

# Simulation Technology at NASA

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*Presented at the The National Academies' Workshop on  
Opportunities for the Employment of Simulation in U.S. Air Force  
Training Environments*

**November 17-19, 2014**



- Overview of simulation capability at NASA
  - Ames Research Center
  - Other facilities
- LVC development and uses
- Research uses and trends
- Limitations
- Thoughts on solutions

# Simulation Uses at NASA

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- Support Research and Development Projects
  - Vehicle Systems and Safety Technologies
  - System-wide Safety and Assurance Technologies
  - NextGen Concept and Technology Development
  - NextGen Systems Analysis and Integration
  - Fixed- and Rotary-Wing Technologies
  - UAS Integration in the NAS
- Support Human Spaceflight Program
  - Shuttle Orbiter Engineering Development
  - Shuttle Orbiter Flight Training
  - Orion Crew Vehicle/Space Launch System
  - Commercial Space Transportation
- Support Government and Industry R&D
  - Leverages high-fidelity simulation facilities and expertise
  - Users include FAA, DoD, major Aerospace companies

# Simulation Facilities at NASA Ames



*Unique, high-fidelity, simulation facilities and skilled staff enable a wide range of aerospace systems research*

**Full-Motion Flight Simulators**



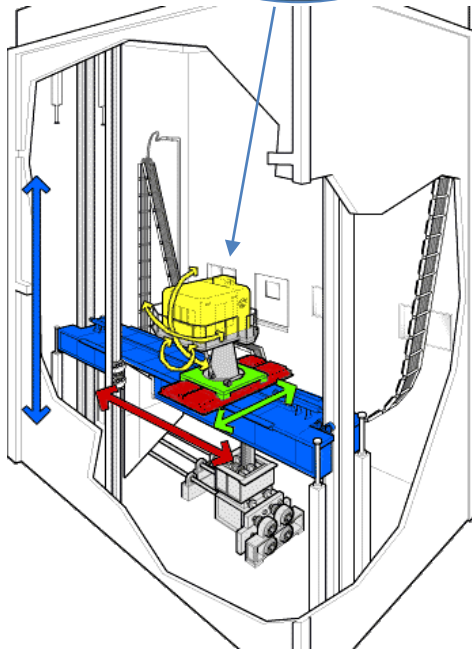
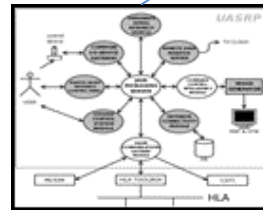
**Airport Control Tower Simulator**



**Air-Traffic Control Simulators**



**Internal Network**



**Vertical Motion Simulator (VMS)**

**Distributed Simulation Research Lab**

# Vertical Motion Simulator (VMS)



- Large amplitude motion system
  - Accurate motion cues for precision maneuvering tasks
  - Customizable motion parameters
- Interchangeable cabs
  - Five cabs with varying visual fields-of-view and cockpit layouts
  - Programmable multi-function displays
  - Programmable force-feel systems with a variety of inceptors
- High-fidelity visual systems
- Flexible simulation architecture
  - Tailored to research applications
  - Accepts user software and hardware modules

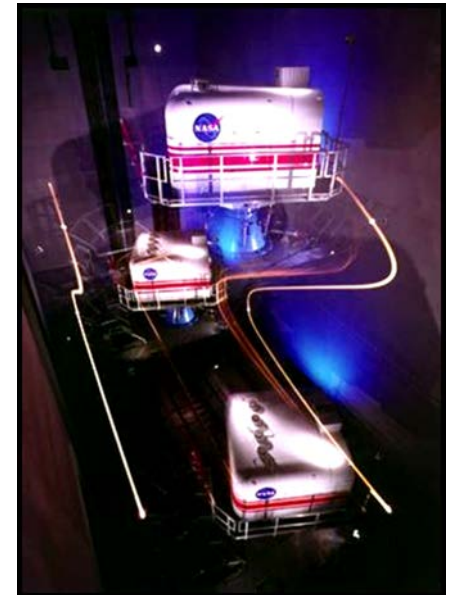
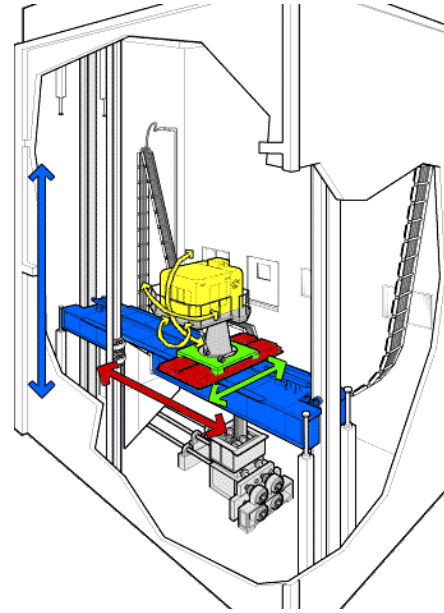


