JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Experiences in Testing Autonomous Systems

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Philosophy for Testing Autonomy

- **APL has been developing autonomy algorithms and conducting related demonstrations for nearly 20 years**
- **Without rigorous testing the use/adoption of "autonomy" will not occur**
- **Near term autonomous implementations**
  - ➢ Autonomous decision aid to relieve operator work loads → YES
  - ➢ Re-supply vehicles that are autonomous (UAS, UAG, USV) → YES
  - ➢ A fully autonomous Group 3, 4, or 5 UAS → NO
  - ➢ A fully autonomous Group 1 UAS → YES

A Live, Virtual, and Constructive (LVC) Toolset with Messaging Formats, Common Middleware, and Open Architecture Specifications Must Be Built/Used for the Testing and Fielding of Autonomous Systems

Operations Aphrodite and Anvil

Aphrodite and **Anvil** were the World War II code names for operations to use B-17 and PB4Y bombers as precision-guided munitions against bunkers and other hardened/reinforced enemy facilities. The plan called for aircraft that had been taken out of operational service – various nicknames existed such as "robot", "baby", "drone" or "weary Willy" – to be loaded to capacity with high explosives, and flown by radio control into bomb-resistant fortifications such as German U-boat pens and V-weapon sites.

The project was dangerous, expensive, and unsuccessful. One particularly infamous event (August 12, 1944) involved a single US Navy BQ-8 that detonated prematurely over England, killing LT Joseph P. Kennedy, Jr. and LT Wilford J. Willy.

APL Has Conducted 35+ Demos over 15+ years

Robust Autonomous Behavior Demonstrations

- *Multi-mission*
- *Capable Combined Air-Land-Sea-Undersea*
- *Multi-system Cooperation and Coordination*
- *Reduced Operator Load and Communications Requirements*

