UAV Requirements and Design Consideration

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1. SUMMARY

This paper deals with the UAV requirements based on the battlefield experiences. UAV roles in tactical areas and constraints, which affect the UAV mission to be conducted, are explained and suggestions are given. Constraints; such as environmental conditions, effects on UAV missions, battlefield situations, operational restrictions and technological limits are overviewed.

Based on the current applications and systems, some remarks are presented. Considering the future requirements; air vehicle performance, data link and expected payload specifications for a general UAV system are addressed. Assessments and recommendations are given for system design consideration.

2. INTRODUCTION

There have been increasing demands in modern world to use UAV systems as Intelligence, Reconnaissance, Surveillance and Target Acquisition Systems. Although requirements for UAVs change based on the missions to be carried, expectations are generally similar for each type. Cost-effectiveness, reliability, maintainability, usefulness and operational availability are some of the requirements that all systems should have. Besides these, all UAV system should also fulfill certain basic requirements, as outlined below:

- Performing efficient surveillance and reconnaissance missions for the armed forces
- Day and night operations
- Operating in a wide range of weather conditions
- Various altitude operation
- Beyond Line-of-Sight (BLOS) operation
- Real-time operation
- Multi-mission capability, etc.

These requirements help to define the UAV system specifications in terms of the performance parameters of the following basic subsystems:

- Air vehicle
- Ground control station
- Payloads
- Data link
- Support equipment

Performance parameters are closely interrelated and usually shape these subsystems. At the beginning of the program definition phase, requirements are always beyond the technological advances. However, an optimum cost-performance system definition can be reached by adequate trade-off studies, taking operational concepts and technological capabilities as parameters.

Requirements and system specifications for each subsystem are considered in the next section of this paper. Following these assessments, general issues such as reliability, availability, maintainability, mobility, transportability, deployability, sustainability, environmental conditions, survivability, safety, interchangeability and modularity aspects of UAV systems are examined.

3. SUBSYSTEMS

3.1 Air Vehicle

Radius of action is defined as the maximum distance that the UAV can travel away from its base along a given course with normal mission payload, carry out its intended mission, and return without refueling, allowing for all safety and operating factors This distance is directly dependent on the level of military unit that will operate the system and will ideally cover their area of interest.

The endurance at the radius of action is an important parameter that defines the coverage of the air vehicle at the specified loiter speed, typical operating altitude and sensor properties. Endurance is mainly dependent on the air vehicle aerodynamic design, and fuel amount carried. Fuel increase capacity is usually a problem since the space and weight available for fuel is limited. The aerodynamic designs for high endurance systems usually result in powered-glider type configurations.

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Total endurance, as the name implies, includes the total time from take-off to landing. This parameter is defined based on the mission duration that user wants to use air vehicle on the sky without landing. A high endurance system usually does not have a high cruise or dash speed and may spend a considerable time during the climb, cruise-out, cruise-back and descent phases, especially when the radius of action is far.

<u>Typical operating altitude</u> can be defined as the altitude where the specified payload performance (e.g. image quality) and coverage can be obtained with the desired mode of operation (through data link or autonomous recording). Higher altitudes are desirable for better coverage, survivability and line-of-sight for data link operations. However, there are several limitations for achieving a high operating altitude. Apart from the payload technical limitations, the higher altitudes may necessitate the use of specially treated piston engines, or even turbine engines. Turbine engines have higher power-to-weight ratios and lower specific fuel consumption, but the costs associated are usually 3-4 times of a comparable piston engine.

Operational altitude also depends on the air traffic control limitations. It should not be forgotten that unmanned air vehicles are dangerous objects for manned air vehicles in the sky. Therefore this parameter should be considered in terms of air traffic control.

<u>Maximum altitude</u> is important especially if operations over mountainous terrain are involved. The same limitations for the operating altitude also apply for the maximum altitude. One important consideration for the maximum altitude is that it is a service altitude, meaning a 100-feet/min-climb rate, and not the absolute altitude, which takes a long time to achieve.

The <u>cruise and maximum speed</u> is dependent on the engine power and aerodynamic design of the air vehicle. As mentioned before, a high endurance requirement is conflicting with a high speed requirement since high endurance designs usually have efficient small engines (compared to their size) and big wings with high drag. Cruise speed requirements are driven by the timeliness of mission.

