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A MULTI-PURPOSE SIMULATION ENVIRONMENT FOR UAV RESEARCH

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Unmanned aerial vehicles (UAVs) are playing an important role in today's military initiatives. UAVs have proven to be invaluable in locating critical targets and reporting enemy movements or positions to battlefield commanders. Integration of new technologies necessitates simulation prior to fielding new systems in order to avoid costly errors. The unique nature of UAVs in a modern combat environment requires the simulation of a significant part of the battle space to test the robustness of new technologies. Furthermore, simulation environments should be flexible and generic to allow for expedient testing of a wide range of concepts. Members of the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB are developing a multi-purpose simulation environment that will allow for the assessment of many different types of UAV technologies. This paper discusses this simulation activity and describes how it fits into AFRL's corporate plan.

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Abstract

Unmanned aerial vehicles (UAVs) are playing an important role in today's military initiatives. UAVs have proven to be invaluable in locating critical targets and reporting enemy movements or positions to battlefield commanders. Integration of new technologies necessitates simulation prior to fielding new systems in order to avoid costly errors. The unique nature of UAVs in a modern combat environment requires the simulation of a significant part of the battle space to test the robustness of new technologies. Furthermore, simulation environments should be flexible and generic to allow for expedient testing of a wide range of concepts. Members of the Air Force Research Laboratory (AFRL) at Wright-Patterson AFB are developing a multi-purpose simulation environment that will allow for the assessment of many different types of UAV technologies. This paper discusses this simulation activity and describes how it fits into AFRL's corporate plan.

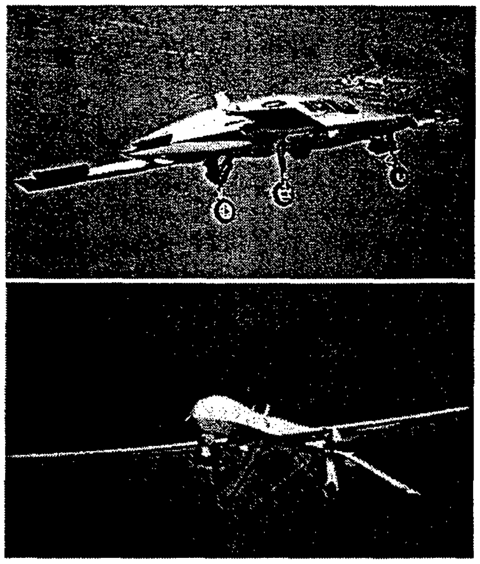

Figure 1 – A Boeing X-45 UCAV (top) and a General Atomics Aeronautical Systems Predator

Introduction

The world's military leaders are looking to unmanned aerial vehicles (UAVs) to play an integral role in combat operations around the globe. The use of UAVs has proven to be invaluable in locating critical targets and reporting enemy movements to battlefield commanders. With continuing advances in sensor technology, unmanned systems will be able to identify targets of interest with greater speed and accuracy, and pass more complete information to the warfighters. Additionally, as more UAV systems become capable of delivering weapons, they can be used to attack strategic targets or lethal ground threat systems without subjecting a manned asset to the same dangerous mission assignment.

Technologically, the UAV is still a work in progress. Although the results so far have been promising, there are still a large number of engineering issues that need to be addressed before the UAV becomes a truly formidable military asset. Simulation of new technologies is critical to the development of future UAV systems. Research and development activities at the Air Force Research Laboratory (AFRL) rely on simulation to assess the impact of new technologies in a dynamic environment. The need for a generic and extensible UAV research facility is becoming clearer as the demand for simulation-based research and development increases.

Past conflicts have highlighted the ability of UAV systems to augment air and ground operations. UAVs did not become significant players in combat until Operation Desert Storm. There, the RQ-2 Pioneer was employed as an observation platform, providing target identification and battle damage assessment. Later in the 1990s, the RQ-1 Predator played an important role in Bosnia as a recon-

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naissance and surveillance platform. Both the Predator and RQ-4 Global Hawk were used in Afghanistan in support of Operation Enduring Freedom. (Schwanhausser, 1997)

In addition to its traditional functions, the UAV is taking on the role of a weapon delivery platform. In October 2001, a Predator armed with Hellfire missiles fired the first weapon from an unmanned vehicle in combat. Since then, Hellfire-equipped Predators have been active players in the War on Terror. In light of the success of combat UAVs, the Air Force is developing a hunter-killer version of the Predator, designated MQ-9. As part of a longer-term UAV initiative, more advanced unmanned combat air vehicles (UCAVs) are also in development. The Boeing X-45 and the Northrop Grumman X-47 will provide the Air Force and Navy, respectively, with high-speed, stealthy strike aircraft that are capable of mission tasks that are currently the realm of only manned aircraft.

