



Demonstration of Submarine Control of an Unmanned Aerial Vehicle

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How often does a person onboard a submarine get to fly an airplane? In a unique demonstration in June 1996 off the California coast, pilots and payload operators in the torpedo room of a fast-attack submarine, the USS *Chicago* (SSN 721), flew a Predator Unmanned Aerial Vehicle (UAV) in support of a Special Operations Forces warfare exercise. The Applied Physics Laboratory was responsible for the initial concept of the UAV control system located on a submarine and then led the extremely successful 10-month effort to develop and install this system and conduct an at-sea demonstration.

(Keywords: At-sea demonstration, Predator, SSN-UAV, Submarine, UAV.)

INTRODUCTION

Imagine the benefit of giving a forward-deployed fast-attack submarine operating in the shallow littoral zone a 25,000-ft-high, movable periscope (say, out to 100 nmi from the submarine). The stealthy submarine would now be able to extend its “eyes” far out to sea and inland to support a variety of missions, such as tactical and intelligence reconnaissance and surveillance, Special Operations Forces (SOF) support, strike support, and battle damage assessment. This capability was demonstrated in June 1996 in an exercise near San Clemente Island, California, involving a fast-attack (SSN 688 class) submarine, the USS *Chicago* (SSN 721), and the Predator Unmanned Aerial Vehicle (UAV). During this exercise, operators onboard the submarine took control of the UAV and demonstrated real-time piloting, payload control, and viewing of real-time imagery. The submarine then used the UAV to support an SOF warfare exercise (SOF laser

designation of target for destruction by aircraft with laser-guided munitions) against a land-based movable missile site. The SOF team commander, who was located on the submarine, used the Predator’s imagery in real time for mission planning; target location, identification, and tracking; monitoring of SOF team ingress and egress; and viewing of target destruction and battle damage assessment. Selected imagery was relayed in near real time to the Joint Task Force Commander (JTFC), who was 3000 miles away.

DEMONSTRATION BACKGROUND

In August 1994, the Office of Naval Intelligence (ONI) requested that the Laboratory’s Ocean Data Acquisition Program assess feasibility and develop a conceptual design for a demonstration of interoperability between a fast-attack submarine and the

Predator UAV. The objectives and constraints of this demonstration were to

- Establish a submarine-UAV data link, demonstrate submarine control of a UAV vehicle and its payload, and demonstrate submarine receipt of UAV and payload status and real-time imagery.
- Pilot the UAV by using existing UAV mission planning software to modify navigation way points. Although real-time piloting was not a requirement, this capability was, in fact, demonstrated.
- Provide submarine operators with the ability to select and process UAV imagery and to fuse UAV imagery with other submarine data (such as periscope imagery or electronic surveillance data from existing submarine antennas). The Submarine Joint Deployable Intelligence Support System (SUB JDISS) was to be used for onboard data fusion and for interfacing to the submarine's satellite communications equipment for subsequent off-board data transmission.
- Demonstrate the submarine-UAV data link to a maximum of 85 nmi.
- Demonstrate operational and tactical benefits achieved in SSN missions with UAV support (support an operational exercise).
- Ensure the compatibility of the SSN-UAV demonstration system with all SSN 688 class submarines.
- Complete the entire demonstration in less than 1 year, including design, development, land testing, submarine installation, and at-sea technical and operational exercises.
- Achieve these goals without changes to air vehicle hardware or software.

The feasibility assessment, concept design, cost estimate, and 10-month development plan were presented in November 1994 to ONI and are documented by Rau et al.¹

In a January 1995 letter to the Joint Program Office (JPO) for Cruise Missiles and UAVs, Admiral Borda, the Chief of Naval Operations (CNO), stated the Navy's need for a marine variant of the Predator UAV (called UAV "marinization"), and directed the JPO to conduct a detailed study for three levels of operational demonstrations:

- Level I: connectivity with land-based UAV assets to commanders at sea
- Level II: shipboard control of land-based UAV assets (vehicle and payload)
- Level III: shipboard employment (launch and recovery) of UAVs

Three options were initially considered for the Level II demonstration: (1) positioning a ground station on a surface ship (approximate 6-month schedule); (2) going forward with the 10-month APL concept for the

SSN-UAV interaction demonstration; or (3) integrating with the Hunter UAV's prototype data link/workstation (approximate 24-month schedule). Rear Admiral Jones, Director of the Submarine Warfare Division (N87), strongly endorsed the APL proposal in an April 1995 letter to the Deputy CNO (N8):

I feel strongly that the integration of an SSN and UAV would be a tremendous tactical asset The UAV marinization option which utilizes an SSN has the following advantages over the other candidates: enables covert line-of-sight control of the UAV from waters which may be denied to surface units; and provides real time intelligence onboard the SSN which could greatly enhance war fighting capability in a variety of missions such as SOF, strike warfare BDA, and targeting of mobile targets A successful near term demonstration could become an important battle group capability.

The JPO also recommended funding of the Laboratory's near-term demonstration as part of the Predator marinization.

The general opinion of APL and sponsors was that demonstrating Level II marinization from a submarine was the hardest problem. If shipboard control of land-based UAV assets could be demonstrated from a submarine, with its lack of internal and external space and its operational constraints, then such control should be possible for any tactical platform at sea. In April 1995, APL's concept for SSN control of the Predator UAV was selected as the Phase II demonstration in the CNO's UAV Marinization Plan. In August 1995, ONI and N87 jointly funded APL to lead the team effort for the submarine-based technical demonstration. The organizations involved in this team effort and their responsibilities are shown in Table 1.

DESCRIPTION OF THE PREDATOR UAV

The Predator was developed by General Atomics as a 30-month Advanced Concept Technology Demonstration of a medium-altitude endurance UAV. This demonstration was ongoing during the SSN-UAV demonstration. The Predator's primary purpose is to provide near-real-time imagery intelligence to satisfy mission requirements.² The Predator is designed to operate at long ranges (500-nmi radius of action) and for extended on-station times (24 h of continuous coverage at 500 nmi). The UAV system consists of the Predator aircraft and a trailer-housed ground control station (GCS). The baseline sensor payload for the Predator includes infrared and color cameras and synthetic aperture radar (SAR). The SAR was still under development during the SSN-UAV demonstration, and was not offered as a possible payload sensor for this demonstration. Important characteristics of the Predator are presented in Table 2.