*Unparalleled Visual/Motion Cueing*

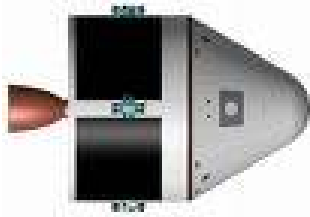
# VMS Motion System



- Six independent degrees-of-freedom
  - One-to-one motion possible
- Large displacement
  - $\pm 30$  ft vertical
  - $\pm 20$  ft lateral
  - $\pm 4$  ft longitudinal
- Longitudinal and lateral axes can be swapped by orienting cab
- 0.7 g vertical acceleration capability



# Vehicles Simulated on the VMS



**Crew Exp. Vehicle**



**Lunar Surf. Acc. Module**



**X-32B**



**X-35B**



**Space Shuttle**



**Speed Agile Concept**



**C-17**



**Tilt-Rotor**



**USAir 427**



**AV-8B**



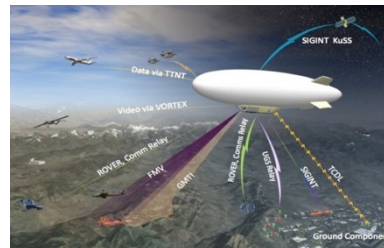
**RAH-66**



**High Speed Civil Transport**



**UH-60**



**USAF MAV6 Airship**



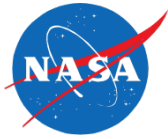
**CH-47 with slung loads**



**NT-33**

Workshop on Employment of Simulation in US Air Force Training Environments,  
Dayton, OH

# Crew Vehicle Systems Research Facility (CVSRF)



- Boeing 747-400 full-flight simulator
  - Certified to FAA Level D
  - NASA has access to model and display software
- Advanced Concepts Flight Simulator (ACFS)
  - Configurable for research
  - B737-800W, C-17, Generic twin-jet models
- Research applications include:
  - NextGen concepts/procedures
  - Quiet arrival/departure procedures
  - Avionics concepts
  - Cockpit human factors



**B747-400 FFS**



**ACFS**

*High-fidelity simulation for flight operations/procedures research and training*



# Air Traffic Control Simulators



- Realistic emulation of the National Airspace System (NAS)
  - Aircraft performance
  - Airspace definitions
- FAA standard controller stations
  - DSR and STARS display simulations
- Actual STARS systems
- Pseudo-pilot stations
- Voice switched audio communication system
- Data and video recording system



*Adaptable, high-fidelity simulation environment for testing ATC concepts and procedures*

