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AUTOMATED AERIAL REFUELING PRESENTATION TO 2007 ARSAG CONFERENCE (PREPRINT)

Jacob Hinchman and Daniel Schreiter

APRIL 2007

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14. ABSTRACT
This presentation was prepared for the 2007 Aerial Refueling Systems Advisory Group (ARSAG) conference to update the status of the Automated Aerial Refueling program at the Air Force Research Laboratory.

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automated aerial refueling, UAV refueling, precision global positioning system, boom-receptacle refueling, station keeping flight test

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Automated Aerial Refueling

ARSAG Presentation
April 2007

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Significance to Air Force

- **Unmanned Aerial Vehicles**
  - Extends Range
  - Shortens Response for Time-Critical Targets
  - Maintains In-Theater Presence Using Fewer Assets
  - Allows Deployment with Manned Fighters and Attack Without the Need of Forward Staging Areas

> *"How does it (J-UCAS) air refuel? … which is persistence and endurance, things men can't do in airplanes "*
>
> -Gen. John Jumper, USAF, February 2005

- **Manned Aircraft**
  - Provides Adverse Weather Operations
  - Improves Fueling Efficiency
  - Improves Pilot Workload

AAR Assists UCAVs in Reaching Its Full Potential, and Greatly Enhances Manned Refueling

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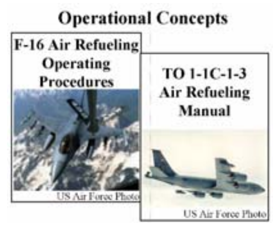
The AAR technology suite has application to both manned and unmanned vehicles. For unmanned vehicles, AAR allows eliminates the tyranny of fuel, allowing unmanned vehicles to be based, deployed, and employed like manned systems.

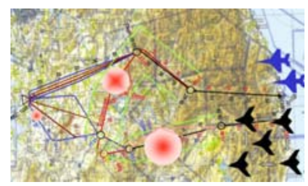
Furthermore as manned mission durations increase, aerial refueling becomes more and more strenuous on the pilot. AAR seeks to reduce the workload in cockpit and provide a in-weather refueling capability. Also, this technology allows manned or unmanned platforms to fly formation in IFR conditions.

The AAR program was created by the War Fighters to address their needs. Since day one, AAR's goal has been to meet this need through operationally relevant technology development and integration. The AAR team was formed with ACC, AMC, AFRL, ASC, NAVAIR, and contractors with the goal of "Same Tracks, Same Tankers, Same Time for manned and unmanned refueling"

Operational Requirements

- **Perform All 3 Rendezvous types**
  - **Point Parallel, Fighter Turn-On, and En-Route/Tactical**
- **Refuel in up to 4 Ship Packages**
- **Integrate into Mixed Fleet Operations**
  - **Minimize Changes to Tanker and Tanker Operations**
- **Operate in an EMCON-3 (Data Encrypted) Environment**



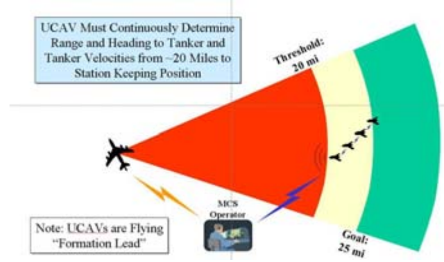


Key Technology Challenges

See Near
- Determine Relative Position with Tanker
  - Using Position/Velocities to Close Control Loop
  - High Confidence in Position Accuracy
  - Avoid Aircraft in AAR Area