<u>Loiter speed</u> is usually the optimum speed for endurance and is somehow slow (close to the stall speed). The loiter speed directly affects the payload coverage area.

<u>Climb rate</u> is related with the speed and altitude performance of the air vehicle. It is an operationally important parameter especially when the terrain to clear is close and/or steep. A high climb rate also improves the survivability of the air vehicle.

3.2 Ground Control Station

The Ground Control Station (GCS) is the operational control center of the entire UAV system (Figure 2). It controls the launch, flight and recovery of the air vehicle, receives and processes data from the payloads, controls the operation of those payloads (often in real time), and provides the interface between the UAV system and the outside world (6,7).

Some of the expected functions of a GCS can be described as follows:

3.2.1 General

GCS should

- provide an open system architecture so that can support the future requirements; as the system expands in the future, the system architecture should support it without restructuring the GCS completely.
- be scalable so that it can be used in different platforms (ground, airborne, ship).
- be modular so that the system attributes can be changed by physically changing modules.
- be flexible so that as the user and mission requirements vary, the system attributes can be easily changed.
- be capable of executing maintenance software and displaying appropriate status results.
- have ergonomically designed operator controls and displays.
- be capable of operation within the specified environmental conditions.
- be easily deployed and transported.

3.2.2 Mission Planning, Control and Monitoring

GCS should

- have the functionality to allow the operator to generate and process UAV mission plans.
- permit dynamic mission and payload retasking during all phases of operational mission execution.
- provide the system functionality necessary to upload a flight route plan and payload plan to the UAV via the selected system data link as well as direct ground connection.
- automatically check the validity of the intended mission plan prior to being uploaded including altitude constraints, payload constraints, data link range constraints, airspace restrictions, fuel

limitations, threat constraints, data link terrain masking effects, and Loss of Link Plan.

- have the capability to control and monitor AV, payload, data link, and C2 interfaces during the execution of a mission.
- have the capability to control and monitor multiple UAVs.
- pass control of a UAV to another GCS, and take control of a UAV from another GCS.
- implement an emergency action plan to control the AV during equipment failures.
- monitor payload and telemetry data in real-time, and record all the data for future review and processing.
- receive, process, display and exploit the payload output data.
- display data on the same monitor from more than one payload simultaneously.

3.2.3 C3 System Interfaces

GCS should

- provide interfaces with various C3 systems to satisfy the operational requirements.
- manage all aspects of C3 system interfaces to include receiving, processing, and transmitting tactical information.

3.2.4 Safety and Security

GCS should

- have appropriate cautions and warnings if the UAV system enters into an unsafe operating mode.
- provide the required information to allow the operator to maintain safe separation from other aircrafts (manned or unmanned).
- be capable of restoring power in sufficient time to avoid loss of UAV control during power outages.
- be designed to protect its communication and data links against enemy Electronic Warfare (EW) threats and physical destruction.

3.3 Payloads

The term "payload" is referred to the equipment that is added to the UAV for the purpose of performing some operational mission (Figure 2). In other words, the equipment for which the basic UAV provides a platform and transportation. This excludes the flight avionics, data-link and fuel.

Using this definition, the payload capacity of a UAV is a measure of the size, weight and power available to perform functions over and above the basic ability to take-off, fly around and landing.

The types of payloads carried by the air vehicle are defined by the different mission requirements of the user. Reconnaissance payloads are the most common used by UAV systems and are of the highest priority for most users. The primary payload technologies for reconnaissance mission are Electro-Optic (EO), Infrared and Synthetic Aperture Radar (SAR). The key issues associated with them are; having the resolution to see far enough and at the same time over a wide enough area, and having a payload that is small, light, low power consumption and at an affordable price, such that a UAV can carry it for a period long enough to satisfy the end users' needs. Additionally, in conjunction with other sensors, such as range finders, and the UAV's navigation system, the payload may be required to determine the location of the target with a degree of precision that depends on the use to which the information will be put (6,7,8).