# Air Traffic Control Tower Simulator

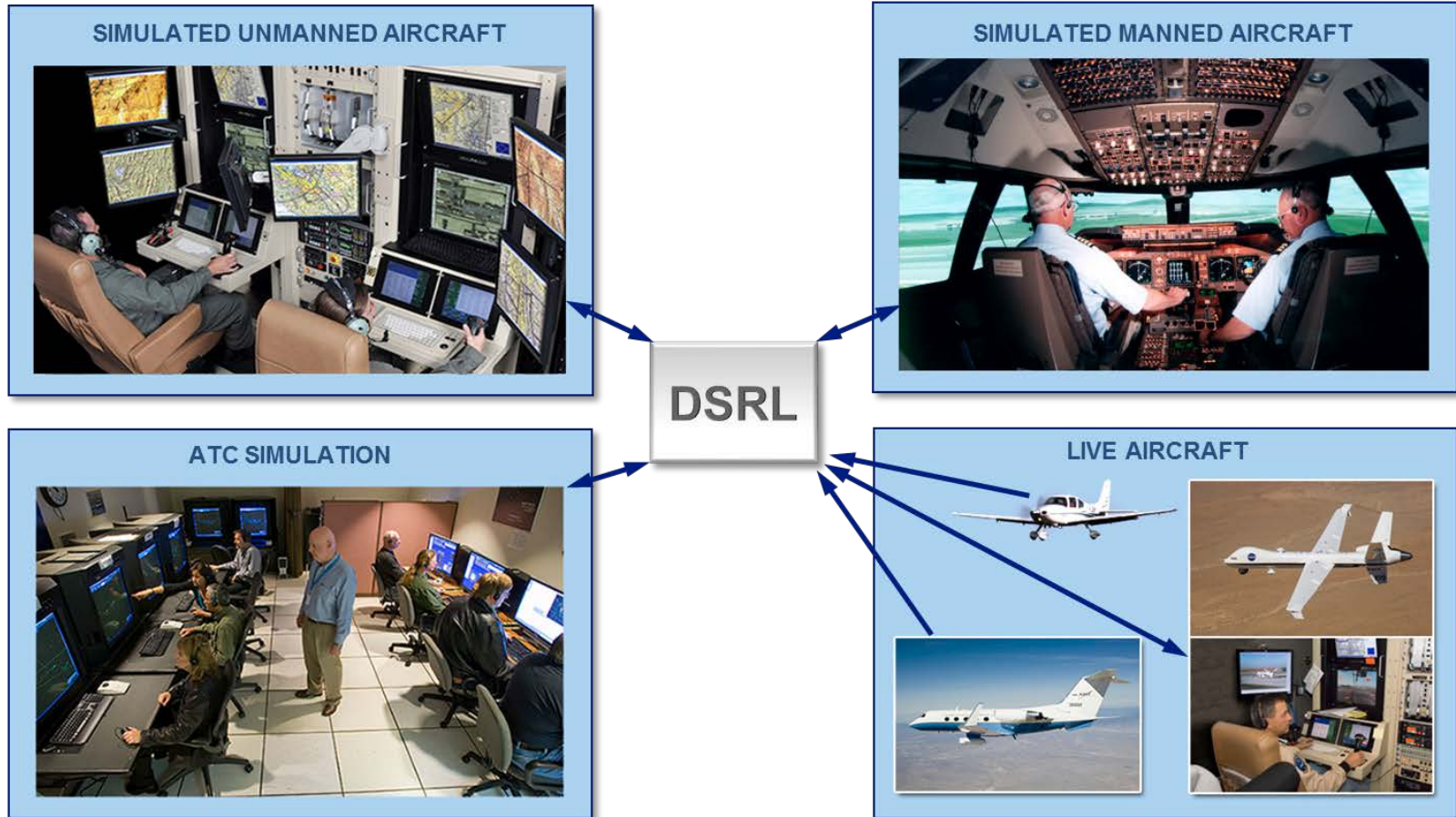


- Full-scale, 20-ft diameter, airport control tower simulator
- 360-degree high-resolution out-the-tower displays
- Realistic traffic/environment simulation
- Adaptable software/hardware architecture for testing future concepts and systems
- Research applications include:
  - NextGen concepts/procedures
  - Airport design and safety research
  - Remote robotic operation command and control



