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# Unmanned Air Vehicles (UAVs) for Cooperative Monitoring

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Prepared by
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# Unmanned Air Vehicles (UAVs) for Cooperative Monitoring

Prepared for
Sandia National Laboratories

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## Abstract

Unmanned Air Vehicles (UAVs) have several characteristics that make them potentially attractive for cooperative monitoring applications. These characteristics include no danger to human pilots, long endurance, potential for real-time data dissemination, shared control among several parties to an agreement, potential to tailor UAVs to a particular mission, and low cost. This study analyzes UAV utility for several cooperative-monitoring applications. For several missions, including border patrol, environmental monitoring, and disaster relief, UAVs could have advantages over the use of manned aircraft. An in-depth examination of the use of UAVs for monitoring a military force disengagement agreement in the Siachen Glacier region of South Asia was performed. UAVs could offer significant advantages over competing manned airborne platforms for performing this mission.

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## Acronyms and Glossary

| | |
|---|---|
| Chemical sampler | In this study, an instrument that performs chemical analyses on air samples to determine what chemical species are present. |
| Coherent change detection | A SAR technique that compares two SAR images and detects differences between them. |
| Digital camera | A still camera that records an image in the form of a digital file, rather than on film. |
| Electromagnetic induction sensors | Sensors that use very low frequency electromagnetic radiation to penetrate the earth and reveal subsurface conditions. |
| EO | Electro-optical |
| Gravimeter | A sensor that detects minute changes in the Earth's gravitational field. |
| Ground control station (GCS) | A station for remote control of a UAV. |
| Hyperspectral imager | An imaging sensor that collects images in many (20-100+) discrete bands in the electromagnetic spectrum. |
| Interferometric SAR | A SAR technique that records terrain elevation data in an image. |
| IR | Infrared |
| IR imager | An imaging sensor that is sensitive to electromagnetic radiation in the infrared portion of the spectrum. |
| Maximum gross takeoff weight (MGTOW) | The maximum that an aircraft of a given design can weigh and still is able to fly. |
| Multispectral imager | