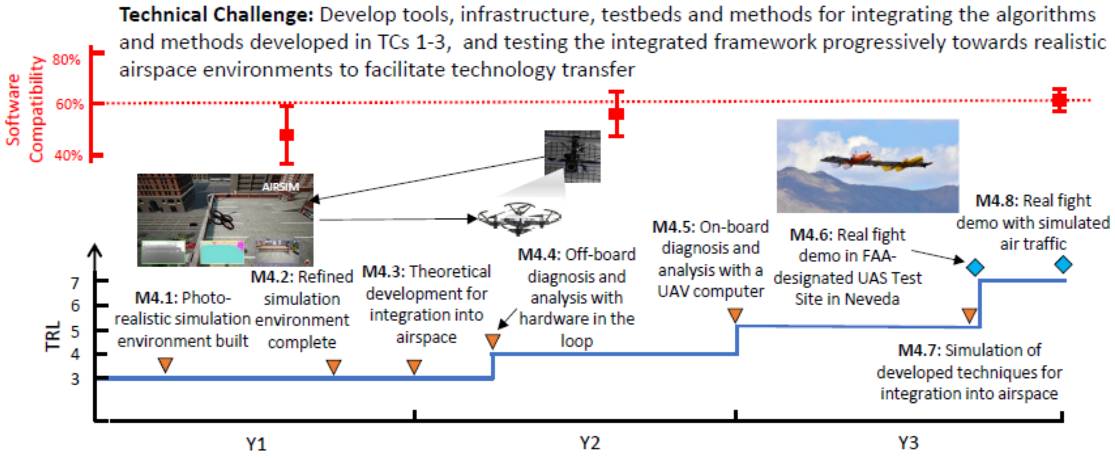


Figure 5: Progress indicator for TC4

Today’s Agenda

- Motivating Robust and Resilient Autonomy
  - Obvious/immediate extensions
- Original DVEPS Focused Integration
  - DVEPS Overview
  - Simulation development
  - Transition to support GUAM model
- New Transition to Voly-10 Integration
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Robust and Resilient Autonomy Within the DoD

- Many (most -> all) of the DoD's systems are reliant on a combination of GPS and active/RF emissions
  - GPS can be easily jammed
  - Active communications and sensing give away your location
- Simultaneous push towards unmanned systems
  - Complicated when you can't depend on GPS or an RF link to an operator
  - Solutions must work reliably on thousands of systems in dynamic, unknown, and adversarial environments – "Enemy gets a vote"
- Inherent need for robust and resilient autonomy
  - Robust controls and perception are critical to field 1000s of systems
  - Many active efforts to develop verifiable ML safety and function
- Applies across multiple domains
  - Autonomous surface/sub-surface vehicles
  - 4/5 next generation ground platforms are optionally manned/unmanned
  - Traditional UAS and 10,000's of sUAS being developed around the world




RAA Opportunity - Automatic Landing Systems

- ALS provide precision approach and automatic taxi, takeoff, and landing for manned and unmanned aircraft
  - SNC has performed 1M+ Landings without major incident

- Multiple Technologies
  - Differential GPS
  - MMW Transponder Tracking Radars
  - Dual Sensor (MMW Radar & DGPS)

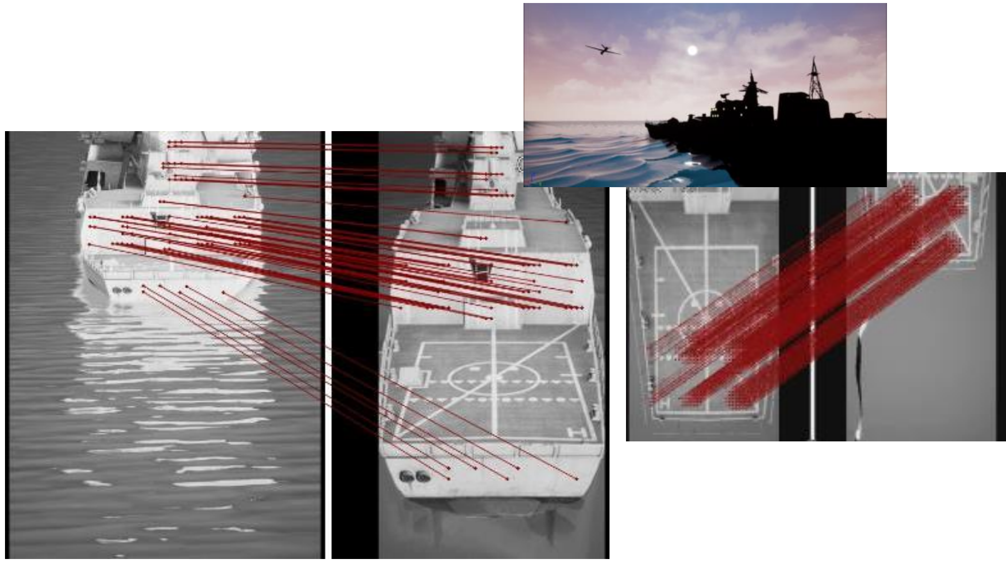
Tactical Automatic Landing System (TALS)
(Land Based)

UCARS-V2
(Ship Based)

Vision-Based Landing Applications

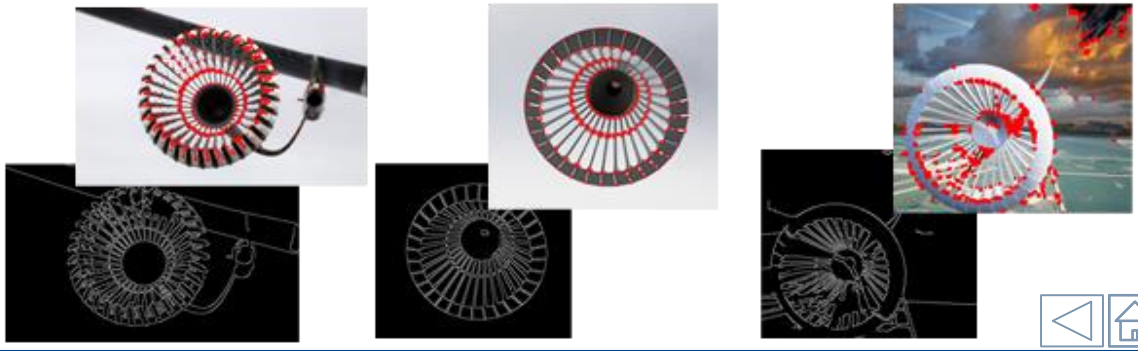
- Future will almost certainly use a combination of ML and computer vision
  - Desire to move away from GPS and emissive radar systems
  - How do you do it verifiably safe and with high confidence ($P_{Fail} < 10^{-7}$) current systems provide?
  - How do you do it in real time on SWAP-C constrained “safe” hardware?