*High-fidelity, adaptable, visual environment  
for research and training*

# Distributed Simulation Research Laboratory

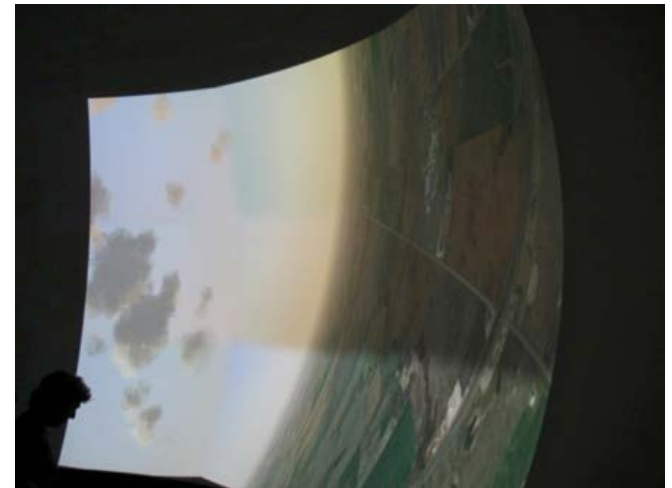


*Flexible development environment for networked distributed simulation*

# Operational Based Vision Assessment Simulator



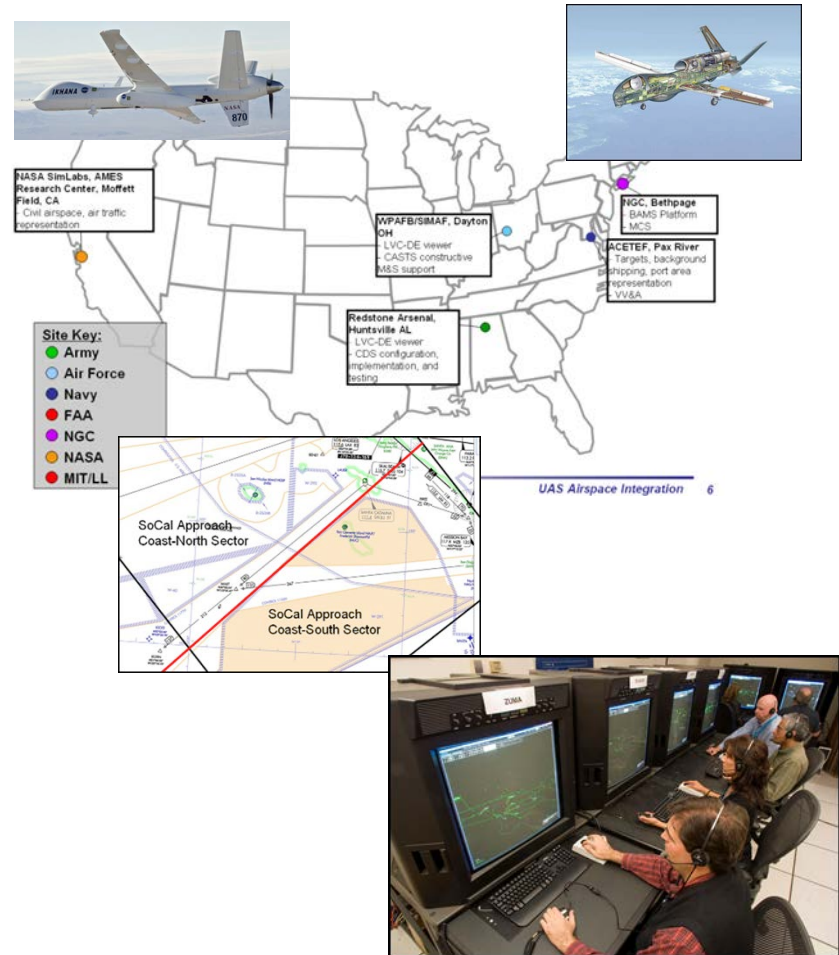
- USAF needed to correlate clinical vision standards with aircrew operational performance
- Required simulator with visual acuity of 20/10 or better using COTS hardware/software
- System researched, designed, and built at NASA Ames with USAF funding
- Flexible simulation architecture using COTS hardware and software
- Complete simulator system installed at WPAFB in 2012

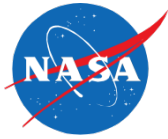


# NASA Ames LVC Experience



- 2004 - Now: NASA Air Traffic Management Research leveraging AVSimNet and Virtual Airspace Simulation Technology (VAST)
- 2009 & 2010: Navy BAMS (RQ-4N) Live Virtual Constructive Distributed Environment (LVC-DE)
- 2011: American Recovery & Reinvestment Act (ARRA)
  - TCAS & GCS Automation Study
- NASA UAS-NAS Project IT&E
  - Progressive build-up and test of LVC capability





RT1

## UAS Integration

- Airspace integration procedures and performance standards to enable UAS integration in the air transportation system

RT2

## Test Infrastructure

- Test infrastructure to enable development and validation of airspace integration procedures and performance standards.