UAV Research at AFRL

Despite the rising interest in UAV systems, there are still only a handful of UAVs in service. The Global Hawk is not yet in full production and there are approximately two-dozen Predators in the Air Force inventory. (Zaloga, 2002) Current systems also have several drawbacks. Only a small number of Predators are equipped with wings capable of handling icing conditions and current limitations with their communications and control systems restrict the number of UAVs that can operate simultaneously. With UAVs emerging as combat vehicles, they are also vulnerable to threats. Although more difficult to engage than a manned aircraft, current UAVs have no counter-measure capability. Consequently, they have a limited self-protection capability, as was evidenced in December 2002 when an Iraqi warplane shot down a Predator in a no-fly zone. Also, UAVs are currently not permitted to operate in FAA controlled airspace without a special waiver.

Recognizing the unique capabilities of these machines and the necessity to overcome some of their current limitations, the U.S. Air Force is investing in research to develop new technologies and explore the potential applications of UAVs in future conflicts. A leader in this research area is the Air Vehicles Directorate of the Air Force Research Laboratory. Here, research is being conducted in the areas of advanced UAV configurations, multifunctional structures, propulsion integration, wing efficiency, structural weight reduction, and autonomous control.

Future unmanned systems must be able to operate in the same airspace as manned aircraft if they are to become an integrated part of Air Force combat operations. Mission planning, adjusting to a changing threat environment, self-defense, responding to the actions of manned aircraft, and integration into the command, control, and communications framework are areas being investigated within the Air Vehicles Directorate as part of autonomous control research and development. Furthermore, the relative infancy of UAV operations not only requires research into the technical aspects of UAV system design but also in the development of concepts of operations (CONOPS). The unique characteristics of UAVs and their interactions with manned assts enable new approaches to air combat.

Simulation-based research and development (SBR&D) is used to explore the mission-level operations of UAVs in a dynamic environment that focuses on mission planning, cooperative control, and varying levels of vehicle autonomy. UAV command and control schemes as well as new CONOPS for UAVs are tested in a simulation environment to aid in the determination of their applicability and robustness. The SBR&D hierarchy (Figure 2) illustrates the types of simulations that are used in evaluating new technologies. This paper focuses on mission-level simulations. Missions are usually defined as scenarios in which tactics, rather than strategy, are employed to achieve a short-term objective. Mission-level simulations are used to test the effectiveness of systems or processes and can be used for "many-versus-many" scenarios where several types of entities interact. Mission-level simulations often involve a representation of real threats, specific objectives for each player, and an element of