- Landing on a ship is really hard
  - Ship moves under its own power at ~fixed speed/heading
  - Wave induced motion can oscillate the touch down point ~+/-2.5m vertically and roll ~+/- 10 degrees
  - Approach begins ~2,000 ft away
  - Unpredictable induced air-wake behind ship structure while tracking deck motion



RAA Opportunity - Aerial Refueling and Docking

- Airborne UAV Launch, Approach, Recovery, and Refueling solutions typically use a combination
  - Blended Relative GPS/INS using Kinematic Carrier Phase Tracking (KCPT) provides precision relative navigation (<2.5 cm) with integrity, and continuity of function
  - Cameras and traditional computer vision bounded by GPS/INS solution
- Desire to remove GPS dependance and active emissions using a combination of ML and CV
  - Same concerns over safety and verification
- Controls complicated by induced drogue motion
  - Atmospheric changes
  - Motion of the carrier
  - Motion/Shape of the docking system



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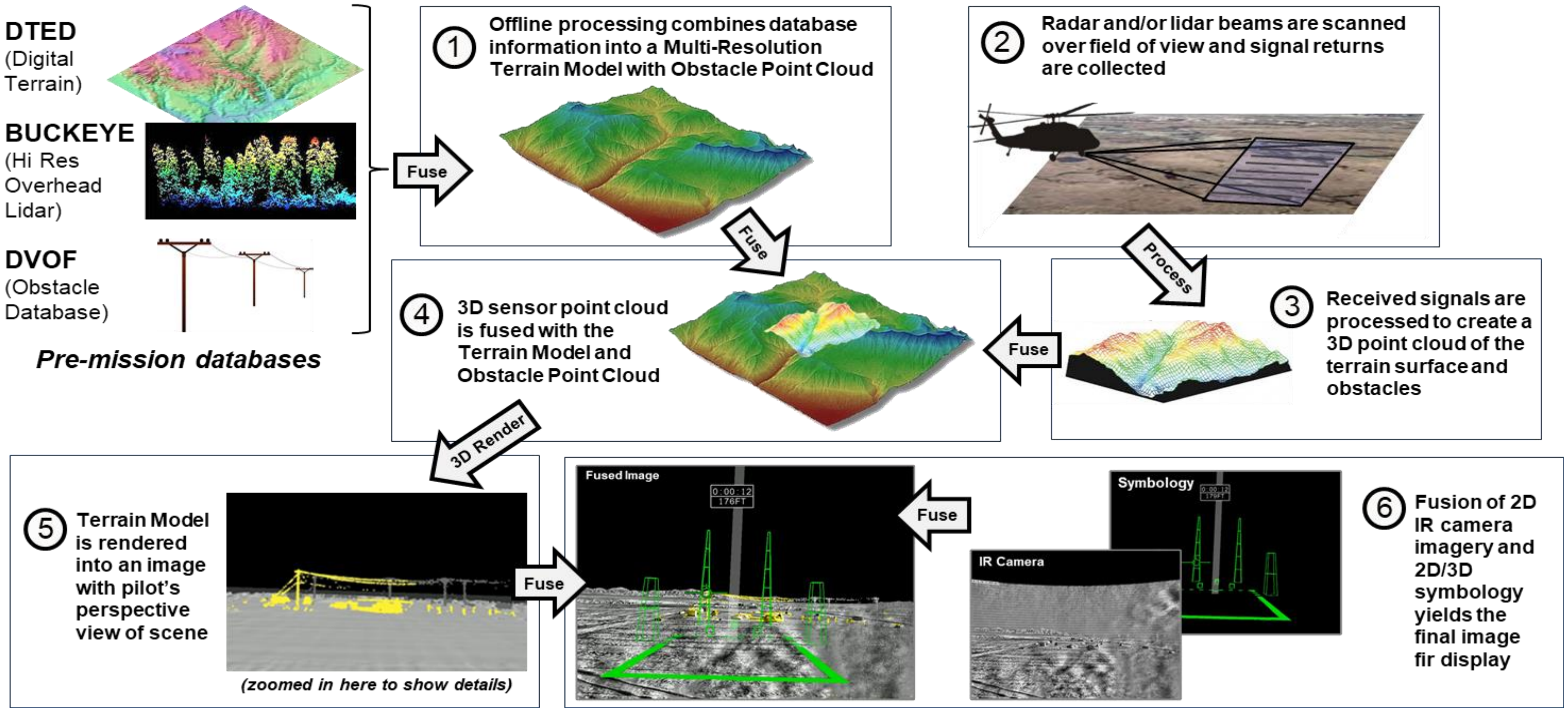
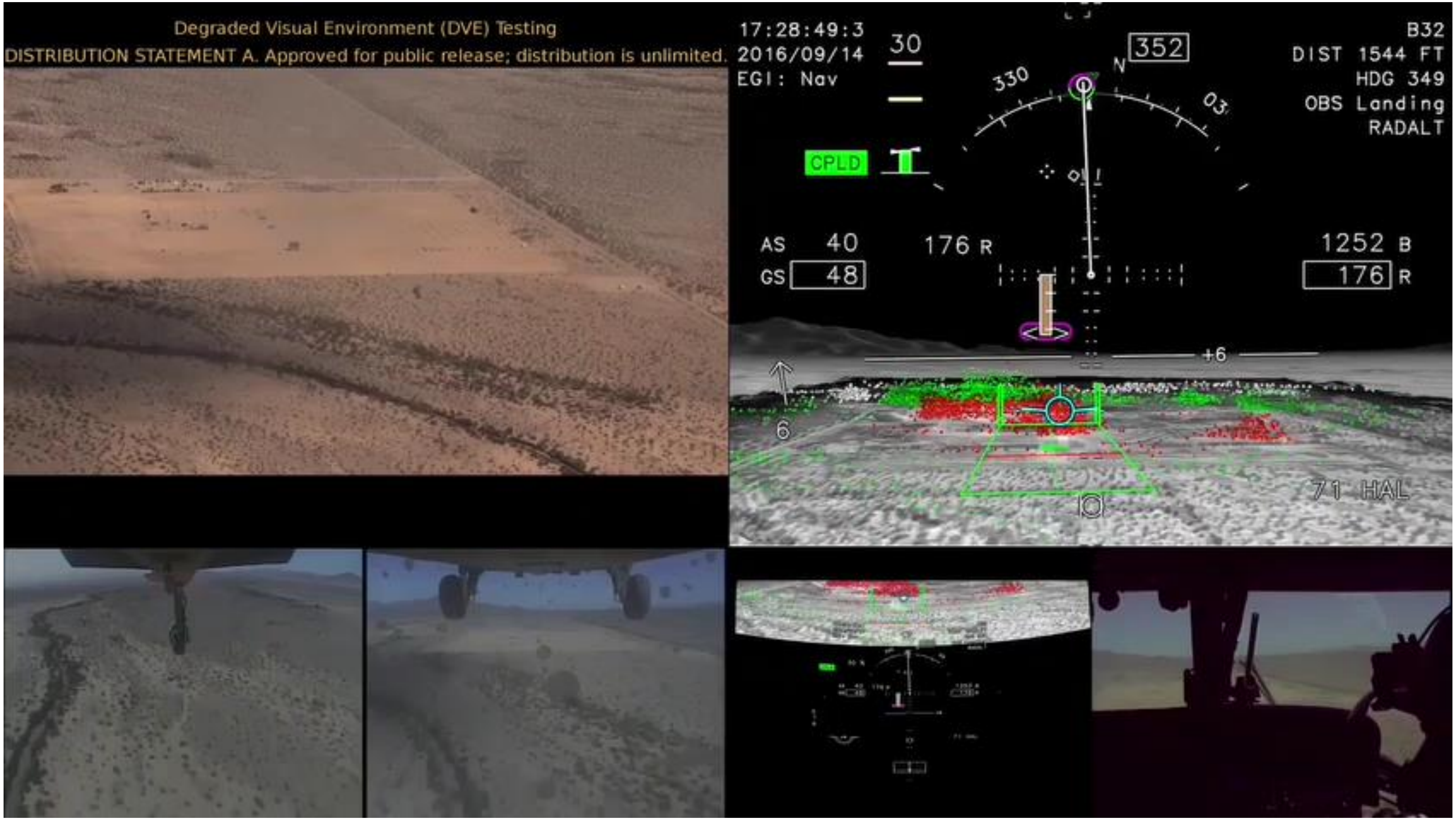
Degraded Visual Environment Pilotage System (DVEPS)