## LVC

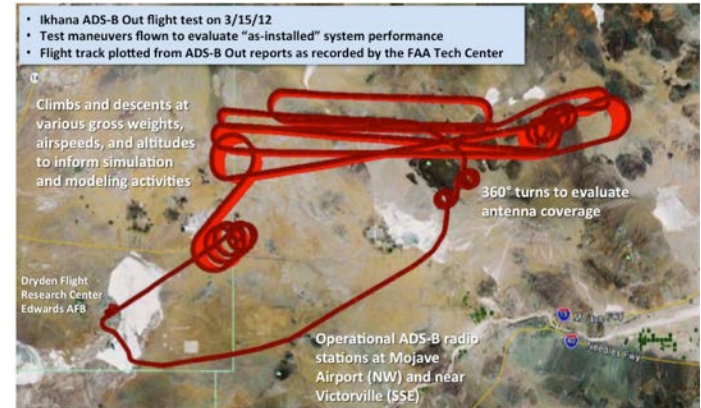
An adaptable, scalable, and schedulable relevant test environment for validating concepts and technologies for unmanned aircraft systems to safely operate in the NAS

# Early Equipment Integration and Checkout



## ADS-B Integration on the Ikhana UAS

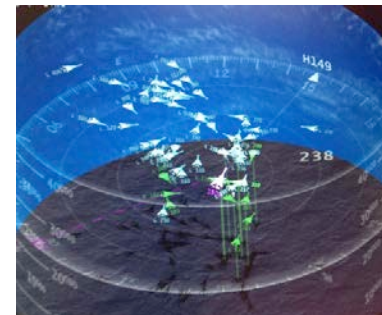
- Integrated a COTS (Garmin GDL-90) ADS-B onto a large UAS
  - Full ADS-B Out and In functionality
  - Unprecedented traffic situational awareness to UAS pilots
- Collected ADS-B “as installed” performance flight test data
  - Accuracy, uncertainty of position, velocity, and altitude reports
- Flight test results (Flight Test Series 1)
  - Verified ADS-B Out met FAA Advisory Circular AC 20-165 for ADS-B Out equipage
  - Valuable FAA Tech Center support with validated data analysis tools
  - **Connected Armstrong to LVC and Verified data exchange of live, virtual, and constructive traffic information between all participants**



*Ikhana flight path as tracked by the national ITT ADS-B Surveillance Network*

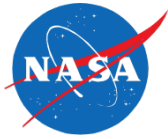


*ADS-B Ground Tests on Ikhana UAS*



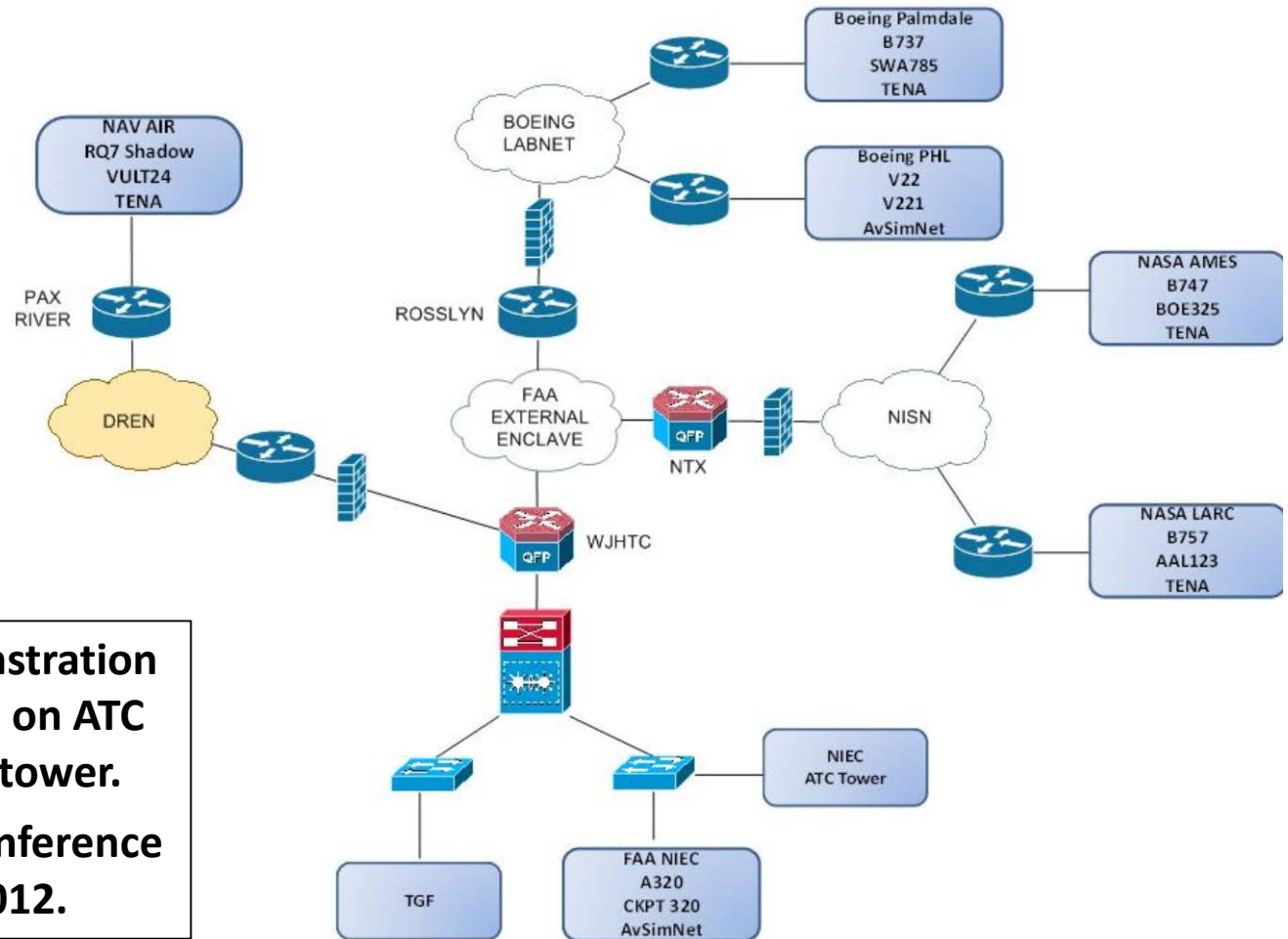
*Live ADS-B and TIS-B data shown on virtual cockpit display*