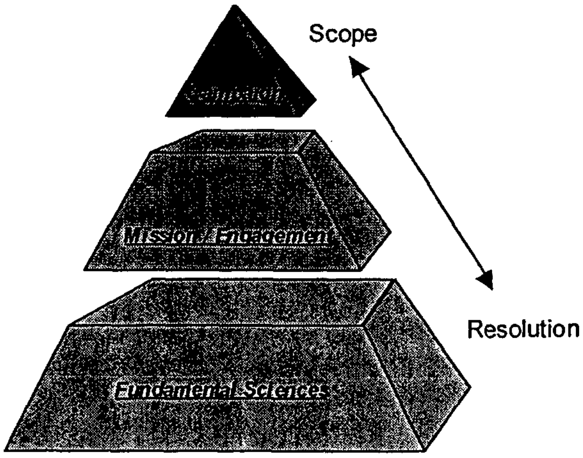

Figure 2 – The simulation pyramid

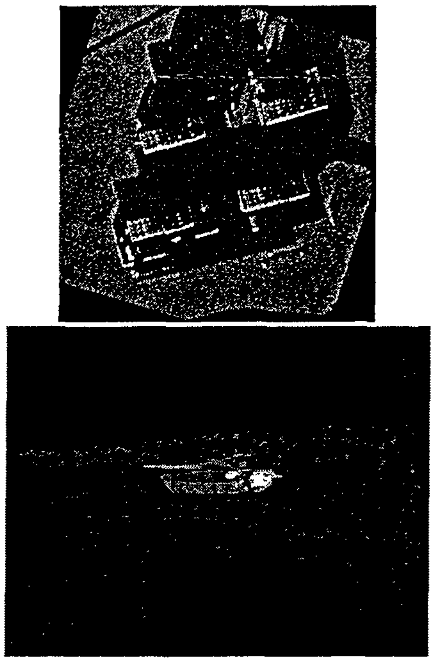

Figure 3 – SAR (top) and FLIR simulations

probability. By combining elements beyond those applicable only to the operation of a single vehicle, mission-level simulations can examine the effectiveness of a design or plan as part of a larger scenario. The results from mission simulations can be used to form a campaign simulation (shown at the top of the pyramid in Figure 2) to expand the scope of the study.

The Air Vehicles Directorate is developing a mission simulation capability dedicated to UAV research and development. This capability, located in the Aerospace Vehicle Technology Assessment and Simulation (AVTAS) Laboratory, will use both constructive (simulations that are executed without real-time input from human participants) and virtual (real-time simulations involving human inputs) mission-level simulations for evaluating emerging UAV technologies. The objective of this effort is to establish a generic and reusable mission simulation environment incorporating interactive manned aircraft simulators, an operator-vehicle interface for multiple UAVs, and a mission-level simulation software architecture.

Mission Simulation Software Components

Since mission-level simulations often involve many types of players and interactions, often a suite of software tools are combined to form the simulation environment. The software component that is used to simulate a manned aircraft, for instance, is obviously different from that which represents the actions of a UAVs or ground threats. Furthermore, hardware-based inputs must be integrated so that human operators can interact in the virtual simulations. The AVTAS mission simulation environment integrates several commercial and government-developed hardware and software components.

For studies that explore the actions of assets in a dynamic environment, a real-time mission planner, LNAVSIM, is being developed as part of an Air Vehicles directorate small business innovative research (SBIR) program. Each UAV and manned aircraft is assigned tasks and a specific route to fly through LNAVSIM. The routes for each aircraft are based on a pre-determined set of objectives and current information regarding the threat environment. As new threats are discovered, LNAVSIM can re-route the aircraft "on-the-fly." Further details regarding the capabilities of LNAVSIM can be found in Allen (2003).

Imaging ground objects is an important part of mission simulation since it enables human-in-the-loop identification of targets. Simulation of these systems is a key part of many mission-level studies because the results of the imagery are often used to task or re-task assets. It is also envisioned that imagery from multiple assets would be available to multiple players in the simulation to enable collaboration between players to achieve objectives. Target identification and battle damage assessment (BDA) are often conducted through the use of forward-looking infrared (FLIR) sensors and synthetic aperture radar (SAR). Both return imagery to operators to identify or assess the condition of combat targets. By including human interpretation of SAR and FLIR imagery, a more robust test of UAV systems is possible since human actions are a likely factor in any operational implementation of UAV technologies.

Figure 3 shows examples SAR and FLIR simulations.

The Joint Integrated Mission Model (JIMM) is a data driven, event-stepped, simulation system that can be executed as both a virtual and constructive simulation tool. For clarification, an event-stepped model is one in which the interactions within a given scenario are updated when a new interaction occurs rather than at a specific increment of time. For example, if there is a sensor system within a scenario that is scheduled to perform detections every second, then, if there are no other events occurring within the scenario, the JIMM model will remain idle until one second has elapsed and it is time to check for sensor detections. This methodology allows for very efficient and fast execution of the model because it is processing only those interactions that have changed or have been scheduled.

Figure 4 – OVI Station Concept

JIMM is a mission level simulation model that allows its users to create entities with a low to medium level of operational fidelity. JIMM is used to simulate many different systems and war-gaming effects such as sensors (such as radio frequency, infrared, electro-optical, radar warning, sonar, and acoustic), communication systems, jammers, weapons, movers (such as tanks, planes, missiles, and trucks), signatures (infrared, radio frequency, and acoustic), and tactics. In order for the model to implement these systems and effects in a realistic fashion, six generic functions were implemented within JIMM: (TRW Systems, 2001)

- **Move** - The process by which an object changes position and orientation within a scenario.
- **Shoot** - The transmission of matter or energy within a scenario with the intent of damaging or destroying a target.
- **Talk** - The cooperative exchange of information between entities.
- **Sense** - The non-cooperative gathering of information about other entities or objects.
- **Disrupt** - The ability to interfere with the sending or communicating functions of an object.
- **Think** - Provides the capability to realistically model human behavior.