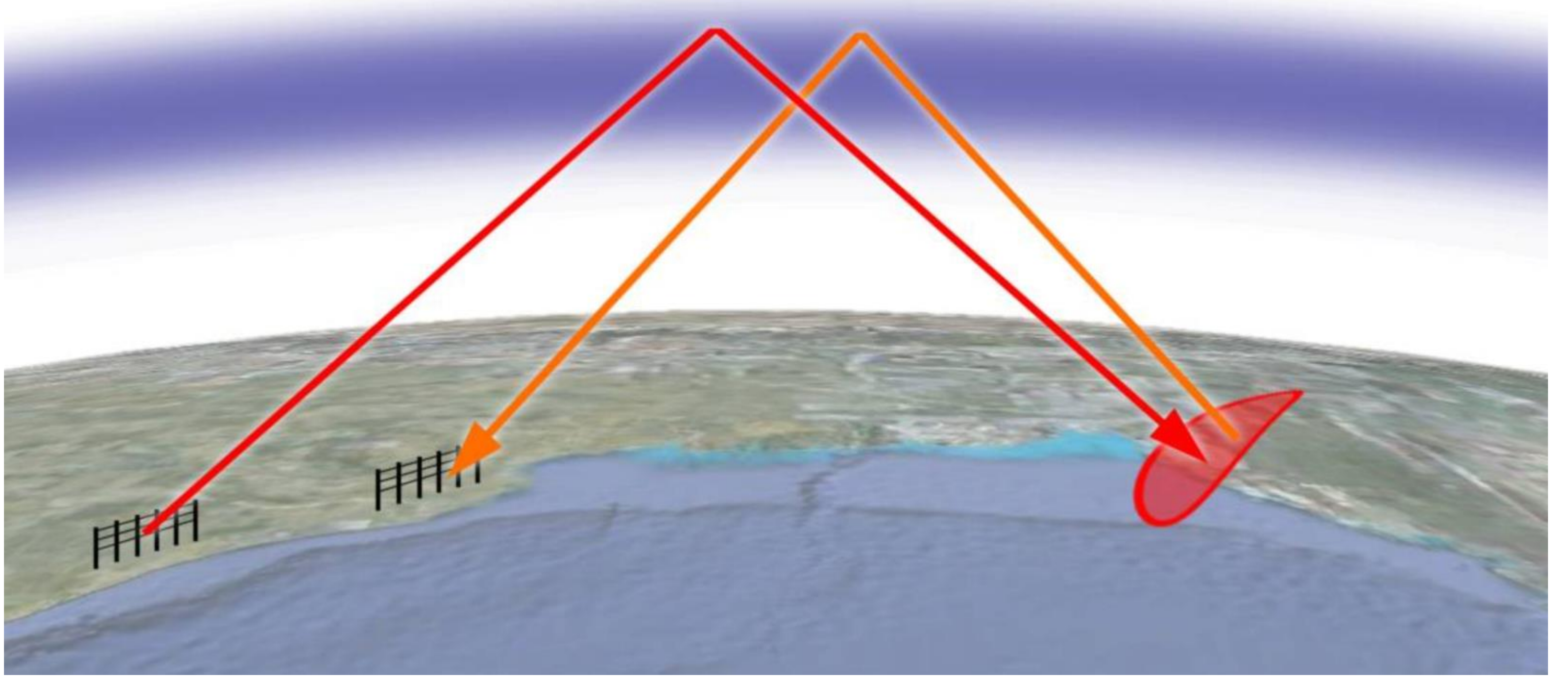
Demos at TRL 5-6

- *Self-Forming Comms Networks*
- *Search and Patrol*
- *Airspace Deconflicton*
- *Blue Overwatch*
- *Strike (with human confirmation)*
- *Missile Defense*
- *ISR & Chem-Bio Sensor Collection*

“Autonomy” Is Lurking in Existing Systems

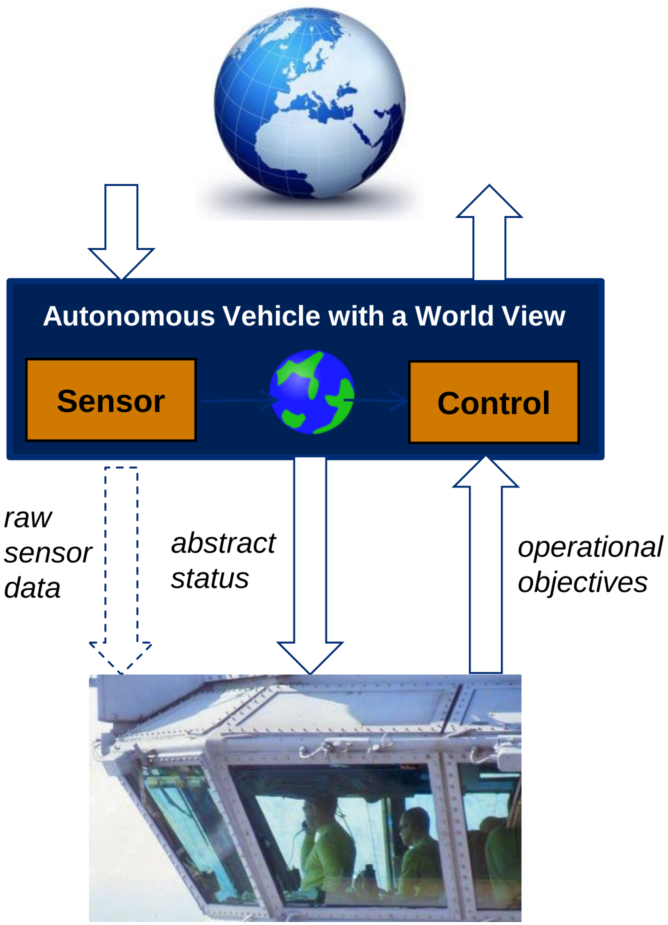
- Is this system “highly automated or autonomous?”
- Is there ”direct human” oversight in the decision making?
- Who makes the “this is a target & OK to shoot” decisions?