For the users and designers of UAV systems, choosing the optimum payload for the mission requirements is of prime importance. The relative advantages of the sensor types and their potential for satisfying a range of common mission goals should be evaluated. Technology is advancing rapidly in many sensor and signal processing fields and the probability (potential) for new solutions to current problems should be considered.

Some mission require to put and control more than one payload at same time. But AV size, data link and interface limitations and GCS control capabilities allow to have this request.

Whatever the operational requirements are for payloads, the other important point is to have payload modularity. In another words, different types of payloads such as reconnaissance, Electronic Warfare (EW), mine detection, NBC, meteorology and etc. should be easily plugged in the AV without SW and HW modifications.

Having payload data in GCS is not sufficient itself. Evaluated data should also be disseminated to the active units in real time through the well-established C^4I network.

3.4 Data-Link

The data-link is a key subsystem for any UAV system. It provides two-way communication, either upon demand or a continuous basis. An up-link provides control of the air vehicle flight path and commands to its payloads. The downlink provides both a low data rate channel to acknowledge commands and transmit status information about the air vehicle and a high data rate channel for payload data such as video and radar.

The data-link typically consists of two major subsystems; the Air Data Terminal (ADT, the portion of the data-link that is located on the AV) and the Ground Data Terminal (GDT, the equipment on the ground, (Figure 2)). Payload data can also be received through the use of passive remote video terminal (Figure 3).

On a battlefield the UAV system may face a variety of EW threats, including direction finding used to target artillery on the ground station, anti-radiation munitions (ARMs) that home on the emissions from the GDT, interception and exploitation, deception and jamming of the data-link. It is highly desirable that the data-link provides as much protection against these threats as reasonably can be afforded.

Depending on the mission and secenarios, the desirable attributes for a UAV data-link can be summarized as follows (6,7):

i. Worldwide Availability of Frequency Allocation: Operate on frequencies at all locations of interest to the user in peacetime as well as being available during wartime.

ii. Resistance to Unintentional Interference: Operate successfully despite the intermittent presence of in-band signals from other RF systems.

iii. Low Probability of Intercept (LPI): This is highly desirable for the up-link, since the GCS is likely to have to remain stationary for long periods of time while it has air vehicle(s) in the air, making it a target for artillery or homing missiles if it is located.

LPI can be provided by frequency spreading, frequency agility, power management, low duty cycles and using directional antennas.

iv. Security: Unintelligible if intercepted, due to signal encoding.

As a general rule, it appears that security is of only marginal value in a UAV data-link. However, some intelligence missions could introduce security requirements.

v. Resistance to Jamming: Operate successfully despite deliberate attempts to jam the up and/or downlink.

The overall priority of anti-jam capability depends on the threat that the UAV is expected to face and the degree to which the mission can tolerate jamming.

vi. Resistance to Deception: Reject attempts by an enemy to send commands to the air vehicle or deceptive information to the GDT.

Deception of the up-link would allow an enemy to take control of the air vehicle and either crash, redirect, or recover it. Deception of the up-link only requires getting the air vehicle to accept one catastrophic command (e.g., stop engine, switch datalink frequency, change altitude to lower than terrain, etc.). Deception on the downlink is more difficult, since the operators are likely to recognize it. Resistance to deception can be provided by authentication codes and by some of the techniques that provide resistance to jamming, such as spread-spectrum transmission using secure codes.

Line-of-Sight range constrains, AV/GCS relative position, link availability, data characteristics, EW environments and installation requirements are the main characteristics to define data link for a UAV system (6). Data link can be established by hub/prime site deployments and utilization of relays (ground, airborne, satellite) (Figure 3). Operational cost, missions, deployment area and above characteristics are important parameters to choose the means that extend the mission radius. Since users never prefer link loss between air vehicle and ground control station during real time operations, both telemetry data and video link should be well established.

Since the interaction between the data-link and the rest of the UAV system is complex and multifaceted, the design tradeoff between them should occur early in the overall system design process. This allows a partitioning of the burden between the data-link, processing in the air and on the ground, mission requirements, and operator training.