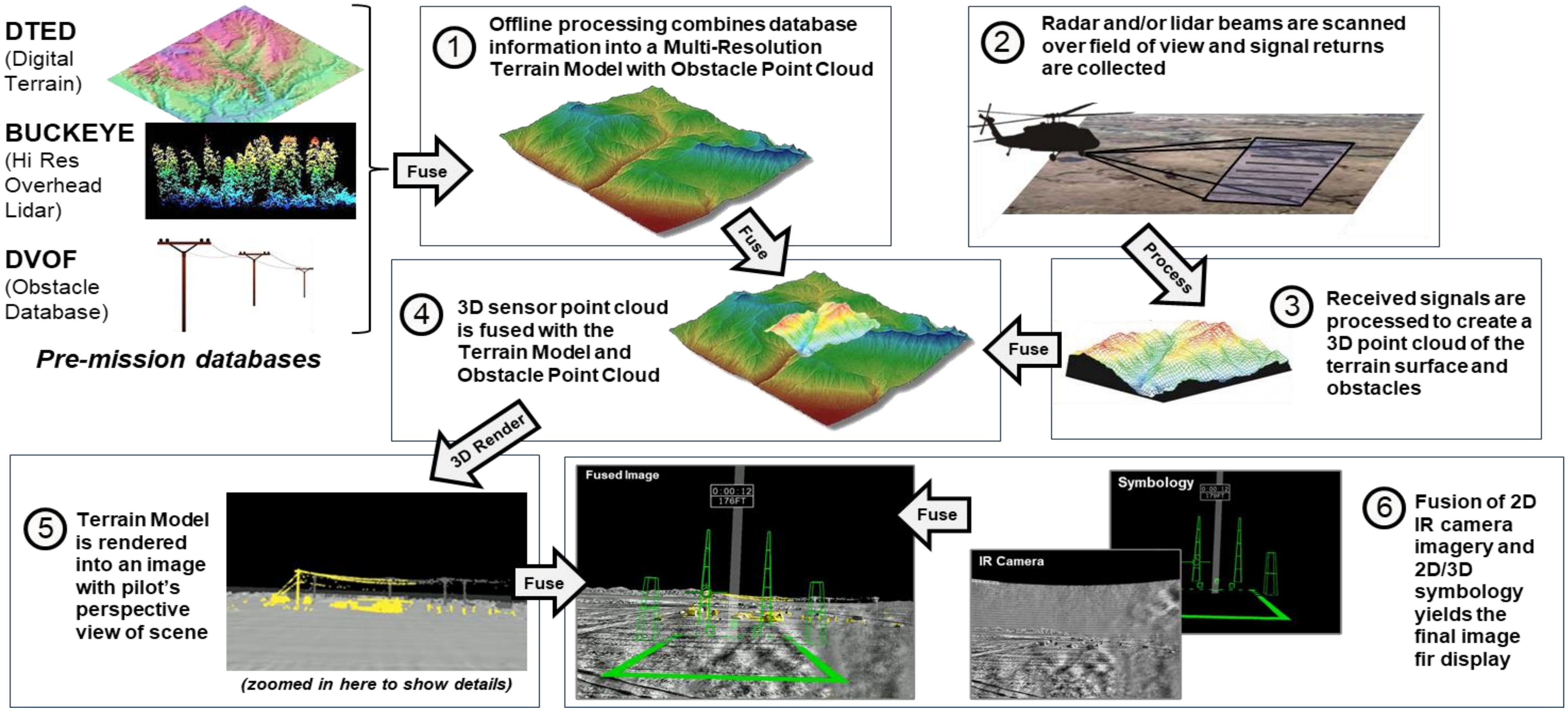


Overview of DVEPS data fusion pipeline combines a priori and real-time sensor data to continuously update the 3D world model and operator's display



Publicly releasable demonstration of SNC's fielded Degraded Visual Environment (DVE) during a 2016 test flight

Degraded Visual Environment Pilotage System (DVEPS)



Overview of DVEPS data fusion pipeline combines a priori and real-time sensor data to continuously update the 3D world model and operator's display

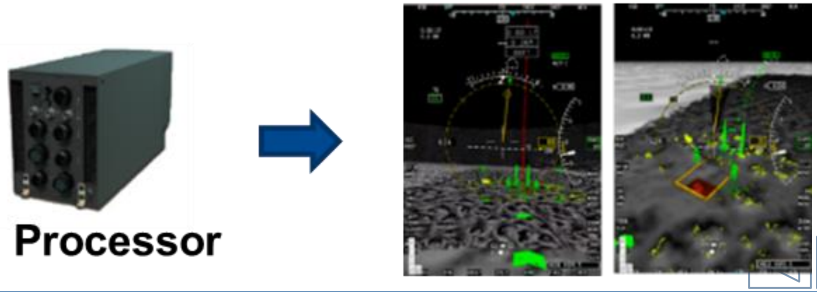
DVE Solutions

- **SNC can provide a sensor and platform agnostic fusion solution for all-weather operation across a range of platforms**
- **DVE sensor solutions include:**
  - An SNC-designed millimeter-wave imaging radar sensor for moderate resolution imaging through DVE
  - Multiple options for high resolution lidar imaging in light DVE
  - Multiple options for IR camera imaging in light DVE
- **DVE multi-resolution, sensor fusion processing fuses sensor inputs with digital terrain and obstacle databases to produce a 3D world model**
  - This data can be shared across platforms so that manned and unmanned systems can predict the environment in front of them
    - Road closures, deep potholes, fences, construction, and any anomalies
    - Current system maintains and updates ~3,000 km^2 area in the onboard flight computer
- **Underlying 3D representation allows imagery to be produced from of any location or desired vantage point and displayed on any 2D display or 3D map format**
  - Heads up display for drivers / pilots / remote operators
  - Point cloud / Octree / SDF for unmanned systems planning