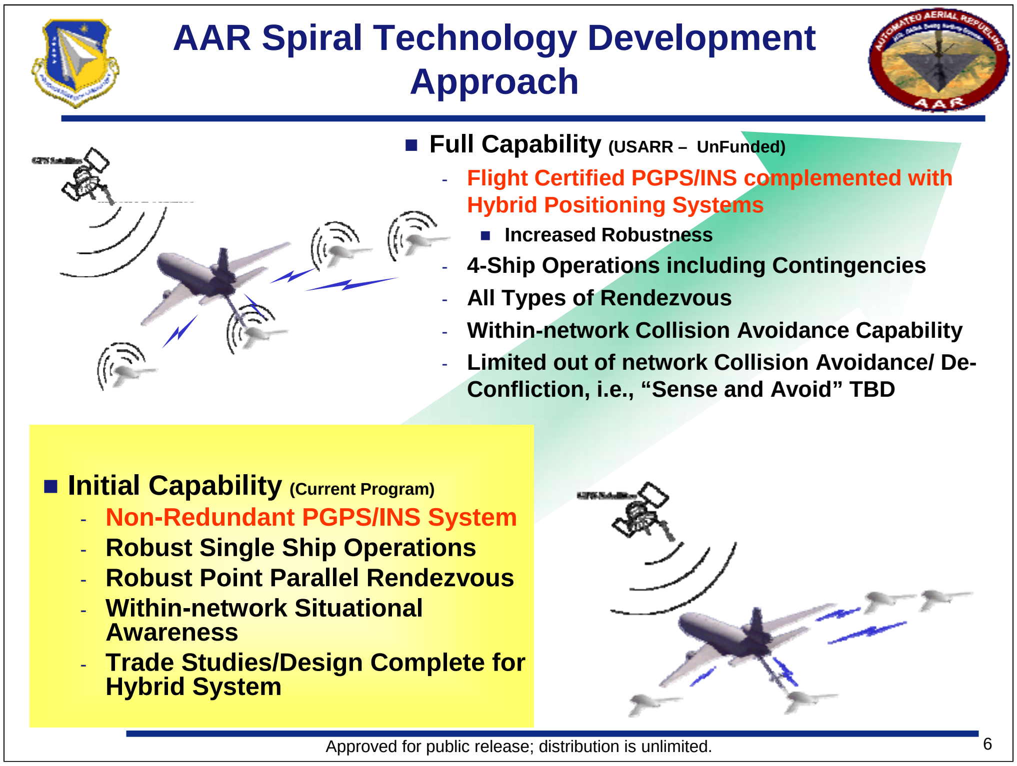
Collision Avoidance
- AAR Brings Many Aircraft into Same Airspace

Command and Control
- Assure UCAS Accurately Responds Boomer Break-Away Commands



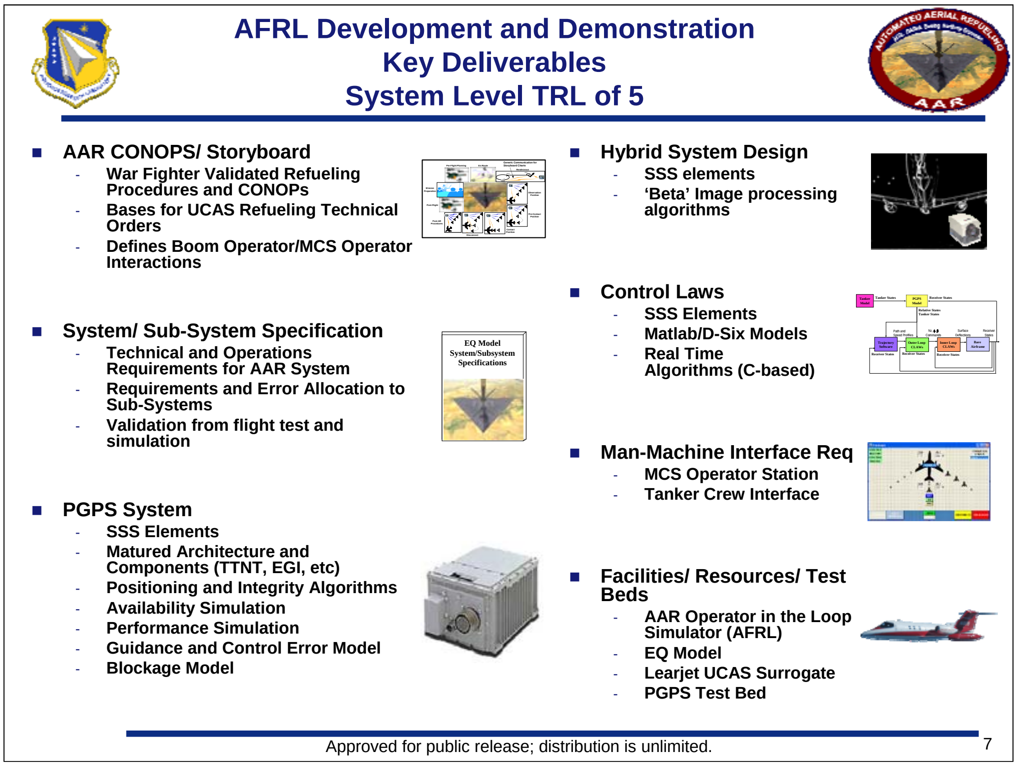
Aircraft Integration
- Minimize impacts to tanker fleet
- Fit within constrained volume of UCAS
- Precision control of UCAS
- Flight critical integration