Table 1. Major participants in the demonstration of submarine control of a UAV.

| Organization | Area of responsibility |
|----------------------------------|---|
| ONI and N87 | Demonstration sponsors |
| JPO for Cruise Missiles and UAVs | Predator assets |
| SEAL Team One | SOF team for operational demonstration |
| USS <i>Chicago</i> (SSN 721) | Submarine for demonstrations |
| USS <i>Coronado</i> (AGF 11) | Location of the JTFC |
| APL | Technical Lead for development and testing |
| General Atomics | Predator system (under contract to JPO) |
| Naval Undersea Warfare Center | SUB JDISS and interfaces to ship's data |
| Naval Surface Warfare Center | Installation of SSN antenna for UAV control |

Note: JPO = Joint Program Office; JTFC = Joint Task Force Commander; N87 = Submarine Warfare Division; ONI = Office of Naval Intelligence; SEAL = Sea, Air, Land; SOF = Special Operations Forces; SSN = fast-attack submarine; SUB JDISS = Submarine Joint Deployable Intelligence Support System; and UAV = Unmanned Aerial Vehicle.

The Predator supports three types of communications links: C-band line-of-sight (LOS), ultra-high frequency (UHF) satellite communications (SATCOM), and Ku-band SATCOM. The 20-MHz bandwidth of the analog C-band link contains two channels of real-time color video and one audio channel for control and status data, and it supports real-time piloting and payload control. The UHF SATCOM link is limited to 16.5 kilobits per second and supports only low-resolution, low-frame-rate, black-and-white imagery. This link's minimum 6-s control delay makes it unusable for real-time piloting and problematic for payload control. The Ku-band SATCOM 1.544-megabit per second digital link supports 7 frames per second of imagery and is the only link to support transmission of digital SAR data.

The GCS typically includes a dish antenna and a ground data terminal (GDT) to support the C-band LOS link; a Pilot Payload Operator (PPO) for air vehicle and payload control and viewing of imagery; and a Data Exploitation Mission Planning and Communication (DEMPC) system used for mission planning and validation, data recording, and imagery processing. The Trojan Spirit II communications equipment may be included to support the Ku-band data link. Figure 1 shows the Predator UAV. Figure 2 depicts the normal concept of operations using the GCS. The concept of operations for sharing the UAV between the GCS and the SSN is described later in this article.

SSN-UAV SYSTEM CONCEPT

APL's concept for the SSN-UAV system included the following:

- Use of the C-band LOS as the communications link between the SSN and the UAV.

- Use of C-band antennas (horn and flat-plate) mounted in a radome on the AN/BRD-7 mast in place of the submarine's AN/BRD-7 antenna. These C-band antennas were mounted on a pedestal that provided antenna pointing and motion stabilization. The SSN-UAV system is linked to the UAV while the submarine is surfaced or at periscope depth with the mast extended so that the radome is above waterline.

Use of low-loss radio frequency (RF) underwater cables from the radome to a modified ship's electrical hull fitting for routing of signals from the antennas to the inboard electronics. An outboard low-noise amplifier was included to overcome the signal losses between the mast-located antennas and inboard electronics.

- Use of the GDT (from General Atomics) for decoding of the proprietary LOS link into two channels of

Table 2. Important characteristics of the Predator UAV.

| | |
|---------------------|--|
| Dimensions | Length: 27 ft Wing span: 49 ft |
| Maximum altitude | 25,000 ft |
| Endurance | 500-nmi radius of operations 24 h on station |
| Sensors | Electro-optical Infrared SAR |
| Navigation | GPS Inertial navigation |
| Communication links | C-band LOS UHF SATCOM Ku-band SATCOM |
| Antennas | Omnidirectional (3 dB of gain) Directional horn (15 dB of gain) |

Note: LOS = line of sight, GPS = Global Positioning System, SAR = synthetic aperture radar, SATCOM = satellite communications, and UHF = ultra-high frequency.



Figure 1. General Atomics Predator UAV.

real-time color video for imagery and one digital channel containing control and status data.

- Use of a subset of General Atomics' ground control PPO station for UAV and payload operation, status and imagery viewing, and UAV data recording. This submarine "mini-PPO" was functionally equivalent to the ground station PPO, except that the submarine PPO did not support actual UAV takeoff or landing.

- Use of additional computer equipment for interfacing to ship data, antenna pointing, and imagery selection, processing, reformatting, and transmitting to the SUB JDISS.
- Use of the SUB JDISS for data fusion and off-board transmission of imagery using the submarine UHF satellite link.

This SSN-UAV system was designed to duplicate all GCS functions except takeoff and landing; that is, it was designed to functionally replace the equipment that filled the 40-ft GCS trailer with equipment fitting on one torpedo room skid and to replace the 3-ft GCS dish antenna with a much smaller but equal or better antenna that would fit into the space available on a submarine mast.

Figure 3 shows the SSN-UAV system installed on the *Chicago*. Figure 4 is a system block diagram. As noted earlier, the data link selected for the SSN-UAV system was the C-band RF LOS link. The C-band link, while suffering from LOS limitations, was the only link to provide real-time piloting and two channels of real-time color video. The UHF link does not support