4. GENERAL UAV SYSTEM REQUIREMENTS AND RECOMENDATIONS

4.1 Reliability, Maintainability, Availability

System reliability is a very important parameter and is a direct result of system hardware and software maturity. Hardware failures and software bugs are common during the development stage of the system and directly effect system reliability. Among the UAV systems, engine and software are seen to be the most critical items. Reliability is especially critical for the bigger and more expensive UAV systems that can carry multiple payloads for extended duration.

Mission reliability is defined as the probability that the UAV system will perform failure-free during all phases of its specified mission, including pre-flight, take-off, cruise-out, payload operation, data link operation, cruise-back and landing (3). Most accidents do occur during the landing phase, and automatic methods of landing are becoming more and more common to reduce human error and weather-related problems. Icing is another common problem that affects the mission reliability.

Another important reliability parameter is the **Mean Time Between Loss** (MTBL) figure, which can be improved by the redundancies in the system. MTBL directly affects the Life Cycle Cost of the UAV system.

Maintainability is the ability of the system to be retained in or restored to operating condition when maintenance is performed by personnel having specified skills using prescribed procedures and resources at each prescribed level of maintenance and repair. Mean Time To Repair (MTTR) or direct maintenance man-hours per flight hour (DMMH/FH) are frequently used parameters to measure the maintainability of a system. Number of LRUs, accessibility features, Built-in-Test (BIT) and other automatic testing utilities improve maintainability.

Operational availability is the probability that a system is operable and ready to perform its intended mission at any given time in the specified operational environment. It is predicated on the design factors of reliability and maintainability, and considers maintenance (preventive and corrective), supply (logistics) and administrative downtimes.

4.2 Mobility, Transportability, Deployability

Mobility, transportability and deployability of UAV systems are largely determined by the existing operational requirements and available infrastructure.

Mobility is the capability of the system to be moved from place to place while retaining the ability to fulfill the primary mission (4).

Transportability is the capability of the system to be moved by towing, self-propulsion, or carrier (highway, railways, waterways, and airways).

Deployability requirements are defined in terms of numerical limits (for example two C-130 aircraft). The limits should be related to the transport of a specific number of items over a specific distance for a specified period of deployment (which defines spares and supplies required) (5).

A tactical UAV system usually requires more mobility and transportability than a large UAV system that will operate from the same base for extended periods of time. The mobility requirements for tactical systems necessitate take-off and landing operations without the need for a prepared runway. The design solutions may involve Short Take-off and Landing (STOL) operations from unprepared runways, catapult launching or VTOL air vehicles.

4.3 Sustainability

Operational Sustainability is the ability to maintain the necessary level and duration of operational activity to achieve military objectives. It is a function of providing for and maintaining those levels of ready forces, material, and consumables necessary to support military effort (4). The UAV system should be capable of completing a sustained operation of specified duration in the operational site without resupply or support from personnel other than system crew, in order to have high availability rates. This is especially important for the highly mobile tactical UAV systems.

4.5 Environmental Conditions and Electromagnetic Effects

UAV system design should allow operation, storage and transportation in user specified operational environments. The environmental conditions typically include temperature, humidity, precipitation, wind speed (steady and gust), dust, solar radiation and icing. Separate specifications are usually required for each system mode; such as operation, storage and transportation.

The UAV operational experiences indicate that high altitude/low temperature, icing and wind (especially during landing and at high altitude) conditions form the most limiting environmental cases. Measures should be taken for icing problem, but its impact on cost and performance should not be overlooked.

The electromagnetic effects are very important for UAV systems that depend heavily on the avionics and data link for carrying out its mission. This is especially critical in communications relay and SIGINT operations (2) and shipboard applications.

4.5 Survivability and Vulnerability

It is essential that the UAV's level of detectability permits continued operations in a hostile area (3). Usually the following measures are required:

- Small visual silhouette
- Small infra-red signature
- Small radar cross section
- Small electronic emission
- Small acoustic emission

4.6 Safety

The safety measures should be taken so that undesired consequences are kept to a minimum during a hazardous event. Risk of personnel injuries or material damage due to hardware, software, procedural or environmental hazards must be at acceptable levels. Air vehicle emergency modes and flight termination systems improve the operational safety. However, larger UAVs might have space and weight limitations for termination system, and therefore must have better reliability figures. Using communications relay between GCS and Air Traffic Control (ATC) is a good solution to improve the air traffic safety.