SNC DVE Radar Sensor

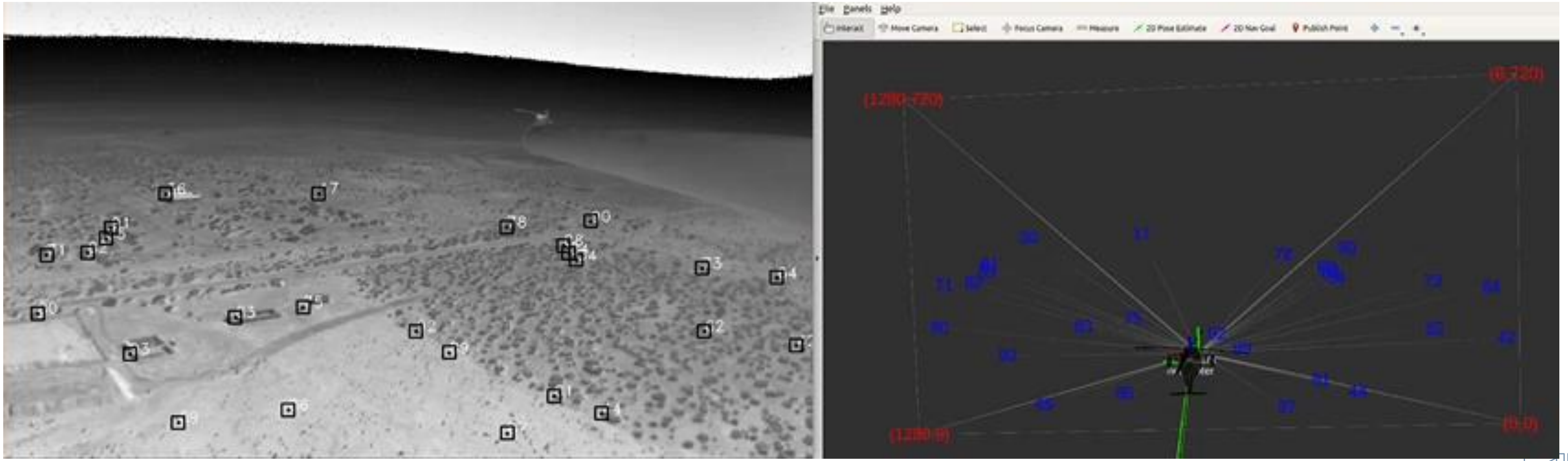
Multiple Lidar Sensor Options

Multiple IR Camera Sensor Options



In-Flight Auto Alignment and Sensor Calibration

- DVE requires accurate alignment between sensors that hard landings can misalign mid-mission
- In-Flight Auto Alignment estimates the motion of the camera and optimizes the alignment with the GPS-measured motion of the EGI
  - This redundancy carries across all sensors



DVEPS Based Development Plan for NASA ULI

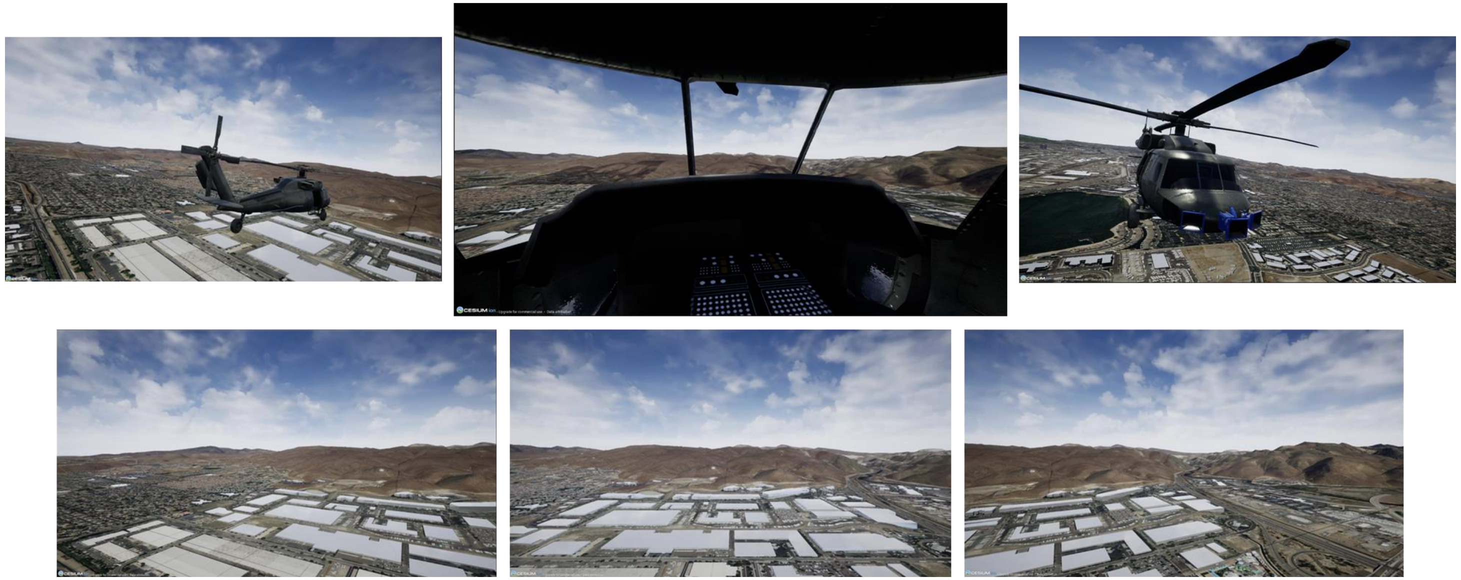
Modify SNC's existing Simulation Environments (UnReal/ROS) to support this effort

Primary efforts will focus on:

- **Integrate high-fidelity flight model**
- **Model disturbances and sensors in a variety of simulated environments**
  - **Varying obstacle types, obstacle density, DVE, wind, and helicopter loading**
- **Integration of assured autonomy framework**
- **Iterative development and testing with the team**