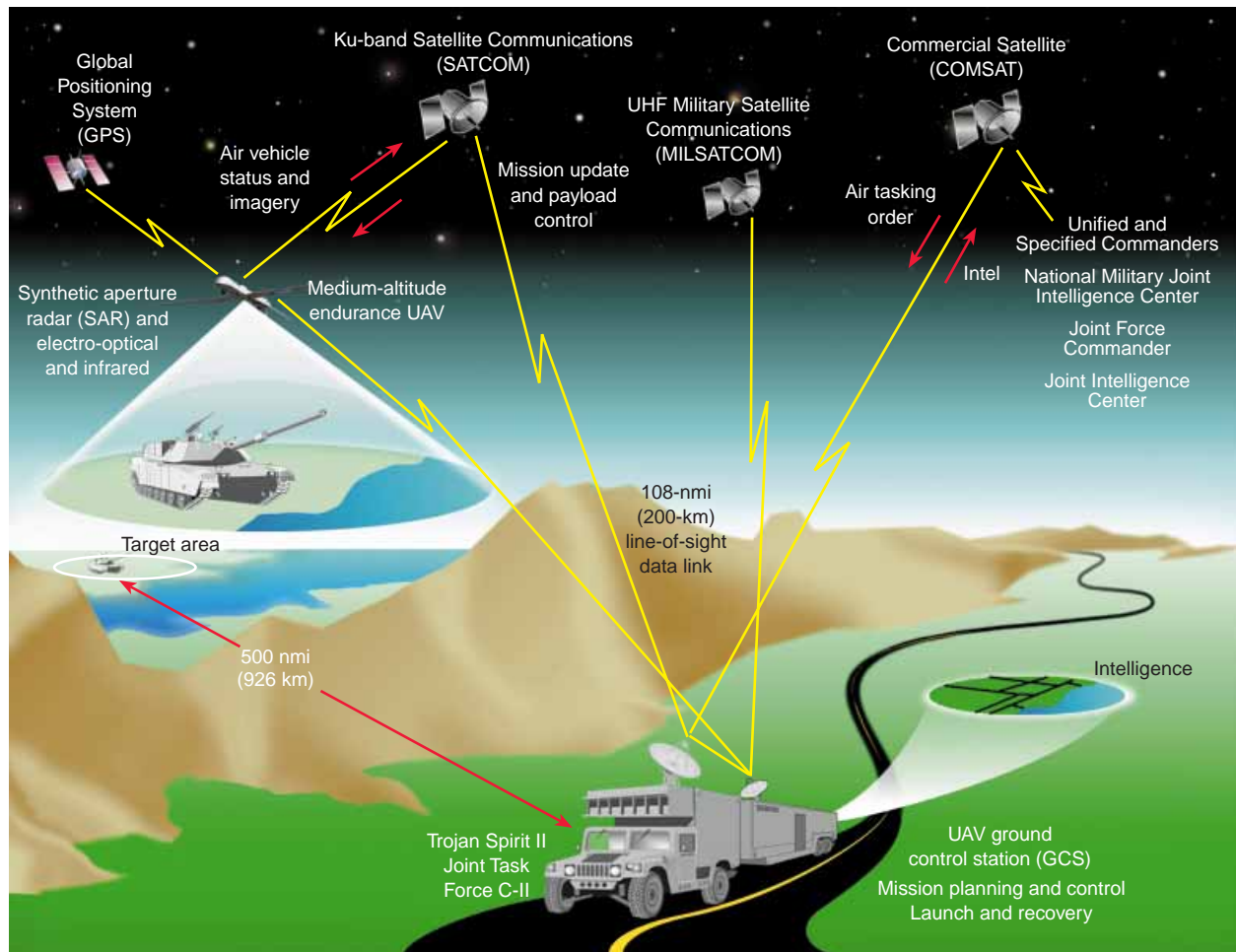


Figure 2. Predator concept of operations.

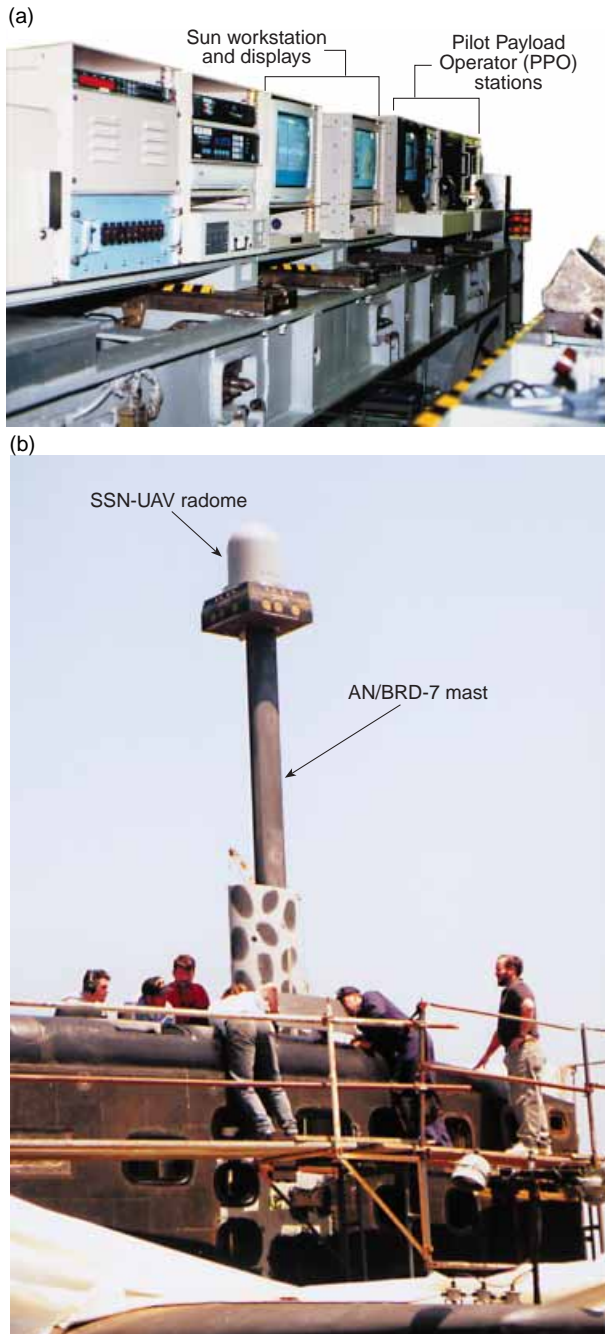


Figure 3. Equipment for the SSN-UAV installed on USS *Chicago*. (a) Torpedo room equipment. (b) SSN-UAV radome mounted on AN/BRD-7 mast.

real-time piloting and provides only a very slow update rate for imagery. The Ku-band link provides flicker rate (seven frames per second) video and SAR data, but was judged too risky since it was still under development during this demonstration.

The SSN 688 class submarine nominally has very limited C-band receive capability and no C-band transmit capability. For this demonstration, C-band receive and transmit capability were added by replacing one of the submarine's existing antennas (the

AN/BRD-7) with a slightly modified commercial off-the-shelf antenna assembly housed in a custom radome. Sea Tel provided the integrated stabilized antenna system (per APL specifications), consisting of outboard-located C-band flat-plate and horn antennas and stabilized pedestal assembly and an inboard-located pedestal controller. The narrow-beam (9°) high-gain (23.4-dB) flat-plate antenna was manufactured by Seavey Engineering Associates, and the wider-beam (30°) lower-gain (15-dB) horn is the duplicate of the Predator's horn antenna. The flat-plate antenna served as the primary communications link and provided the maximum range between the SSN and the UAV. The horn served as a reduced-range backup or for short-range operations. The pedestal provided a full 360° of azimuth coverage and elevation coverage (for both antennas) from -15° to 105° . The 3-axis pedestal compensated for the roll, pitch, and yaw motions of the submarine. A trackball was used for manual pointing of the antenna, but the normal mode of operations was computer-controlled pointing using inputs of submarine heading and position and UAV position. Pictures of the SSN-UAV antenna assembly are shown in Fig. 5, and a block diagram of the overall antenna RF system is given in Fig. 6.