4.7 Interchangeability and Modularity

Interchangeability simply means that all parts having the same manufacturer's part number are directly interchangeable with each other, without any alteration.

The optimal concept for users of UAV systems would be a modular generic type of payload with pre-integrated specialized instrumentation available for all UAVs. Air vehicle integration will then consist of merely plugging in the payload and connecting power and data cables (6). Interchangeable/modular payloads allow much shorter Mission Change Times (MCT) which is very critical.

4.8 Growth Potential

The UAV system must facilitate upgrading to accommodate various sensor payloads. The growth potential should also be considered in the following areas:

- Extended payload range
- Air vehicle capability for spare weight, volume and power consumption
- Air vehicle capability for spare interfaces with avionics system
- Data-link bandwidth capabilities
- Ground system capability for operating future payloads
- Computer resource reserved capabilities for memory, timing, etc.

5. CONCLUSION

In recent years, the high demand for UAVs has resulted in quest for technological advancements expected from these systems. Air vehicle, data link, payload, ground control station and other sub-systems require different technologic areas of expertise on their own. System design therefore became an important factor since all these sub-systems, which effect the operational mission directly, require different disciplines of expertise.

In these paper recommendations on design criteria, which will enable the future requirements of generic UAV, systems for reconnaissance and observation purposes have been given.

6. ACKNOWLEDGEMENT

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7. REFERENCES

1. Options for Enhancing the DOD's UAV Programs, CBO Paper, September 1998
2. UAV Annual Report, DARO, November 1997
3. NATO Staff Requirement for a NATO Maritime UAV System, PG-35, July 1996
4. DOD, Dictionary of Military and Associated Terms, March 1994
5. MIL-STD-961D, Defense Specifications, Appendix A, March 1995
6. Pre-Feasibility Study on UAV Systems Interoperability, NIAG SG-53, Feb. 1998
7. Introduction to UAV Systems, Paul G. Fahlstrom, Thomas J. Gleason
8. Remotely Piloted Vehicles, Twelfth International Conference, Bristol, UK