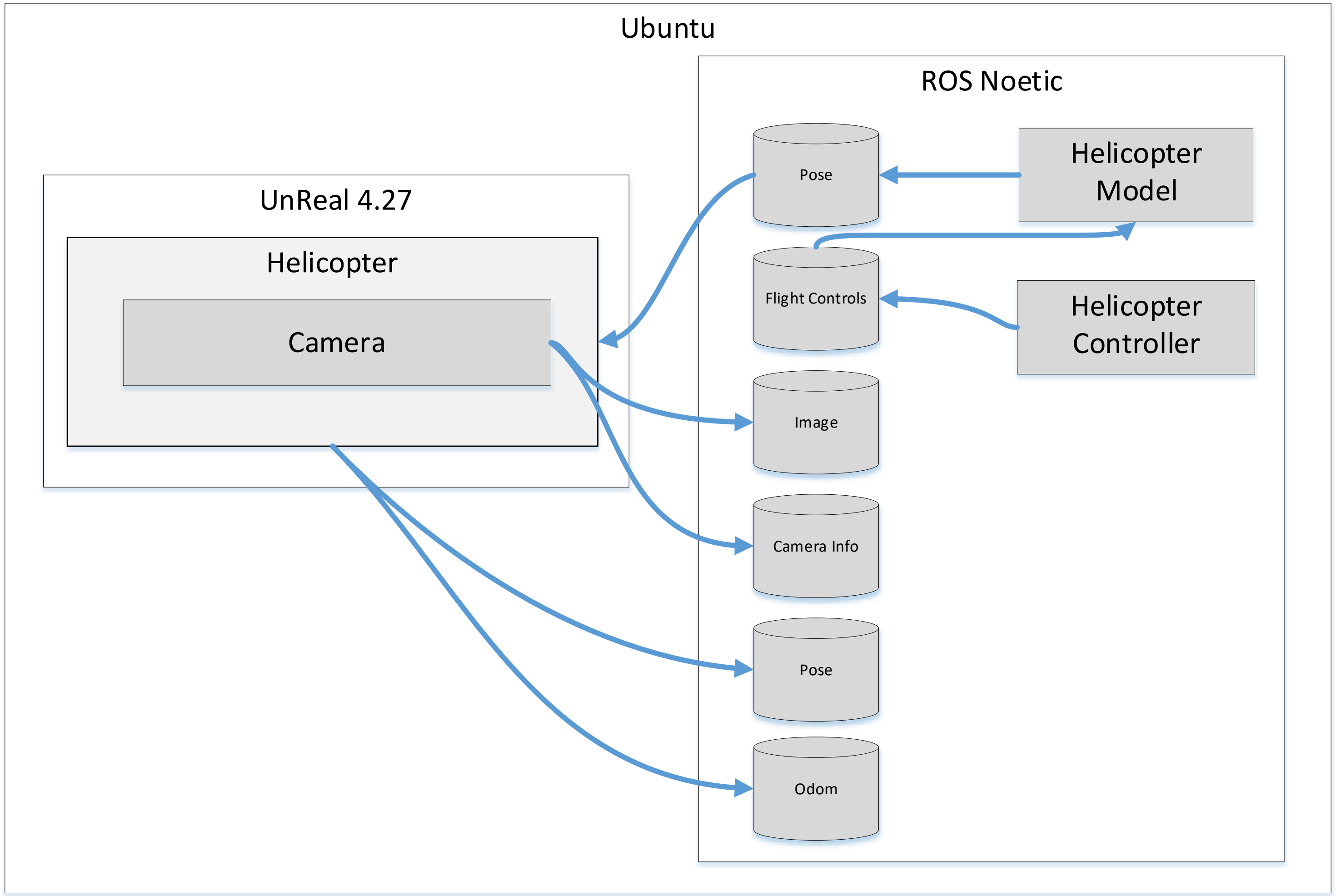
DVEPS Simulator

- UnReal simulation environment is stood up
  - Cesium environment used but can be changed expanded with photogrammetry data
  - Simulates four cameras on helicopter nose
    - Forward, front-left, front-right, down
- Helicopter aerodynamic flight model
- Kinematic flight model to simplify integration and testing



DVEPS Simulator Architecture

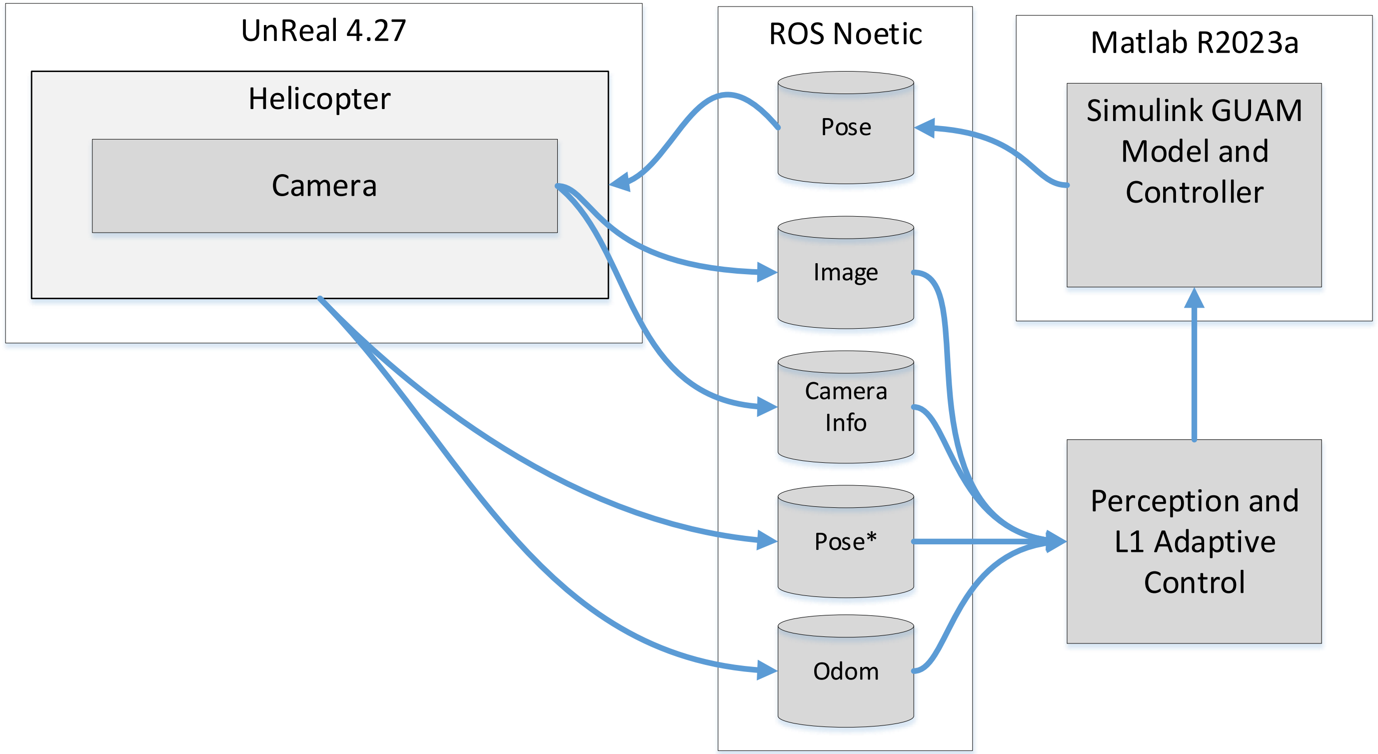
- UnReal
  - Unreal publishes out:
    - pose.msg - position and orientation
    - Camera_info.msg - details for each camera
    - image.msg - camera image for each simulated camera
    - Odometry.msg - giving the angular and linear positions and rates of the helicopter
  - UnReal Subscribes to:
    - Pose.msg – position from Helicopter flight model
- ROS Helicopter Model
  - ROS Helicopter Model Subscribes to:
    - Custom control message - takes in the four pilot controls and publishes out the aircraft pose
  - ROS Helicopter Model Publishes:
    - Pose.msg - position and orientation



DVEPS Proposed GUAM Integration

- ROS, UnReal, and Matlab pipeline
  - ROS moves data between UnReal and Matlab
  - UnReal simulates sensors
  - Matlab hosts GUAM model

- Three step plan
  1. Offline with NASA provided GUAM test scripts generating flight path for replay in ROS/UnReal
  2. NASA provided GUAM polynomial model connected to ROS/UnReal
  3. Use NASA provided 'build_Lift_plus_Cruise.m' script to replicate a model of the DVEPS platform