Over the Horizon (OTH) Radar Example



From “Tele” to “Auto” to “Autonomous”

Autonomous Behavior



Operator interface gives high level mission-like commands with the autonomy engine doing the details

- **The “autonomy world view” from sensors must sufficiently agree with the “operators world view”**
- **APL’s autonomy expertise has for the most part implemented “user-on-the-loop” protocols**
- **We often were asked to “prove” that our autonomy solution would not break or have a fatal flaw**
- **That pushed us to rethink how to T&E autonomous systems – not just our solution – but for autonomous systems in general**

APL was funded under the Unmanned & Autonomous System Test (UAST) program to develop the “Safe Testing of Autonomous Systems in Complex Environments (TACE)

Autonomy Testing Architecture – Key Needs

Synthetic Force Generator → Virtual and constructive entities (white/grey/red), on-rails or autonomous, environmental scenes, C2 & GPS jamming, communication models, autonomy engine with cooperative behavior, etc.

Perception Sensor Models → World View

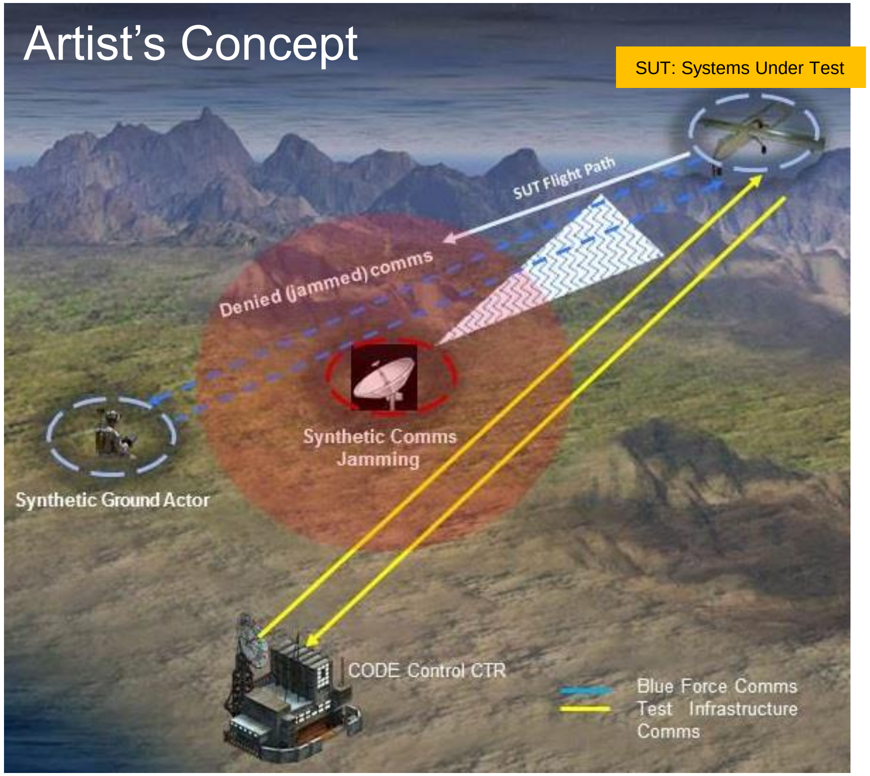
Black & White Box Capabilities → What happened & why did it happen

Watchdog Capabilities → Ground-based platform operator decision aids and on-board HW for “soft” test termination