Real World Considerations
- Fitting Solutions into a Low Probability of Detect/Intercept Environment
  - Latency, Drop-Outs, Re-Encryption, and Limit Power Settings

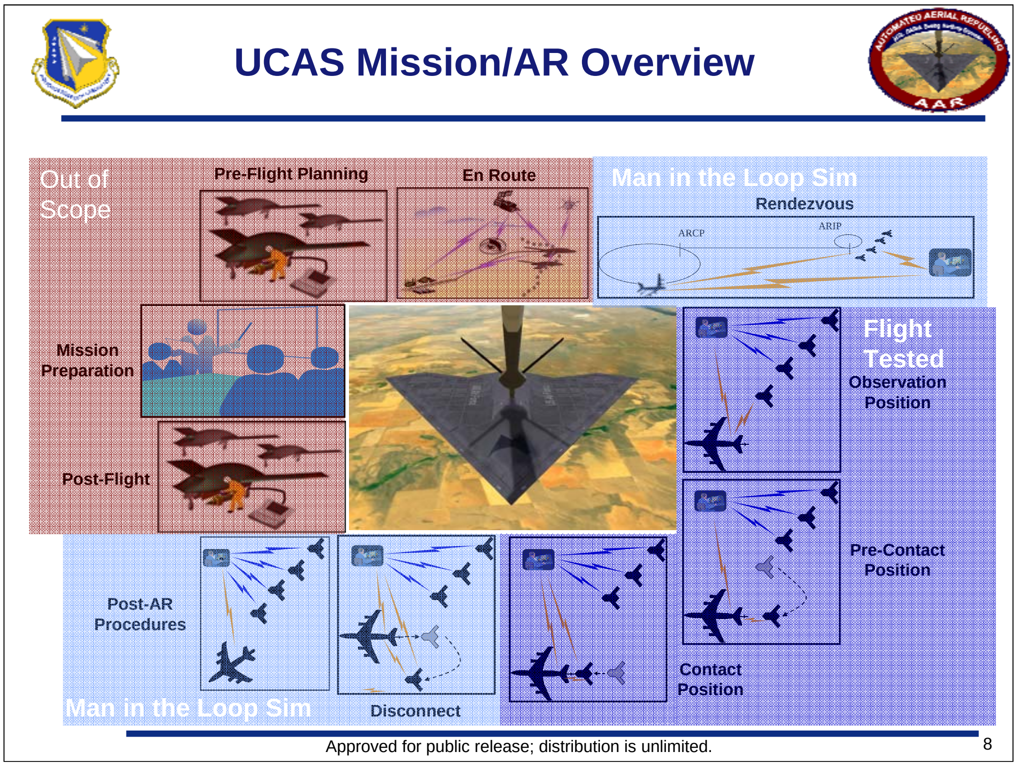


The currently funded AAR program seeks to develop a robust single ship AAR capability based on Precision GPS (PGPS). In order to make sure good design decisions are made, AAR also addresses 4-ship operations, rendezvous, and sensor trade studies/design for hybrid system. While these areas are seriously being addressed, they are not as mature as the PGPS single-ship operations.