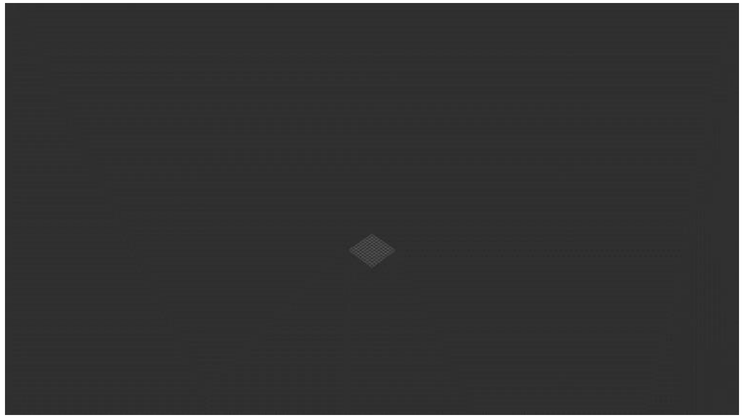


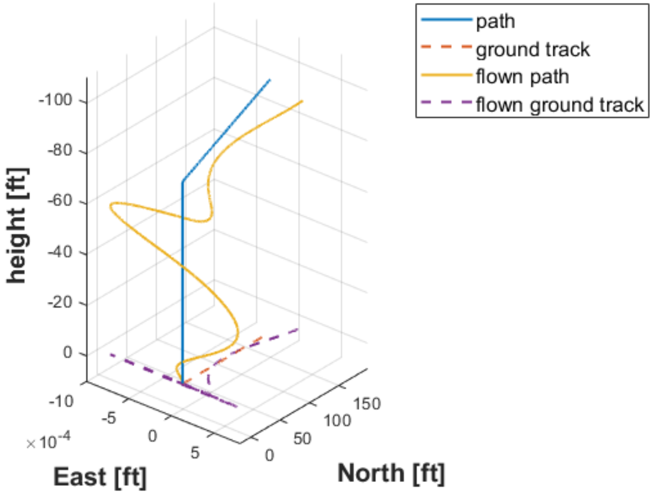
Test Model	Simulated Time (s)	Processing Time Test 1 (s)	Processing Time Test 2 (s)	Processing Time Test 3 (s)	Average Processing Time (s)	X Slower than real-time
Sinusoidal Time Series	20	99.96	107.67	106.01	104.5467	5.3
Hover to Transition Timeseries	40	205.93	218.42	211.96	212.1033	5.3
Cruise Climbing Turn Timeseries	40	202.86	216.9	232.62	217.46	5.4
Ramp Demo	30	162.25	157.46	158.8	159.5033	5.3
Cruise Climbing Turn (Polynomial)	40	8.31	8.58	8.02	8.30	0.2
Ramp Demo (Polynomial)	30	8.03	6.01	5.98	6.34	0.2

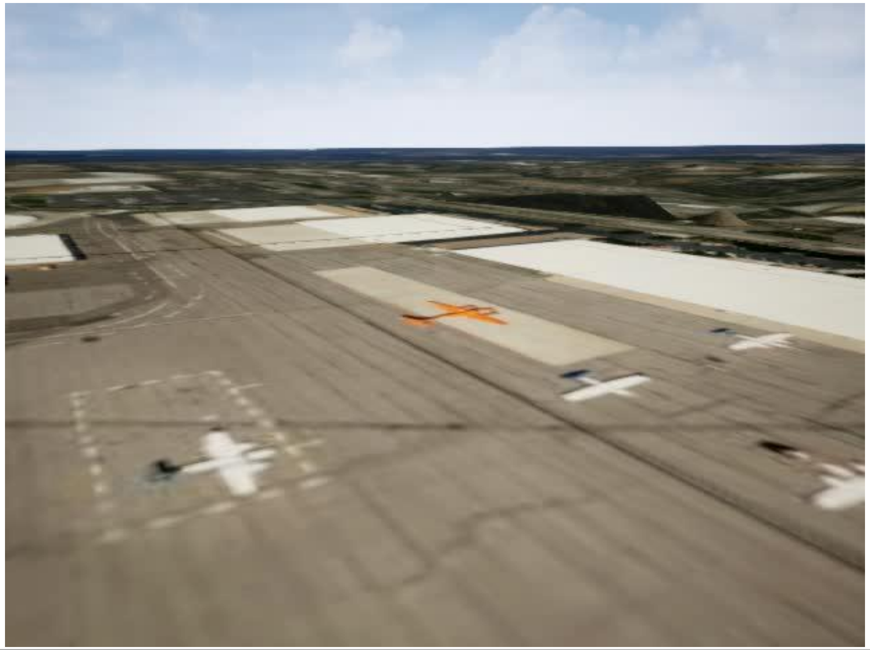
Offline DVEPS GUAM Integration

- Example GUAM Hover to Transition
    1. GUAM ran offline
    2. ROS node reads in GUAM data and publishes poses and updates TF tree
    3. UnReal subscribes to ROS pose messages, collects camera video and publishes back into ROS

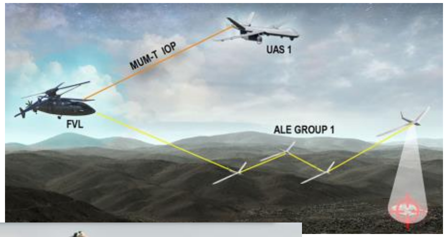
- Next step was to share data between ROS and Matlab in real-time







(Revisiting) Transition Opportunities



SNC's DVEPS is intended to provide a pilotage solution and this effort directly contributes to both the technology and the pathway to flight certification

- Support from DVEPS customer
- Actively working to bring our technology into the civil marketplace, including eVTOL/UAM/AAM

SNC is teamed with Bell for Future Vertical Lift (FVL) developing the next generation of Army helicopters

SNC recently acquired Volansi and is developing a VTOL in support of the multiple DoD efforts and emerging commercial opportunities

Kutta-Technologies, an SNC wholly-owned subsidiary, is a trusted leader in providing safety-critical unmanned systems Command, Control, and Communications (C3) software, components, and subsystems with autonomous applications

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Voly UAS Product Line

Volansi was founded in 2015, Venture Backed

- Based in Bend, OR and SF Bay Area
- $75M of Funding in Third Equity Round
- Purchased by SNC in 2022

Defense and Commercial Lines of Effort

- Platforms – Voly-10, 20, and 50 series
  - Family of Multi-Role, Long-Haul Hybrid Fixed Wing + eVTOL aircraft, 10-50 lbs payloads with 50-350+ mi range
- USG contracts for Ship-to-Ship cargo transfer and resupply
- Demonstrated BLOS logistics commercial deliveries in Ghana and Senegal
- Flew BLOS disaster response proof-of-concept delivery mission for NC DOT
- Completed airspace integration test contract for NASA