These six functions describe everything that objects are capable of within a JIMM scenario. Through these functions, the user is able to create a very realistic representation ofentities and their interactions within a scenario.

For the UAV simulation capability within the AVTAS laboratory, JIMM will be used for modeling various aspects of the digital battle space. Primarily, JIMM will be used for modeling the ground based threat systems. This includes such things as the ground based radar systems, weapons, support equipment and the tactics associated with the operation of these entities. In addition, JIMM will be used to model various UAV capabilities such as sensors, weapons, and vehicle-to-vehicle communications.

Operator/Vehicle Interface Station

Although the ultimate goal for a UAV system is complete autonomy, today's UAVs still require some level of human interaction for direction through the various phases of the mission. To satisfy this need, the AVTAS UAV simulation capability will include an Operator/Vehicle Interface (OVI) Station. This station, shown in Figure 4, will enable the UAV operator to view graphical representations of the UAV's functional status and mission objectives as well as provide the operator with a global perspective of the battle space, as reported by the UAV's sensors or other sources of threat information. The operator will also use the OVI station to pass commands or information to both the UAV and possibly manned vehicle assets in order to execute the mission objectives. Finally, the UAV operator will be using this station along with the LNAVSIM simulation tool to perform real-time mission route planning for the UAVs.

Mini-Crew Stations

For conflicts occurring today and in the near future, the UAV will be used to augment rather than replace manned aircraft systems. Consequently, it is necessary to understand the issues associated with both manned and unmanned systems working together within the same airspace. These issues concern not only how these two aircraft systems can work together as a coordinated strike package but also with the safe operation of these systems when they are flying in close proximity of each other. Within the AVTAS UAV simulation capability, four mini-crew stations (MCS) will be used for manned aircraft operations. These MCS,

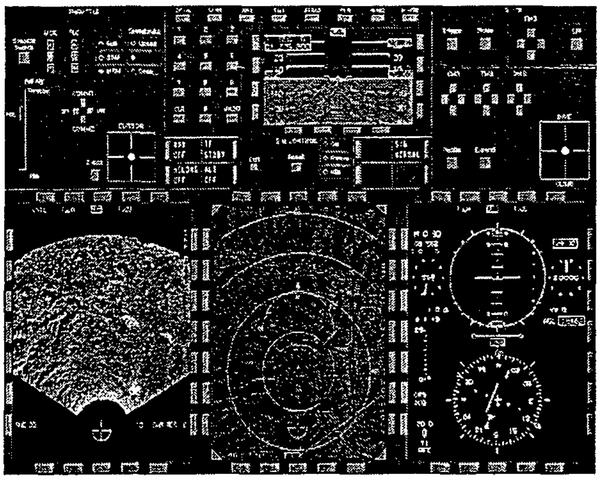

Figure 6 – MCS Cockpit Displays

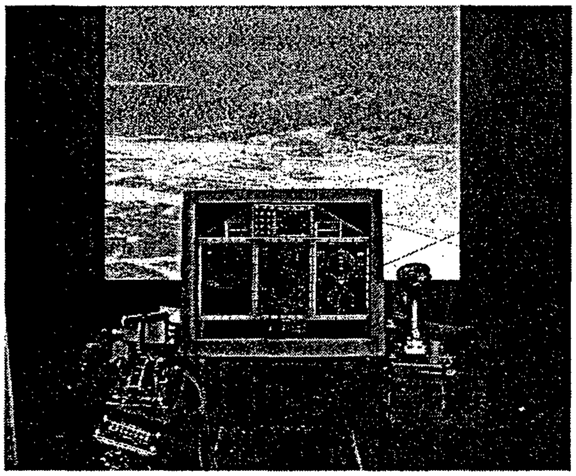

Figure 5 – Mini-crew Stations (MCS)

shown in Figure 5, have very simple, programmable cockpit controls, displays, and instrumentation, an example of which is shown Figure 6. In addition, a PC-based out-the-window visual scene is projected onto a screen located in front of each cockpit. These cockpits can be used for air-to-ground strike and air-to-air attack missions and can be used as any mix of friend or foe manned assets.

Simulation Application

Up to this point, much of the discussion has focused on the need for using simulation to assess UAV technologies and the simulation tools that will be used for these assessments. The remaining focus of this paper will be on a UAV simulation study that will be utilizing the previously mentioned simulation tools. This study is part of an initiative called a Long Term Technology Project (LTTP).