The AAR program has a vision of combining the PGPS system with Sense and Avoid sensor to produce a dissimilar robust positioning capability. This is labeled as the Full Capability (Hybrid Design) on the above chart. Along with the advances in positioning capability, 4-ship operations will be expanded to include contingencies. Along with this, flight demonstration of multi-ship operations and rendezvous would be conducted.



AAR seeks to develop seven key products: AAR Storyboards, System/Sub-System Specification and Design Document (SSS/SSDD), PGPS Prototype Positioning System, Hybrid system Preliminary Design, Formation Flight Control Algorithms, Man-Machine Interface Requirements, and a host of Test Resources. The AAR Storyboards are war-fighter validated CONOPS for AAR Rendezvous through Departure from the tanker. They are tested with AMC and ACC operators in the AFRL high fidelity man-in-the-loop simulation (MILS) The SSS/SSDD in an encapsulation of over 2500 requirements and design decisions into a design spec for future weapon system integration. The PGPS prototype positioning system provides the precise relative position between the tanker and surrogate receiver. This prototype equipment is a key aspect of the AAR flight test program. The control laws are flight tested close formation flight algorithms tuned for the Equivalent model. These control laws allow for rendezvous, station keeping with the tanker, maneuvering from refueling position to position, and departure from the tanker. The man-machine interface (MMI/HSI) Requirement Study is a detailed study into the interface requirements for the ground station and tanker in order to maintain operator situational awareness. HSI preliminary design concepts will be tested in MILS.

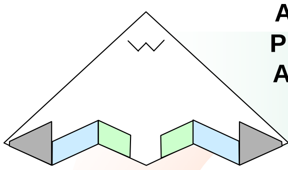


The AAR program addresses only the Air Refueling (AR) operations elements of the overall UCAS mission. Mission preparation, pre-flight planning, en route flying, and post-flight operations are not addressed.

In the AAR man-in-the-loop simulation, air refueling operations are simulated from rendezvous through post-AR procedures.

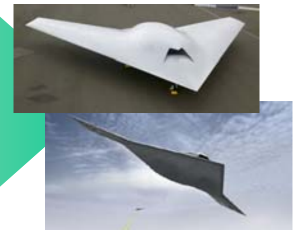
During the AAR flight tests, the program will demonstrate a subset of AR operations sequencing the UCAS surrogate vehicle through the observation, pre-contact, and contact positions. The flight tests not only validate the simulation, but also demonstrate the AAR components in a relevant environment.

EQ Model Facilitates Precision Navigation System Development



AAR: CLAW, Requirements; Precision Navigation System Architecture and Algorithms Maturation Via Off-Line Analyses and Real-Time Manned Simulations

UCAS



AAR: CLAWs, Requirements; Precision Navigation System Architecture and Algorithms