Commercial Best Practices

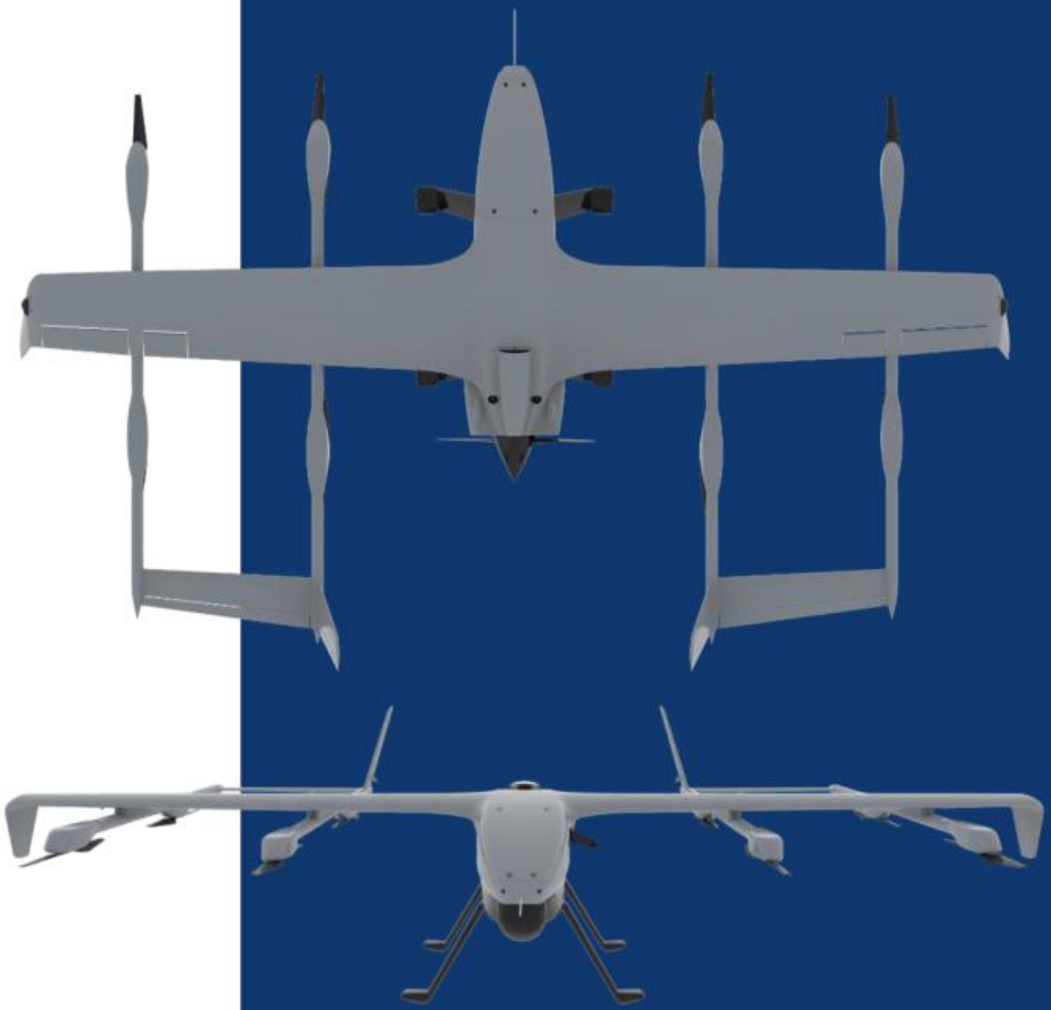
- Ongoing CONUS/OCONUS commercial delivery trials
  - Conducted medical vaccine delivery for Merck Pharmaceutical in North Carolina and Alaska

Voly-T Airframe Overview

SNC's Hybrid VTOL UAS, the Voly-T, incorporates evolutionary lessons learned via Commercial and DoD contracts from the predecessor Voly-10/Voly-20 aircraft.

The system is derived from our commercial business model requirements, which emphasizes ease of use and maintenance, low operating costs, rapid reconfigurability, and regulatory compliance.

- **Wingspan:** 24'
- **MGTOW:** Up to 275 lbs (Min); 400+ lbs (Full)
- **Weight:** 50 lbs Payload + 35 lbs Fuel Load
- **Endurance:** 9.5+ Hours (with 25 lbs Payload)
- **Cruise Speed:** 57 kts



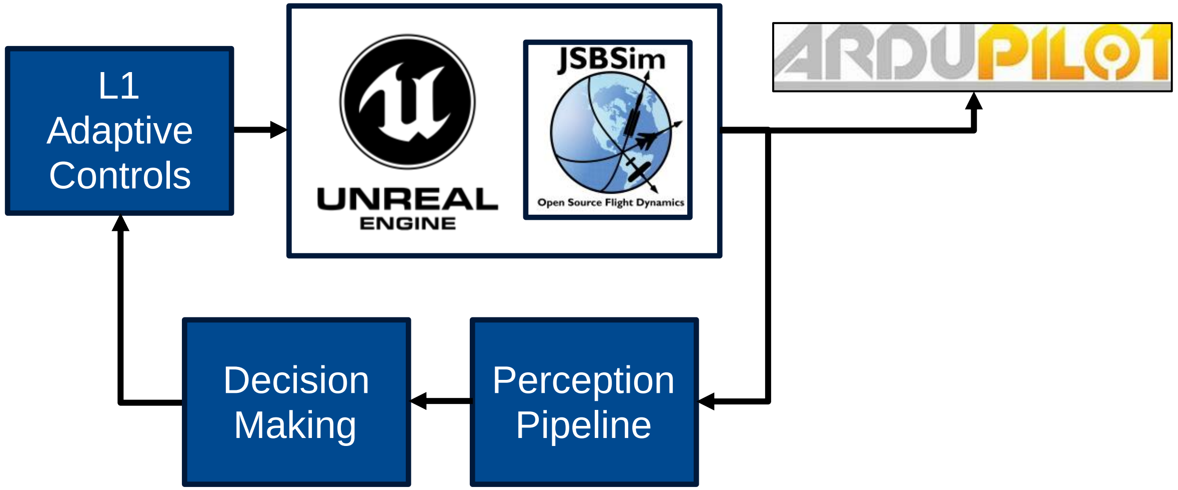
Voly-10 Airframe Overview

- Voly-10 is the Voly-T test / development platform

- **Wingspan:** 2.93m (9.6 ft)
  - **Length:** 2.03m (6.7 ft)
- **MGTOW:** 25 kg (55lbs)
- **Payload Weight:** 6 kg (13.2 lbs)
- **Endurance:** 90 minutes max
  - 60 min with VTOL realistic
- **Cruise Speed:** 25 m/s (55.9 mph)
- **Stall Speed:** 20 m/s (44.7 mph)
- **Max Speed:** 30 m/s (67.1 mph)
- **Power:** 59VDC Nominal
- **Flight Controller:** Ardupilot
  - Modified variant of latest stable* version