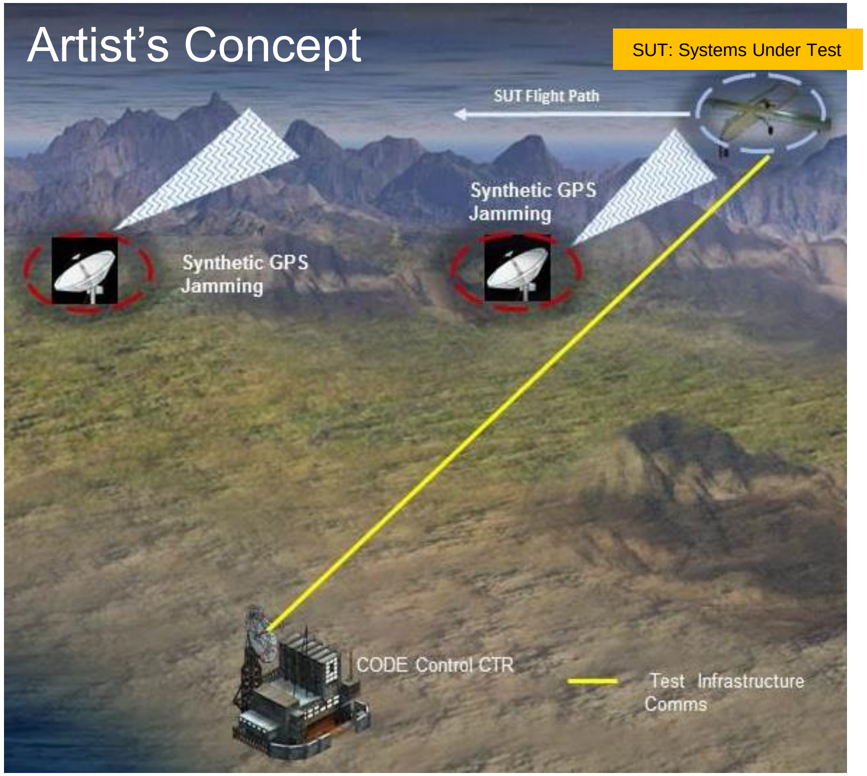
Wireless Capabilities → Usual platform data (1-way) & stimulate the autonomous system under test (ASUT) & monitor response (2-way) – proximate data

TACE provides the connective architecture to support these modules – but these can be YOUR modules

White Force Network Capabilities



Communications Denied

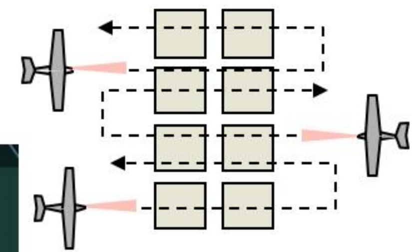


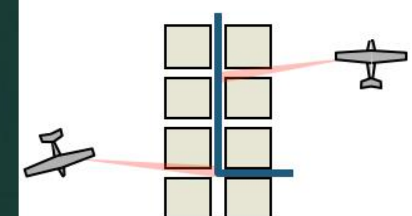
GPS Denied

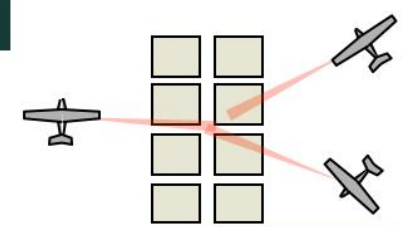
Distribution Statement "A" (Approved for Public Release, Distribution Unlimited)

UxAS: Unmanned Systems Autonomy Services

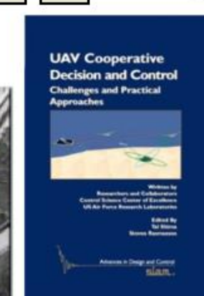
- **Net-centric collection of software modules that interconnect to automate mission-level decision making**
  - **Task assignment**
  - **Route planning**
  - **Cooperative control**
  - **Sensor steering**







- **Used to conduct experiments and demonstrations of cooperative control and human-machine teaming (live and simulated)**
- **Draws upon nearly 20 years of basic research in UAV cooperative control**



- **Designed for flexibility, rapid extensibility**
- **Open-source**

Distribution A: Approved for public release. Case #88ABW-2017-1985

Improving the Tool Set for DoD Purposes

- Autonomy testing tool sets will have an evolutionary life
- These tool sets must also be “matured” for test range use
- This will involve the use of stricter coding formats and the use of ”formal methods” type mathematical tools
- Overly strict and unique tools may dramatically slow the fielding of autonomous systems – we must find a solution path

Summary

- Autonomous systems are a key part of the strategies that seek to outmaneuver advantages of top adversaries primarily through highly advanced technologies
- LVC testing based upon range compliant middleware and an open architecture are key to advancing the testing and use of autonomy
  - Constructive models → test planning and archives for "range safety"
  - Virtual players add the "human element"
  - The "switch" to LIVE supports hardware-in-the-loop & controlled outdoor tests
- A testing architecture to support developmental testing must be transitioned for use by operational testers and the training community → saves time and dramatically lowers overall costs
- Autonomous systems can learn and must be continuously tested, trained, and warfighter operated

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