An LTTP is an international working group comprised of representatives from Germany, France, the United Kingdom and the United States. The purpose of an LTTP is to collaborate on the research of technologies whose maturation may lead to the development of future technologically superior, conventional weapon systems. Currently, there are several LTTP arrangements in place to address various technology areas. For example, aging aircraft issues, air refueling technologies, aircraft survivability, and high power microwave weapons. The simulation capability being developed within AVTAS will apply to the Unmanned Air Vehicles for Offensive Missions (UAVOM) LTTP.

The UAVOM LTTP will utilize simulation to fulfill the following key objectives:

- Explore operational and technical issues critical to the cost effective use of UAVs for offensive missions.
- Assess the impact of emerging technologies and current systems in post-2015 scenarios to aid in the development of future UAV systems.
- Gain insight on how LTTP members solve, implement, and operate UAV simulations.
- Apply the lessons learned from the partner countries to each nation's individual research projects.

Additionally, the UAVOM LTTP will use each nation's simulation results to potentially create, modify, and improve current doctrines associated with the deployment of UAVs.

Because UAV research encompasses a wide range of areas, it was necessary for the UAVOM LTTP to categorize this research in order to identify where simulation could be most effective. These categories are shown in Table 1. Although

Table 1– UAVOM LTTP Technology Areas
(Technologies that are addressed in
this simulation are in **bold**)

Level of Autonomy	**Mission Planning and Control**
Vulnerability	**C4I Integration**
Interoperability	*Data Link Issues*
In-flight Refueling	**Situational Awareness**
Role of the Operator	**Mixed Fleet Operations**
Intelligent Flight Management	*Terminal Area Operations*

this table is not all-inclusive, it does cover many of the principal areas of interest currently being explored by researchers.

Since the technology areas in Table 1 are already being investigated within each nation, the intent of this LTTP is to not duplicate any of this current research. Rather, it is to develop a unique set of simulation experiments whose results can be used to augment current research areas or to open up new avenues of UAV research within each nation. The United States' simulation experiment will utilize the previously discussed simulation tools to address several of the UAVOM LTTP technology areas.

Figure 7 – Notional future strike mission

Simulation Experiment

The objective of the United States' simulation experiment is to evaluate the role and capabilities of combat UAVs in a realistic, mixed fleet, combat environment. A mixed fleet environment, for this experiment, is the use of both manned and unmanned airborne platforms in the same airspace acting as a coordinated strike package to achieve a common set of objectives.

Figure 7 shows an artists rendition of a future strike mission and acts as an example of mixed fleet operations. Because of the density and lethality of future ground threat systems, it would not be feasible for a manned aircraft to ingress into the hostile area to destroy a high value target. Rather, the manned strike package would be used as the second attack group and the UAVs would be tasked to ingress into the dangerous region. The job of the UAVs then would be to neutralize the hostile ground threats and clear a safe path for the manned aircraft to deliver a weapon against the high value target. In addition, the UAVs would also be working as Information, Surveillance and Reconnaissance (ISR) systems and relaying current targeting information to the manned vehicles. This type of strike package provides the least risk and largest attack payoff for airborne weapon systems.

Using the scenario depicted in Figure 7, the scope of the U.S. simulation experiment is as follows:

- Create a combat environment that allows for the interaction of both manned and unmanned combat air vehicles to engage mobile and/or highly defended targets.
- Utilize an operator control station for monitoring and guiding UAVs through their mission profile.
- Assess the amount of UAV operator interaction required for controlling UAVs that are operating alone or with manned airborne assets.
- Assess the types of information required by the UAV operator (from both manned and unmanned sources) in order to assess the progress of the mission and plan assignments for the UAVs.
- Dynamically re-task or re-route assets based on changes in the mission environment.

In addition to these items, this simulation will be demonstrating to today's warfighter community the importance of UAVs and how they can be used with manned aircraft to more effectively and efficiently execute a mission.

To create this simulation, there are several technical challenges that need to be overcome. These are:

- Developing a communication's architecture that will enable data passing between the manned assets, the UAVs and the UAV operator.
- Providing targeting information from various sources to the UAV control station in a way that will not overwhelm the UAV operator or make it difficult for him to maintain situational awareness of the battle space. This is critical in order to be able to dynamically re-route the UAVs as the battle space changes.
- Managing the mission timeline when unforeseen events such as "pop-up" (unplanned) targets or the loss of a vehicle require the mission objectives and routes to be changed. This coordination needs

to occur between both the manned and unmanned vehicles.