The SSN-UAV antenna assembly was housed in a custom radome. The major requirements for this radome were (1) that it fit within the footprint of the AN/BRD-7 antenna, so that mast closure doors would not have to be redesigned; (2) that it survive hydrostatic pressures of 1000 psi; and (3) that it limit RF losses through the radome at the frequencies of interest. APL specified detailed radome requirements and then contracted with NURAD, who built the radome using cyanate ester with quartz fiber. Measured signal losses through the radome for the LOS C-band frequencies were less than 0.3 dB. NURAD also built the APL-designed base plate, which mated to the AN/BRD-7 mast equipment.

A subset of General Atomics' PPO console was installed in the submarine's torpedo room. This mini-PPO provided UAV and payload control (including way point navigation and real-time piloting), way point mission planning, and display and recording of UAV and payload status and imagery. Commercial and APL-developed software operated on a Sun workstation, also installed in the torpedo room, which supported UAV image selection, enhancement, and reformatting for SUB JDISS compatibility; transmission of imagery to JDISS; communicating with the PPO for exchange of UAV and SSN data; and calculating and transmitting antenna pointing information to the pedestal control unit. The submarine's position was sent to the PPO for use in pointing the UAV's directional horn antenna at the SSN.

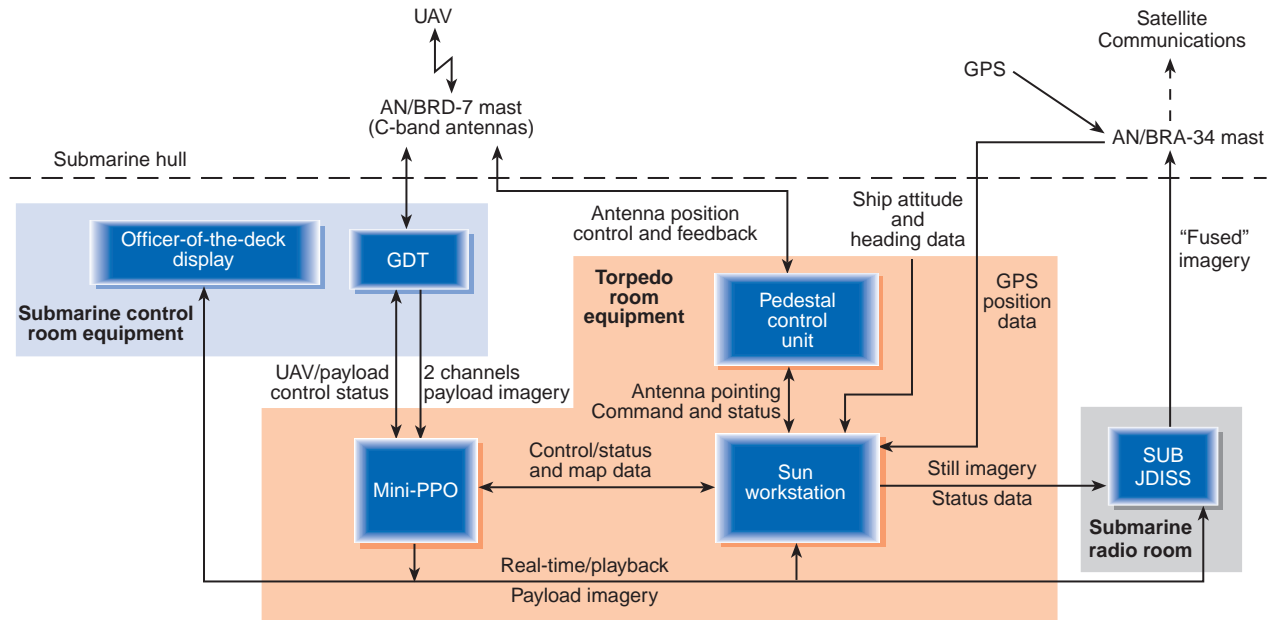


Figure 4. Functional block diagram of the SSN-UAV system. (GDT = ground data terminal, GPS = Global Positioning System, PPO = Pilot Payload Operator, SUB JDISS = Submarine Joint Deployable Intelligence Support System.)