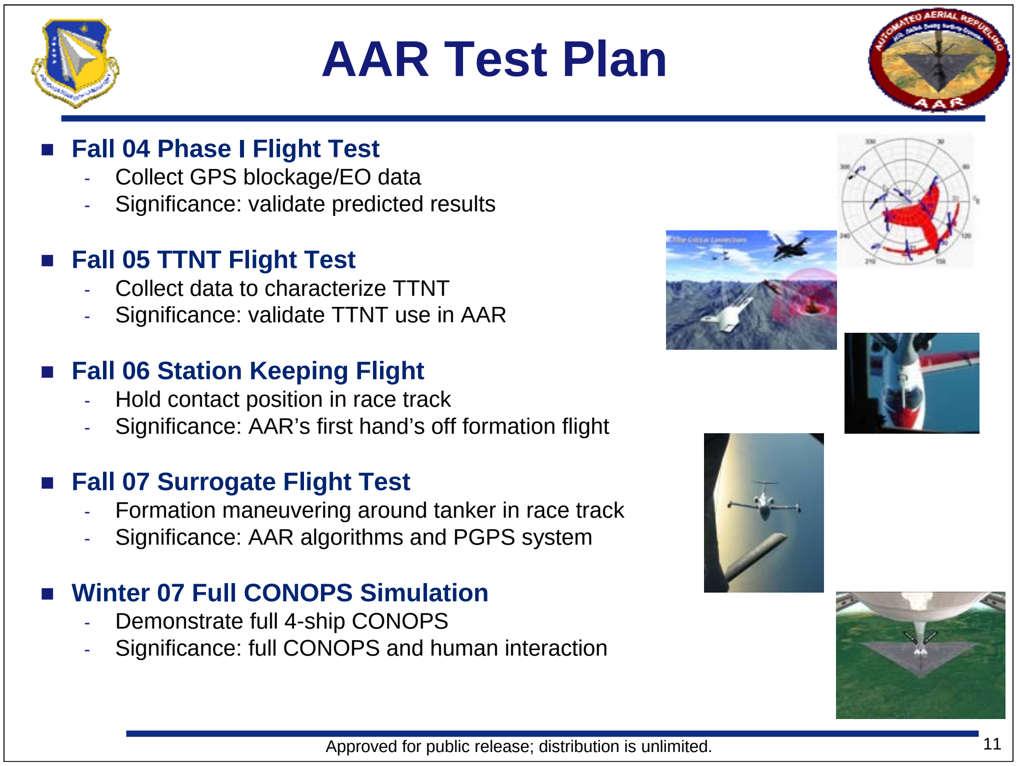
Calspan Learjet 25

Flight Test Results/Lessons Learned

Calspan Learjet 2
AAR UAS Surrogate

- **UAS Manned Surrogate**
  - **Autonomous Capability with Safety Pilot Override**
  - **Variable Stablitily Flight Controls**

- **Represented EQ Model Performance Parameters**
  - **Frequency and Damping**



AAR has four major flight tests:

Phase I Flight Test:

The objective of this test was to collect GPS blockage data and EO Sensor data around the tanker in order to verify the predict performance with actual flight test data. This flight test was key in determining PGPS feasibility. Out of this flight test, it was determine that the AAR system can track GPS satellites through the KC-135 tanker tail.

Tactical Targeting Network Technology (TTNT) Flight Test:

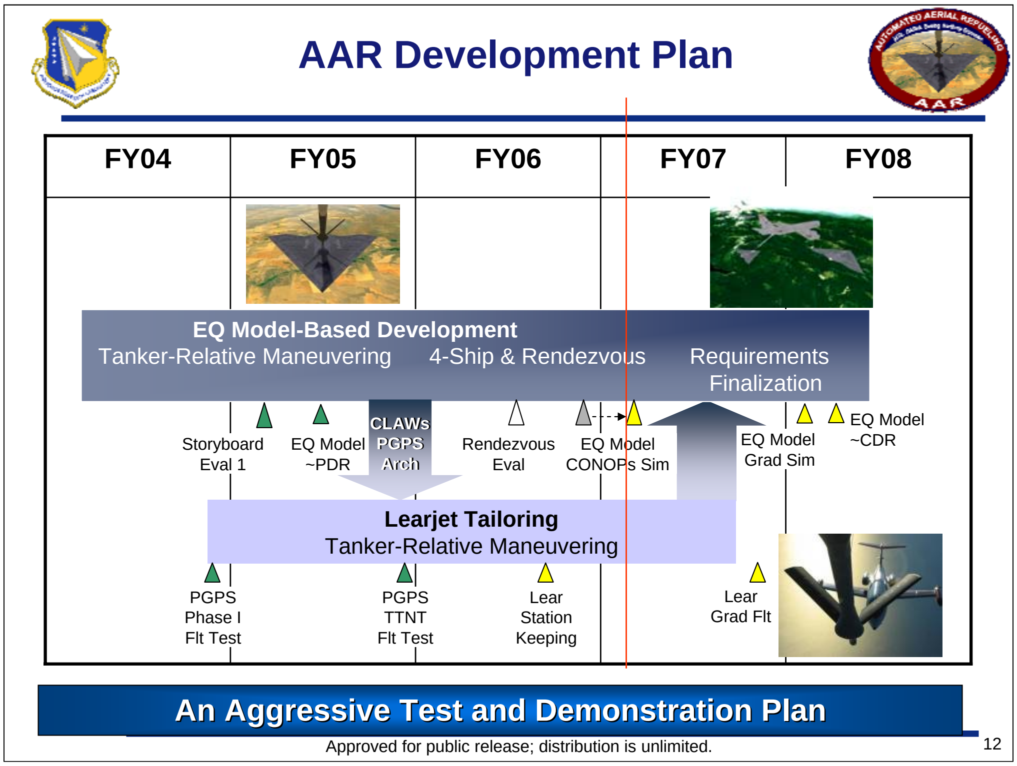
The objective of this test was to transmit PGPS data over a loaded TTNT network. The goal was to determine how network loading effects signal delay. This also was the first test that integrated PGPS with TTNT. The test was conducted in conjunction with the DARPA TTNT China Lake test It was determine that TTNT needed slight modifications which have been incorporated.