- Determining the role of the manned and unmanned vehicles for such things as target identification and battle damage assessment

Table 2– Experiment 1 Test Matrix

Vehicle Type	Sensors	Weapons
4 Strike	Radar	TS 2
2 Strike 2 Sensor	Radar TS 1	TS 2
4 Strike 1 ISR	Radar TBD	TS 2

TS 1: Trade-off between enhanced radar, SAR, and IR sensors.

TS 2: Trade-off between short range and long range weapons.

Because these challenges are primarily concerned with the coordination of objectives between the manned and unmanned airborne assets, the overarching question that must be addressed is the role of each manned and unmanned asset in the coordinated strike package and the risks associated with each role. In order to begin addressing many of these issues, the United States' simulation study will be divided into two separate experiments.

Experiment 1 will evaluate the UAV operator's ability to interpret different sources of sensor data being sent to his control station and then using this data to request and assign new UAV flight routes to accomplish the mission objectives. This experiment only utilizes UAVs and the test matrix is shown in Table 2. There are two different trade studies being examined within this study. These are denoted as "TS 1" and "TS 2" in the table and will be looking at various levels of capability in both sensors and weapons. The sensor trade study (TS 1) will assess the operator's ability to make decisions as more detailed targeting information is provided. The weapon trade study (TS 2) will be used to influence the operator's decision process. The long range weapons will enable the operator to task his UAVs at distances outside the lethal range of the threat systems and thus allow him more time to make decisions. The short-range weapons, on the other hand, will force the UAVs further in to the threat territory where the risk of being engaged is greater and thus require the UAV operator to make quicker decisions about the changing battle space.

Experiment 2 will analyze how manned and unmanned vehicles, along with the UAV operator, can be used as an integrated attack system as well as analyze how these interactions affect the mission timeline. The test matrix for this experiment is shown in Table 3. This experiment uses the same UAV trade spaces as Experiment 1 and utilizes both manned and unmanned vehicles, the only difference being that this experiment will only be using two UAVs and both will be acting as strike vehicles. The two UAVs will be used with the two manned vehicles to form a four-ship strike package. In addition, since the focus of the simulation experiment is not on the manned vehicles, their configuration will be held constant throughout the test matrix. Through these two experiments, several of the aforementioned technology areas, shown in bold in Table 1, will be addressed either directly or indirectly.

Development Status

The UAV simulation capability being developed within the AVTAS laboratory is an on-going effort that began in October 2001. The hardware within the laboratory, which includes the laboratory itself, four Mini-crew stations (MCS) and an operator station console were completed in December of

Table 3– Experiment 2 Test Matrix

Unmanned Vehicle Type	Sensors	Weapons	Manned Vehicle Type	Sensors	Weapons
2 Strike	Radar	TS 2	2 Strike	Radar/SAR	TS 2
2 Strike	TS 1	TS 2	2 Strike	Radar/SAR	TS 2
2 Strike 1 ISR	TS 1 TBD	TS 2	2 Strike	Radar/SAR	TS 2

TS 1: Trade-off between enhanced radar, SAR, and IR sensors.
TS 2: Trade-off between short range and long range weapons.

2002. Since that time, the focus of the development effort is to bring together the previously discussed simulation tools to create an integrated UAV simulation environment. Currently, the MCS cockpits, JIMM and a SAR radar simulation are integrated and operational. The current phase of UAV simulation development involves:

- the creation of a generic UAV simulation scenario for JIMM,
- integration of the LNAVSIM tool with JIMM and the OVI station,
- integration of the SAR radar simulation with the OVI station,
- and the integration of the FLIR radar simulation with the MCS stations and the OVI station.

The current schedule allows for the complete integration of these tools to coincide with the UAVOM simulation experiment, which is scheduled to begin in January of 2005.

Conclusions

The modern emphasis on UAV development and the increasing number of new technologies necessitates an extensible simulation toolset to evaluate the efficacy of emerging concepts before they are fielded as operational systems. Through plug and play simulation hardware and software, the AVTAS Laboratory is developing a reusable simulation capability that will enable researchers to investigate the best mix of UAV technologies and capabilities required for this class of vehicle to execute a variety of missions. The plug and play design philosophy of this UAV simulation capability, as well as its tie to the larger simulation-based research and development process, will make it a critical tool for both design engineers and analysts to assess the operational utility of these vehicles.

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