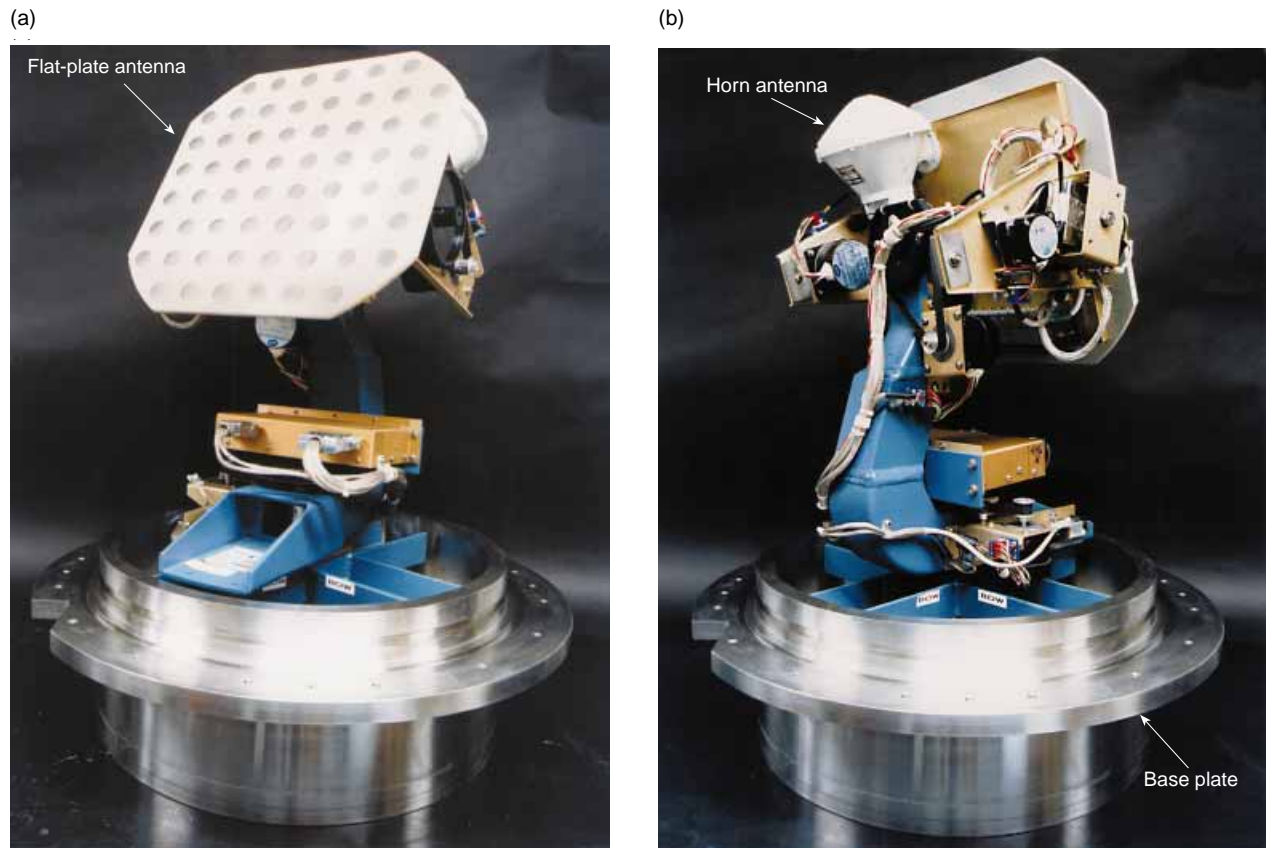


Figure 5. Antennas and pedestal subassembly for the SSN-UAV: (a) front view; (b) rear view. Flat-plate and horn antennas are mounted on a pedestal that provides motion compensation and azimuth and elevation pointing. The custom base plate mates to the submarine's AN/BRD-7 mast.

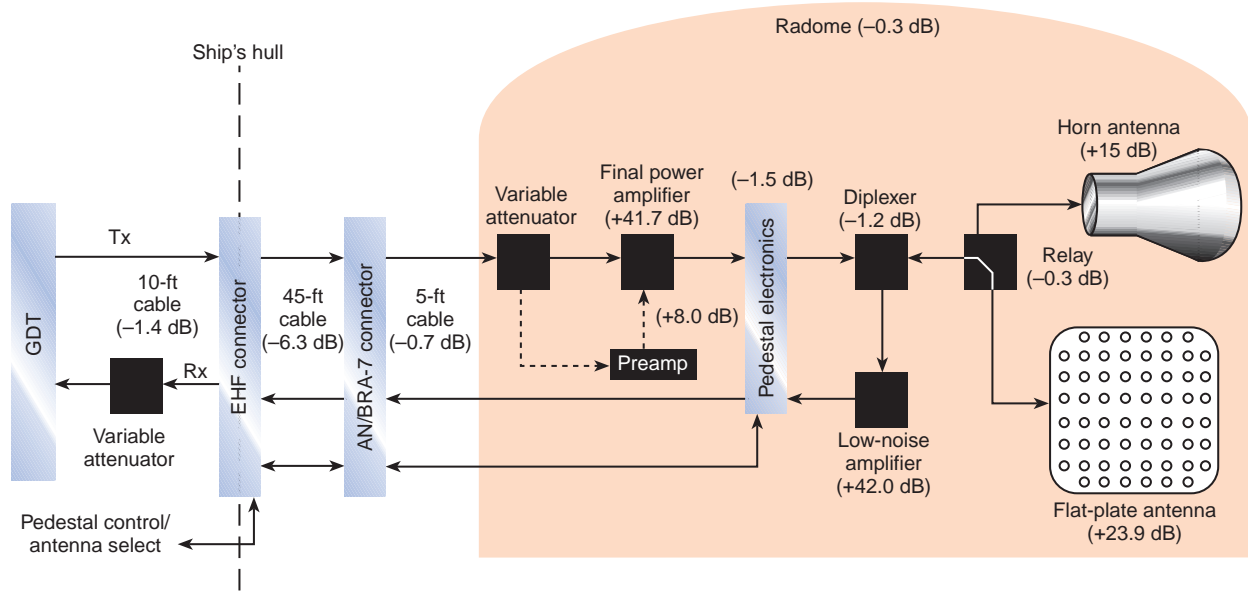


Figure 6. Block diagram of outboard RF system with approximate component RF gains and losses. The signal is received and transmitted by either horn or flat-plate antenna (operator controlled via relay). The low-noise amplifier compensates for receive signal losses from the antenna to the ground data terminal (GDT). The variable attenuator is for adjusting the received signal at the GDT; both variable attenuator and preamplifier adjust the transmit signal. The final power amplifier compensates for transmit signal losses from the GDT to the antenna. (EHF = extremely high frequency.)

The SUB JDISS terminal, located in the submarine's radio room, interfaced directly to the UAV real-time color video and received digital UAV images and pertinent submarine and UAV status data linked via Ethernet to the Sun workstation. SUB JDISS also had a direct connection to imagery collected with one of the submarine's periscopes and was able to fuse these data with UAV data. The SUB JDISS terminal interfaced with the ship's UHF satellite communications equipment for off-board transmission of SSN-UAV data.

SSN-UAV OPERATIONAL CONCEPT

The operational concept for SSN-UAV interoperability is shown in Fig. 7. It includes the following steps:

- The submarine uses its own satellite communications link to request UAV support and to provide time and geodetic location for transfer of UAV control ("hand-off") from the GCS located ashore to the SSN.
- The GCS, located next to the airstrip, controls UAV during takeoff and landing using LOS link.
- During transit to the designated location for the hand-off, the UAV is controlled by the GCS using LOS, UHF, or Ku-band links. If SATCOM communications links are used, then this distance may approach 500 nmi. (Owing to unavailability of equipment and satellite time, the SSN-UAV demonstration was limited strictly to LOS control of the UAV

by the GCS. This limited the hand-off location to within 100 nmi of the GCS, the maximum LOS range supported by the GCS antenna system.)

- The submarine, operating at periscope depth with the AN/BRD-7 mast extended, takes control of the UAV using the C-band LOS link and the established UAV hand-off procedures. Pilot and payload operators in the submarine's torpedo room then have full control of the UAV. Hand-offs and control of the UAV may be at nominal ranges of up to 85 nmi from the submarine's position.
- Established loss-of-link and emergency hand-off procedures are used where the submarine link is unintentionally or intentionally lost.
- Once the submarine's UAV mission concludes, the UAV is flown under submarine control to the predetermined location for hand-off to the GCS ashore.
- The GCS then takes control and returns the UAV to its operational base.