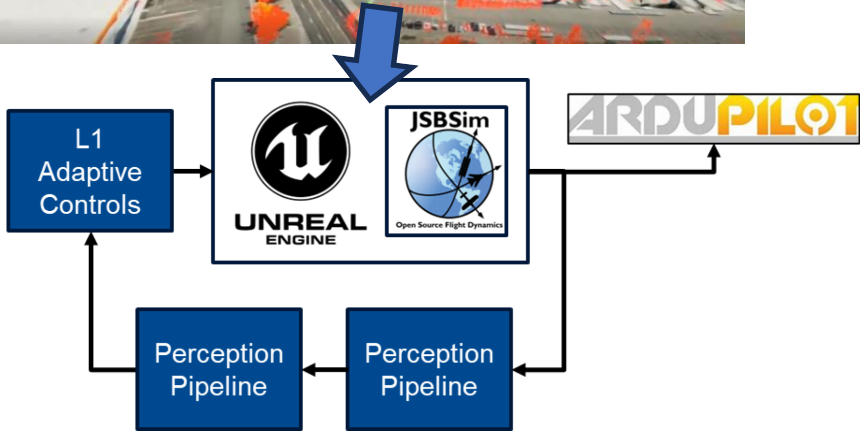
Voly-10 Proposed Integration Plan

1. SNC develops Voly-10 simulation (~6 months)
   - SNC internally uses JSBSim for pre-flight checkout of the Voly-50 (Voly-50 model is CUI)
   1. SNC develops a Voly-10 JSBSim model and integrate into UnReal/ROS
   2. SNC provides team Voly-10 JSBSim model to develop L1 Adaptive Controller
2. ***(Optional)*** Tailor GUAM model to Voly-10 for additional simulation testing (~6 months)
3. SNC works with academic partners for software-in-loop testing with Ardupilot in preparation for flight tests (~6 months)
4. SNC works with academic partners to perform integration and flight test (~12 months)
   1. Perception and mission processor payload development / Integration
   2. TBD flight safety checks / processes
   3. Flight testing in open air and near "safe" obstacles
5. Support additional testing and integration in simulation and hardware as requested by team



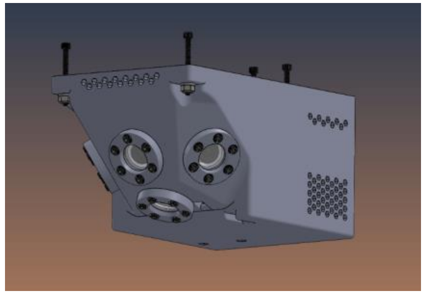
Voly-10 Proposed Test Plan

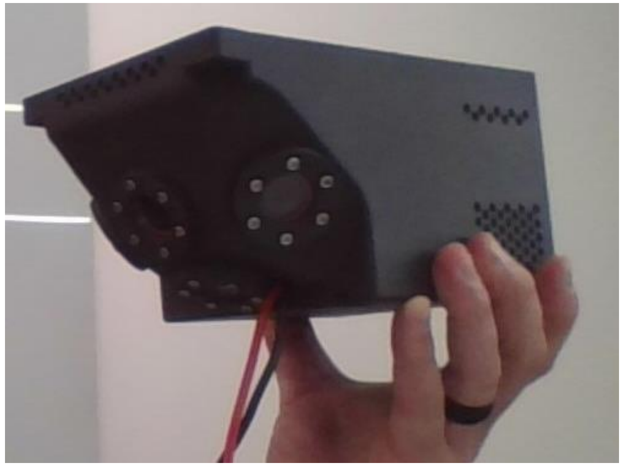
1. Simulation testing
   - Develop simulation environment with SNC acquired commercial photogrammetry data of Northern Nevada and supplemented with SNC collected lidar data
   - Evaluate flight test environments using ROS, JSBSim (and/or GUAM), and UnReal pipeline
2. Hardware in the loop testing
   - TBD Safety/System Checkouts
3. Two flight test environments
   1. Open environment with no collisions to validate safe nominal control of Voly-10
   2. Obstacle environment to stimulate perception system
      1. Initially with pre-mapped obstacles to validate perception **without** perception in the loop
      2. Transition to unmapped obstacles to validate complete pipeline **with** perception in the loop

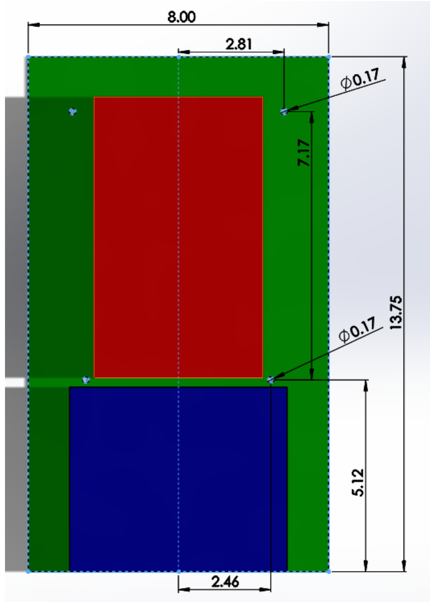


Voly-10 Proposed Integration

- SNC’s Voly-10 Autonomy Test Kit
  - 4x EO cameras
  - VectorNav VN200
  - Nvidia Orin Nano
  - First test flights planned for ~Nov 13th
- Support Payload
  - Novatel RTK-GPS
  - Isolated Power System
- Alternatively develop custom kit
  - 8”x13.75”x5.5” (WxLxH)



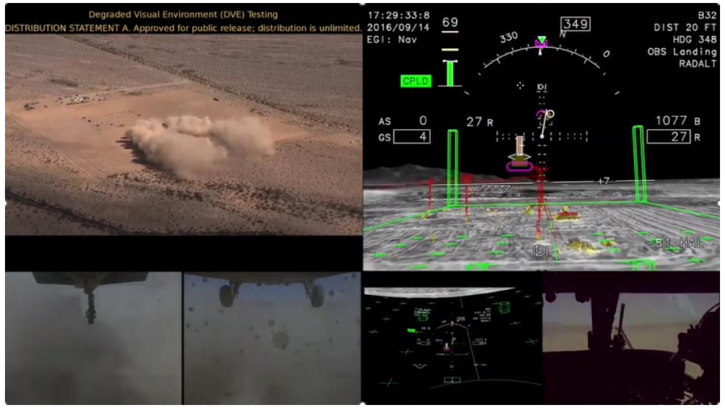




Summary

- SNC's simulation environment is beign adopted from the DVEPS to the Voly
- SNC is adjusting internal development plans on the Voly to support this effort
- Thankful for your attention and opportunity to be part of this team

Questions?



Andy's General Advice To Students Entering Industry

Things didn't realize until I started hiring engineers

- Resume
  - Needs to show your technical expertise but must be human readable by the person in HR with a business degree
  - Tailor it to each application, use 'key words' from the posting, and point heavily to projects you have worked on
- Interview
  - Know something about the company you are interviewing for and be interested in what they do
  - Be ready to discuss every project/skill on your resume and related technical questions
    - Don't be afraid to say "I don't know/remember but I think…"
- Soft Skills
  - A shocking amount of your job will be writing, talking, and presenting to non-technical people – not strictly necessary, but very valuable
  - Lean forward and pursue/create opportunities adjacent to your expertise
- Put some thought into your career, it will consume about 80,000 hours of your time