# Distributed Connectivity Demonstration



Initial test of distributed simulation capability among multiple participants

NASA Ames  
NASA Langley  
DoD NavAir Pax River  
Boeing Palmdale  
Boeing Philadelphia  
FAA Technical Center



**August 2012: Demonstration of simulated targets on ATC scopes and virtual tower. Presented at ITEA conference in September 2012.**



# Integrated Human-in-the-Loop Simulation

Completed Summer 2014



## Routine UAS Operations

- UAS transitioning Class E airspace to/from Class A, D, G airspace
- UAS equipped to detect and avoid traffic
  - IFR
    - ADS-B
    - Transponder
  - VFR
    - Cooperative
      - ADS-B
      - Transponder
    - Non-cooperative

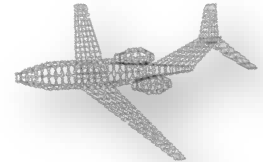
### Virtual UAS



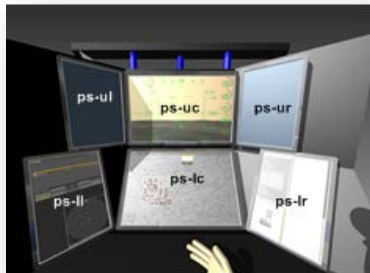
C2  
Data Link Model



Virtual/Constructive  
Intruders



### UAS Pilot as Subject



Research GCS



Basic and Advanced  
Displays of Proximal  
Traffic

### ATC as Subject

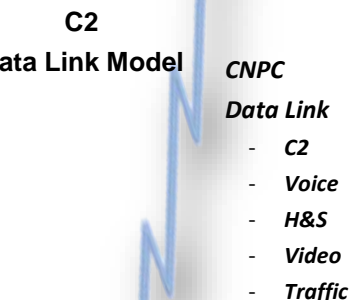


Multi-Aircraft Control  
System

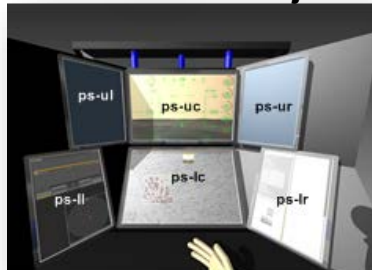


# UAS Flight Test

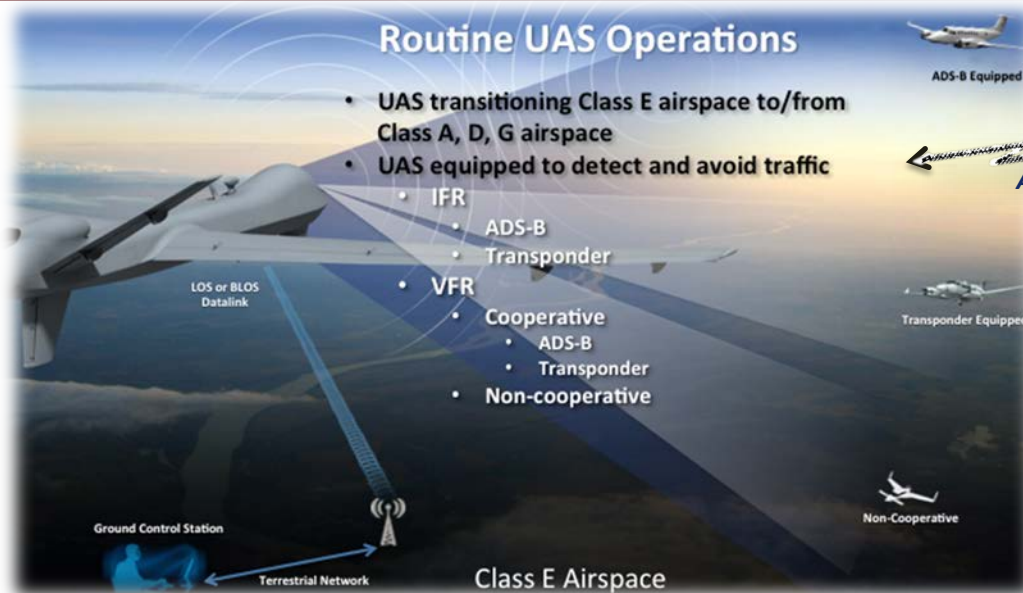
## Summer 2015, Spring 2016



**UAS Pilot as Subject**



**Research GCS**



**Live Intruders**

ADS-B  
TCAS II  
High speed

ADS-B Out

**Virtual/Constructive Intruders**



**Virtual Intruder(s) (Pseudo Pilots)**



**Real-World Airspace and Scenarios**

**VPN**

**Distributed Environment/Connectivity**

**Virtual ATC**



**Displays of Proximal Traffic**



**Multi-Aircraft Control System**

# Assets Connected to UAS LVC



- Live
  - Ikhana (NASA's MQ-9)
  - T-34C (Manned Intruder)
  - S-3B (Viking) (Surrogate UAS)
- Virtual
  - B747 Flight Simulator (NASA Ames)
  - Ikhana Sim (NASA Armstrong)
  - Multi-Aircraft Control System (MACS) ATC Emulator
  - Research Ground Control Station (GCS)
    - Vigilant Spirit Control Station (VSCS)
    - Multiple UAS Simulation (MUSIM)
  - Future Flight Central (NASA Ames)
- Constructive
  - NASA Airspace Simulation (MACS) Pseudo Pilot