Station Keeping Flight Test:

The objective of this test is to demonstrate hands-off formation flight of the Calspan Learjet with a KC-135. The pilot will hand fly the Learjet into the Observation, Pre-Contact, and Contact position and engage the auto-hold system. The Learjet will autonomously hold that position with the KC-135 flying around a refueling racetrack. The will be the first integration test of the PGPS and flight controls system.

Graduation Flight Test:

The objective of this test is to demonstrate the AAR Tanker Maneuvering and Formation Flight System. In this test, the pilot will hand fly the Learjet into the Observation position and engage the system. Then, the flight test engineer will be able to command the software to maneuver the Learjet to the other refueling positions including break-away. The tanker crew will also be able to give the Learjet the breakaway and move back to pre-contact commands to be autonomously executed. Also as part of this test, the PGPS integrity monitoring system will be tested.



The AAR Development and Demonstration Plan consists of two paths. All of the design and development work is conducted on the EQ Model. The EQ Model is a non-proprietary blending of X-45 and X-47 models. The EQ model is the basis for all of the AAR simulation work. The program has 4 major simulation events designed to test the storyboards, HSI, and algorithms. The final simulation, called the graduation simulation, is the full testing of the AAR 4-Ship algorithms from Rendezvous to Departure using high fidelity flight validated models.

The second path consists of tailoring the algorithm developed for the EQ model to the Calspan Variable Stability Learjet and combine the software with the positioning hardware. This enables flight demonstration the close-formation flight capability of the AAR system. There are 4 major flight tests. The first two test are data gathering tests aiding AAR in developing the high fidelity models for the system. The second two flight tests (Station Keeping and Graduation) are autonomous (Hands-Off) flight tests. In the graduation flight test, the pilot will fly into the observation position and engage the system. The system will then, upon command, autonomously fly the Learjet from observation->pre-contact->contact->breakaway->observation while the tanker maintains its normal racetrack pattern.

Precision GPS Closed-Loop Station Keeping Flt Test Aug 06

- **Objectives:**
  - Evaluation of Updated Precision GPS Performance
  - Test Autonomous Formation Flt Algorithms in Contact Position
  - Evaluate EO/IR Camera as AAR Sensor

- **Details:**
  - Aircraft: Calspan Learjet, NY ANG KC-135
  - Simplex (Non-Redundant) AAR System and Safety Pilot

"The System Held Contact Position Better than I Could", Calspan Test Pilot

The Precision GPS Closed-Loop Flight test is the largest technical risk reduction activity on the AAR ATD. This flight tests' first flight was 26 Jul 06; and, the flight test is scheduled to last through 31 Aug 06. So far, the team has successfully tested the precision GPS position system, the EO/IR camera, and the automated flight control system. The primary objective of this flight test is to demonstrate automated formation flight in the contact position around a refueling race track. The AAR system will also be tested in the (left/right in-board/out-board) observations positions, pre-contact, and contact position in straight and level flight, as well as in turns.