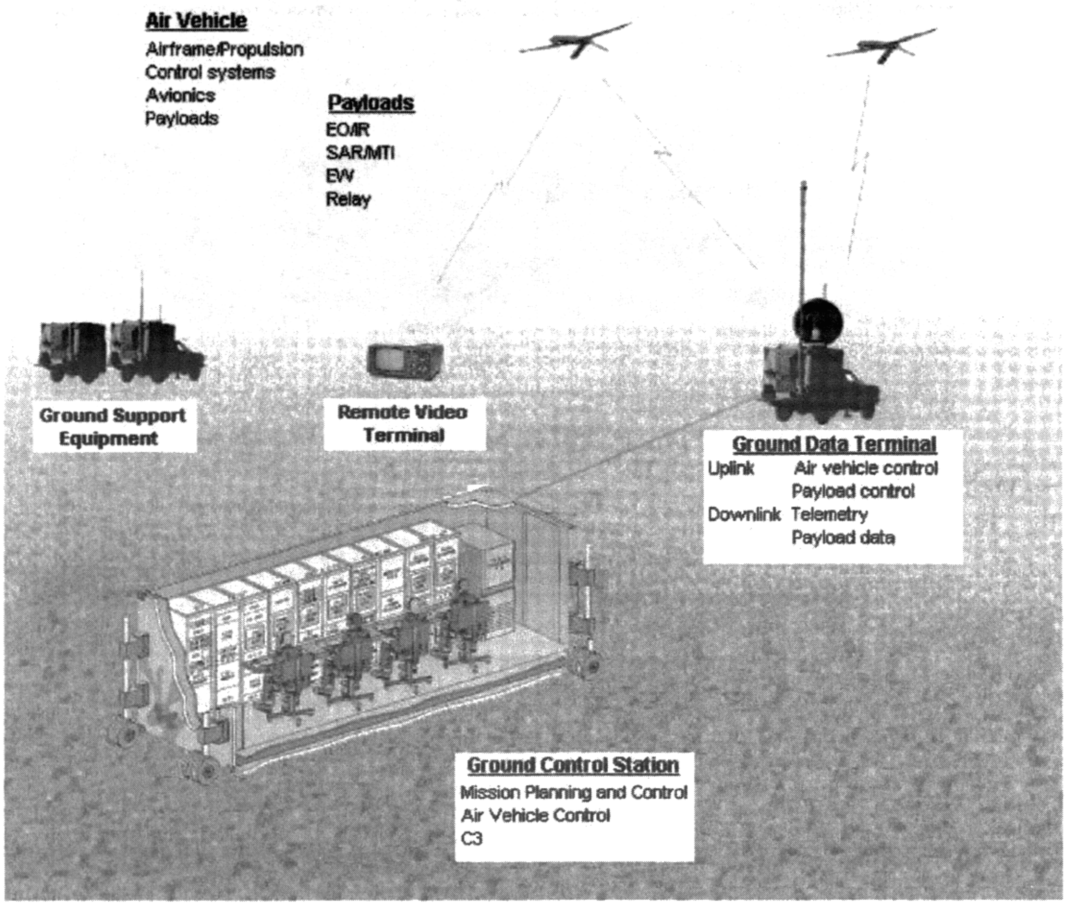

Figure 1. Unmanned Aerial Vehicle System

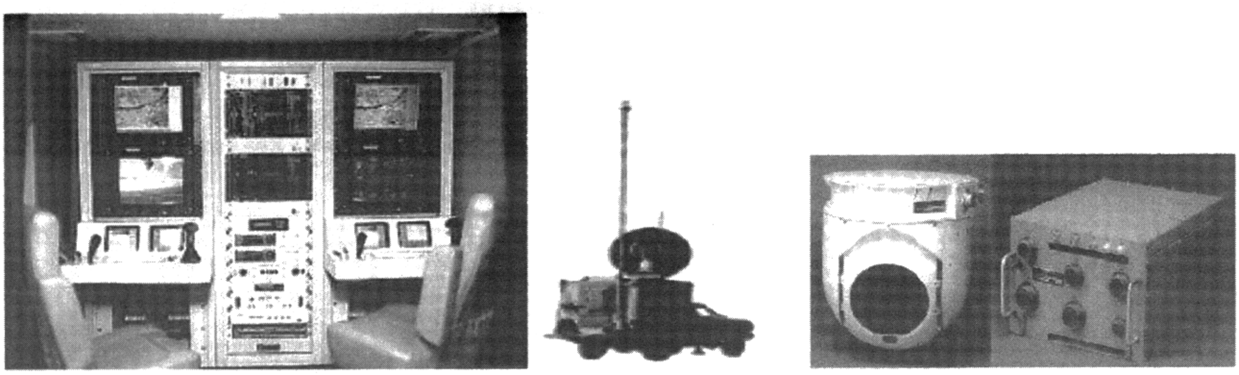

Figure 2. GCS/GDT and Payloads