LAND-BASED AND AT-SEA TECHNICAL TESTS OF THE SSN-UAV SYSTEM

Before the at-sea exercise, a ground test of the SSN-UAV system was conducted at Fort Huachuca, Arizona. This test validated complete system functionality and quantified the RF link performance. Also, the newly developed normal and emergency hand-off procedures of the air vehicle (from the GCS to the SSN-UAV system and from the SSN-UAV system to

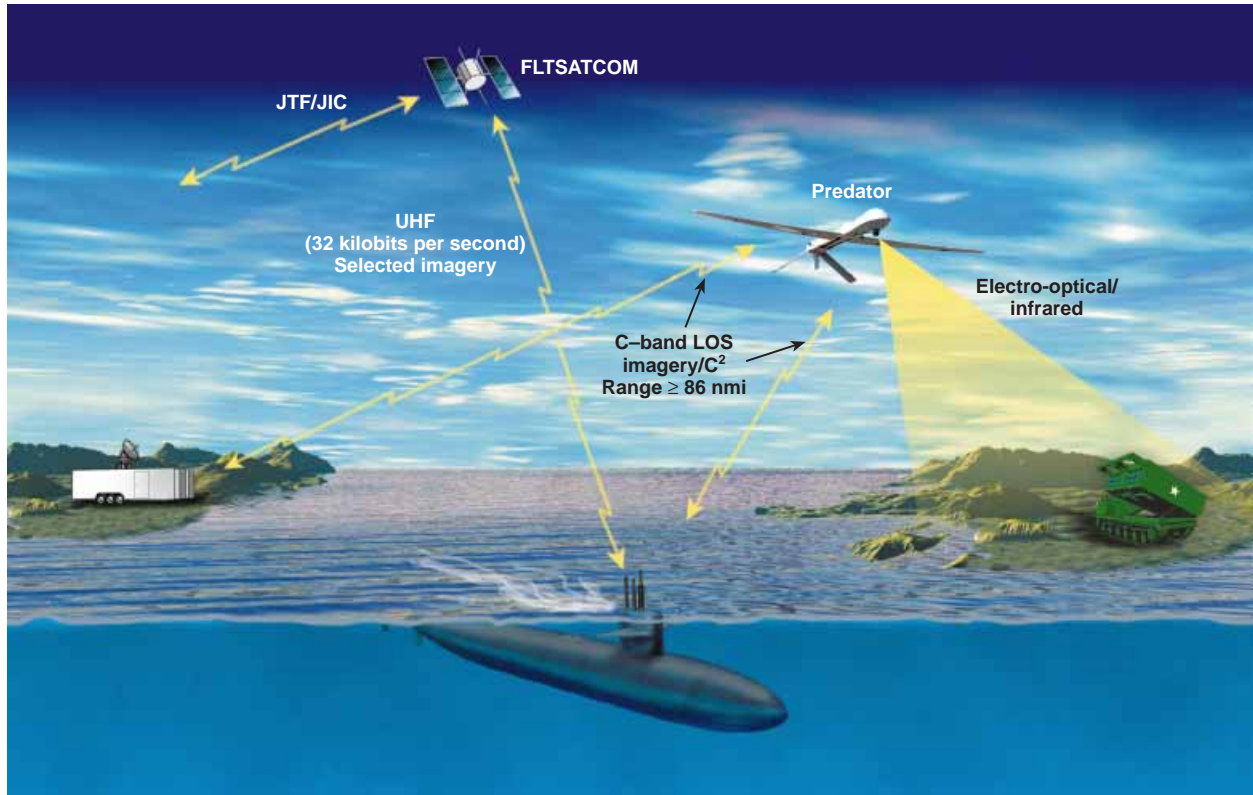


Figure 7. Concept for submarine interoperability with the Predator UAV (FLTSATCOM = Fleet satellite communications, JTF/JIC = Joint Task Force/Joint Intelligence Center Commander).

the GCS) were tested. During this ground test, the air vehicle was flown, under control of the SSN-UAV equipment, out to a range of 92 nmi, which was the limit of available airspace. Based on measurements taken during the test, the maximum RF link range (maximum antenna gain configuration using SSN-UAV flat-plate antenna communicating with the UAV horn antenna) was estimated to be at least 145 nmi, well above the 85-nmi requirement.

After the ground test, the SSN-UAV system was installed on the *Chicago* for the at-sea technical and operational demonstrations. During these at-sea exercises, the GCS ashore was located on San Clemente Island near the runway used for UAV takeoffs and landings, and the *Chicago* operated in the waters around San Clemente. A SEAL (sea, air, land) Navy Special Forces team embarked on the SSN to support the operational demonstration. The USS *Coronado* (AGF 11), underway in the Hawaii operating area 3000 miles away, served as the location of the JTFC for the operational exercise.

The technical tests at sea consisted of submarine operations both at the surface and at periscope depth. These tests primarily involved checks on basic SSN-UAV system functionality, including automatic and manual antenna tracking, switching of

SSN-UAV antennas, display of vehicle status and payload information, control of payload sensors, way point mission planning and mission upload (to the UAV), real-time piloting, and tracking of stationary and moving targets. Various quantitative performance checks also were conducted to assess the quality of the received imagery, to measure the maximum ranges of the RF LOS link for the various SSN and UAV antenna combinations, and to assess the effects of SSN maneuvering on the UAV data link. Significant results of the at-sea technical tests are summarized as follows:

- The SSN-UAV system was fully functional and demonstrated mission planning and way point navigation, real-time piloting and control of UAV payload, and real-time viewing of UAV status (air vehicle and payload) and UAV imagery. Real-time piloting was not part of the original system requirement.
- Numerous hand-offs of the UAV from the GCS ashore to the SSN and from the SSN to the GCS were successfully conducted, including hand-offs both with and without voice communications between the pilot located on the SSN and the pilots located in the GCS. The tests also verified and exercised emergency hand-offs and loss-of-link procedures.