Station-Keeping Flight Test
Example Contact Position Performance

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AAR Station-Keeping Flight Test
Example Contact Position Performance

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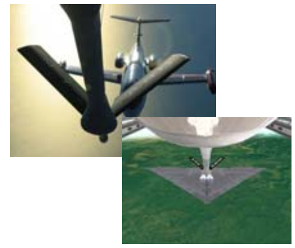
PGPS Conclusions

- All Station-Keeping Flight Test Objects Met
- FTE Met Required Navigation Performance Requirements For All Positions During All FCS Flights
  - More Precise Than Piloted Station-Keeping
  - “A Lot Lower Workload” for Pilot
- Matlab AAR Simulation:
  - Some Station-Keeping Performance Differences With Flight Test Results
  - Adequate to Support Future CLAW Development and Analysis
- Control Law Updates Being Investigated for Inclusion in 2007 Graduation Flight Test

Automated Aerial Refueling (AAR)
Next Steps

- **Demonstration AAR in a relevant environment through wet hookup**
- **Focus areas for further maturation**
  - **Redundancy/contingency management**
  - **Multi-ship operations**
  - **Hybrid (GPS+EO/IR Sensor) positioning system**
  - **Sense and Avoid**
  - **Robust AAR System/CONOPS Simulation**
  - **Full AR CONOPS flight test with hookup**



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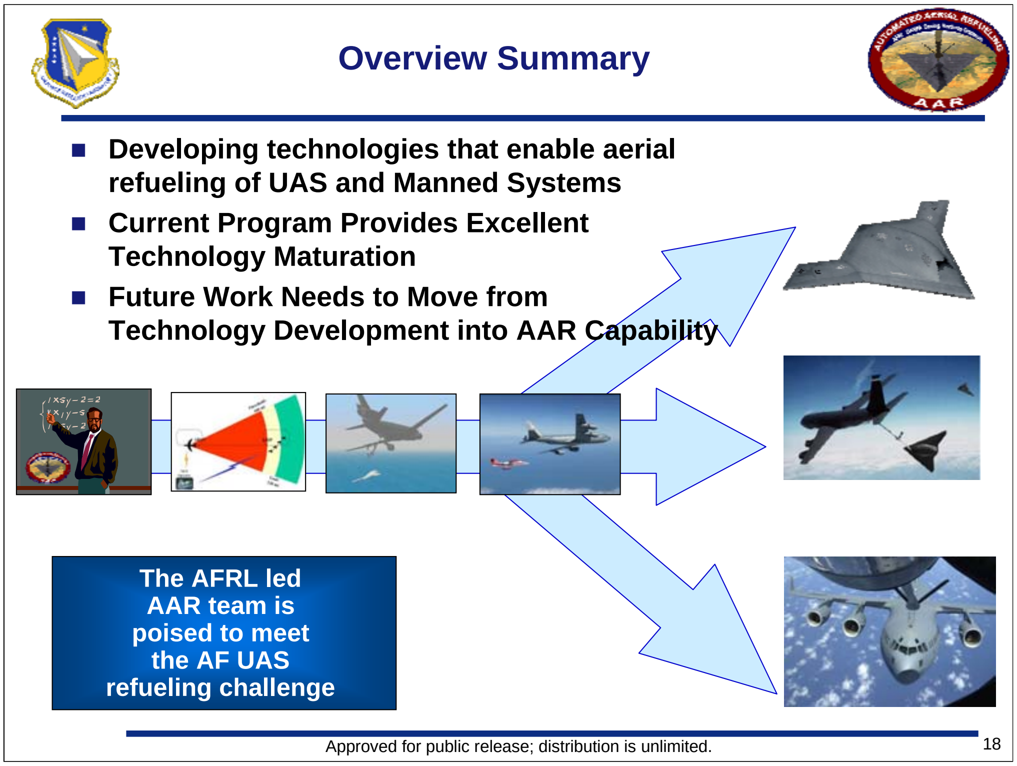
The AAR ATD has made great strides in maturing automated formation flight technology. This programs has pushed the envelope on precision positioning systems and close formation flight. The next step in AAR is to move from technology maturation into capability development. One of the key items that needs to be developed is precision GPS redundancy and contingency management along with dissimilar positioning technologies.



The current AAR program is developing the technology to make UAS refueling a reality. Without this focusing of core technology to the refueling challenge, automated aerial refueling would not be possible. Further work still needs to be completed to truly make AAR and SAA an "off-the-shelf (TRL 6)" capability. Most of this would address the safe and –ility aspects of AAR and SAA.