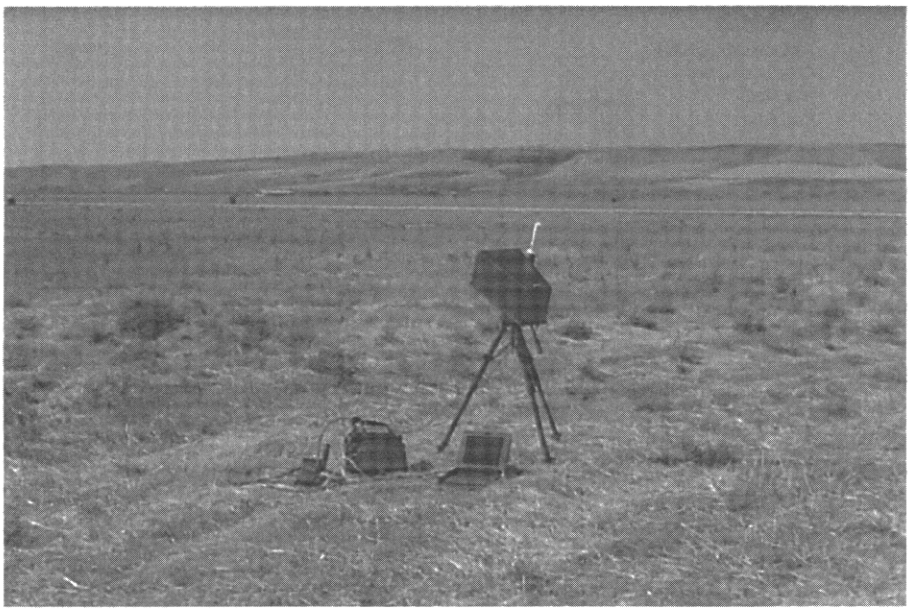

Figure 3. Remote Video Terminal

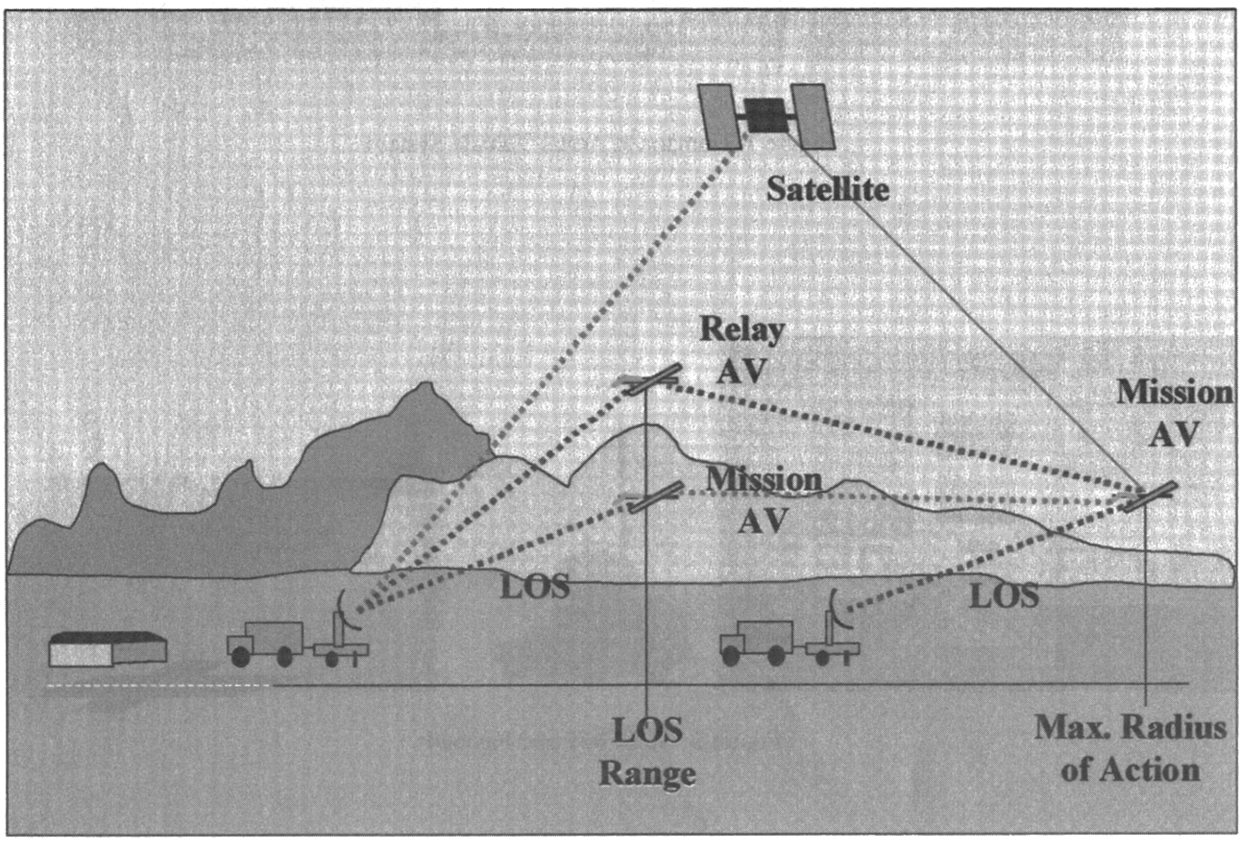

Figure 4. Concept of Operation