# Specific LVC Limitations



- Connection tested with a limited set of clients
- LVC infrastructure tested for a small number of aircraft (<100)
- Translate the location of the a live aircraft into an emulation of another real airspace (under development)
  - Magnetic variance
  - Altitude difference
  - Wind variance
- Matching live and virtual aircraft for precision maneuvers
  - Real vs. predicted wind variance
- Replacement of live target with virtual target
- Lack of aircraft and trajectory modeling for many aircraft classes
  - Small UAS
- Missing Emulation of ADS-B In and Out

# Current Limitations

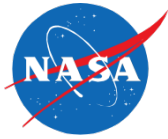
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- Simulation modeling capability
  - Integrated high-fidelity fluid and structural dynamic effects for simulating, aerial refueling, close formation flight, etc.
- Consistency in modeling
  - Consistent coordinate systems, variable definitions, portable visual databases, etc.
- Network throughput for LVC simulation
  - Reduce simulation update times
- Quantify benefits of simulation relative to:
  - Risk mitigation
  - Transfer-of-training/"required level of fidelity"
- Funding to maintain/upgrade technical capabilities
- Workforce replenishment

# Overcoming Limitations

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- Dedicated funding stream to upgrade/maintain simulators to meet future simulation needs
- Improve perceptions on the benefits of simulation
  - Quantify cost/benefit in terms of risk-mitigation
  - Quantify transfer-of-training benefits
- “Plug-and-play” capability for LVC environments



- Provide dedicated funding stream for maintaining and upgrading relevant simulation facilities
- Develop guidelines for interfacing distributed simulations – model interactions, communication protocols, IT security, etc.
- Develop guidelines on simulation fidelity requirements based on task
  - Modeling requirements
  - Human-system interface fidelity
  - Visual and motion fidelity

# QUESTIONS?