- Periscope-depth submarine maneuvers or blockages from other raised masts did not significantly degrade the SSN-UAV communications link.
- The measured RF link performance for all antenna combinations (UAV omnidirectional antenna, UAV horn antenna, SSN-UAV flat-plate antenna, and SSN-UAV horn antenna) significantly exceeded design requirements. The SSN-UAV antenna system consistently provided better imagery, at significantly greater ranges, than did the GCS antenna system ashore (GCS to UAV ranges nominally limited to approximately 100 nmi for LOS link control).
- During long-range testing, the UAV was flown out to 104 nmi under control of the SSN. This demonstrated maximum range was bounded by exercise constraints, not by SSN antenna performance. These long-range tests indicated that the SSN-UAV data link in the maximum gain configuration (SSN-UAV flat-plate antenna communicating with UAV horn antenna) was not limited by RF design, but rather by the radio horizon. This radio horizon corresponds to a maximum data link range of approximately 170 nmi for a submarine at periscope depth and a UAV operating at 20,000 ft (Spangler³)—well in excess of the 85-nmi system requirement. In fact, the SSN-UAV RF link was still functional at 100 nmi using the lower-gain SSN-UAV horn antenna.

In summary, the technical tests during the at-sea demonstration validated that the SSN-UAV system *met or exceeded* all requirements.

SSN-UAV OPERATIONAL DEMONSTRATION

The overall scenario for the operational demonstration developed by N87 was described by Rear Admiral Jones in an April 1995 letter:

U.S. surveillance in a vital littoral region is stepped up in response to threats from a hostile country to close off a strategic strait which controls access to the region. An SSN is operating in the littoral region with a Special Operations Forces (SOF) contingent embarked. Predator UAVs, flying from an adjacent friendly country, are providing near-continuous surveillance of a strategic island in the strait. A Joint Task Force consisting of a Carrier Battle Group and a Marine Amphibious Group is steaming toward the strait to protect merchant traffic entering and exiting the littoral region. The

Carrier's strike aircraft will not be in range of the strait for another 24 hours.

For the purposes of this demonstration, the littoral region was the waters off of San Clemente Island, and the friendly country and strategic island were different locations on that Island.

The actual events of the operational demonstration were as follows:

- The *Chicago* conducted an all-sensor search off the "hostile coast" using the submarine's electronic surveillance equipment and simulated the detection of hostile forces' RF transmissions from a mobile missile site.
- The SSN then requested (from the JTFC) use of a Predator UAV to conduct surveillance and reconnaissance for SOF mission planning. This request was granted; a Predator was launched using the GCS ashore and then handed off to the SSN.
- The SSN took control of the UAV and used it to locate the missile site. Predator video clips were fused with the simulated electronic surveillance information, and annotated imagery was transmitted via SUB JDISS and the ship's satellite communications equipment to the JTFC embarked on the *Coronado*. The imagery dissemination path is shown in Fig. 8. The SOF tactical commander, stationed on the SSN, also used the UAV for detailed surveillance of the coastline, selection of beach landing sites and routes to target, and monitoring of the disposition of hostile forces.
- The JTFC ordered the SSN to conduct an SOF mission to destroy the missile launcher site (use laser

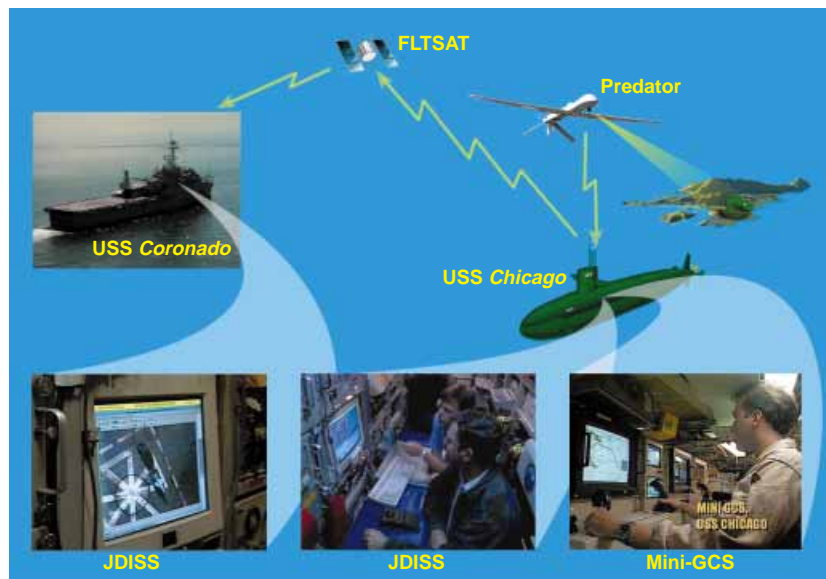


Figure 8. Imagery dissemination path during the operational demonstration. (FLTSAT = Fleet satellite, GCS = ground control station, JDISS = Joint Deployable Intelligence Support System.)

to illuminate target to support an air strike using laser-guided munitions).

- During nighttime operations, the SSN used the UAV to conduct maritime surveillance to verify that the area was clear before surfacing. The SSN surfaced, the SOF team was launched, and the SSN then submerged to periscope depth and remained in control of the UAV. Radio communications were maintained between the SEAL team tactical commander, located on the submarine, and the embarked SOF team.
- The SEAL team tactical commander used UAV infrared imagery to monitor SOF team ingress. An interfering contact (a private yacht moored off San Clemente Island) was observed on the UAV imagery, and the SEALs were directed to an alternate landing site. After landing, the SEAL team was unable to reach the target area on the first night and remained concealed during the following day.
- During the following day, hostile forces repositioned and hid the mobile missile and launcher. The SSN used the UAV to locate the hidden target and to relay target movements to the SEAL team. Submarine operators then observed the missile being moved once again and saw that preparations were being made for missile launch. Selected imagery showing the missile in launch position was transmitted to the JTFC. The JTFC ordered a precision strike against the target, with the SOF team using a laser to designate the target.
- The target was destroyed (an air strike was simulated by detonating charges around the mobile missile). The SOF commander onboard the SSN monitored the strike and assessed battle damage in real time. The assessment was relayed to JTFC in near real time.
- The SOF commander used the UAV to aid the SOF team's egress by monitoring reaction of hostile forces.

Figure 9 shows highlights from the operational demonstration.

This operational exercise conducted with the *Chicago* and the Predator UAV conclusively demonstrated that an SSN can employ UAVs for real-time tactical intelligence. Furthermore, employment of a UAV can add significant capability to a variety of submarine missions. It can add precision target location and surveillance, reconnaissance for real-time SOF mission planning, relay of real-time intelligence to a deployed SEAL team, real-time situational awareness for the SEAL team commander deployed on the SSN, and real-time battle damage assessment. An important result for the SSN and UAV Concept of Operations derived from this demonstration was that the on-scene tactical commander must have direct real-time control of the UAV.

SUMMARY

The Laboratory successfully planned and completed the first-ever demonstration of interoperability between a UAV (Predator) and a submarine (*Chicago*). This task was accomplished in 10 months, and all requirements for the demonstration were met or exceeded. The effort included development of a mast-mounted low-loss radome housing a size-limited, motion-compensated steerable C-band antenna with sufficient gain to achieve data link ranges in excess of 100 nmi; an RF system design using low-noise amplifiers and low-loss cables to account for signal losses associated with the submarine installation; smaller UAV control consoles compatible with a torpedo room installation; and procedures for transferring UAV control between the GCS and a moving SSN. During the demonstration, UAV pilots aboard the SSN, submerged (at periscope depth), took control of both the Predator and its sensor payload and used the UAV to support an SOF team that had embarked from the SSN and headed ashore to help destroy a simulated mobile land-based missile site. The SOF team commander, located on the SSN, used real-time data and imagery from the UAV for reconnaissance of potential beach landing sites and land routes to the target; for monitoring of the location, movements and readiness (for launch) of the mobile missile; for real-time battle damage assessment; and for observing the SOF team ingress and egress and the location and reaction of hostile forces. In addition, selected UAV imagery was transmitted in near real time via satellite to the JTFC located 3000 miles away.

This type of demonstration showcases APL's capability for responding quickly to sponsor requirements to design, develop, and deploy operational systems that work, and work well, the first time. This message from Rear Admiral E. P. Giambastiani (N87) was received in July 1996 after the test:

Congratulations to the crew of USS *Chicago*, SEAL Team One and the Johns Hopkins University Applied Physics Laboratory for the extremely successful completion of the SSN-Predator Unmanned Aerial Vehicle Demonstration. The recent at-sea demonstration of a submarine's ability to fly a Predator UAV and control its payloads in support of a special warfare exercise is unprecedented in the history of the submarine force and the United States Navy.

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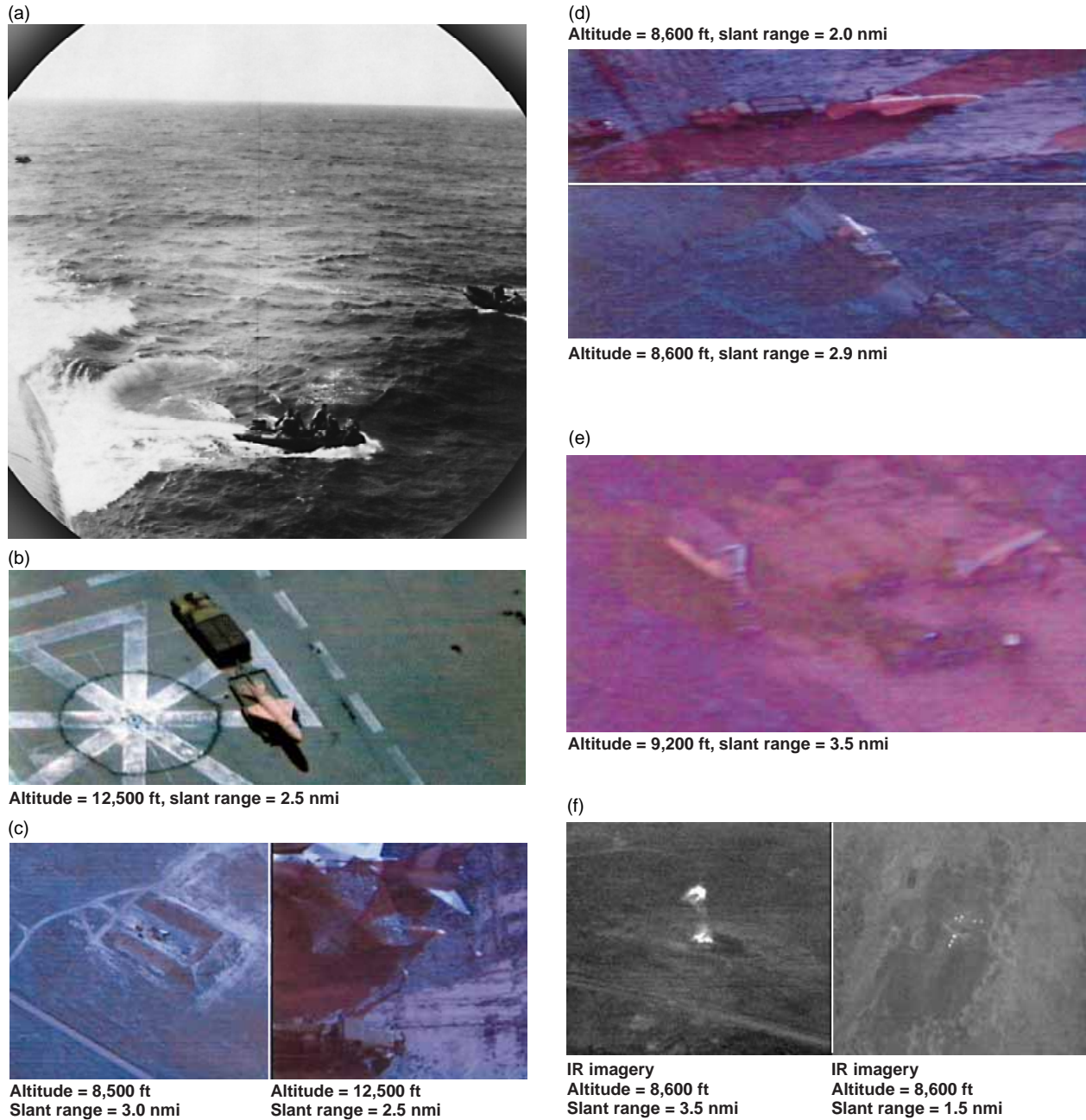


Figure 9. Highlights of the operational demonstration, showing the UAV under control of submarine operators and UAV imagery viewed in real time by the SOF team commander located on the submarine. UAV imagery also was transmitted in near real time (via satellite) to the JTFC, who was 3000 miles away. (a) SEAL team practicing deployment (submarine periscope image). (b) UAV used to locate and image the hidden threat missile system. (c) After the threat missile is moved, the UAV again locates it. (d) UAV tracks repositioning of target. (e) UAV images the “ready-to-launch” missile. (f) UAV images are used by SOF commander for real-time viewing of target destruction and for battle damage assessment.

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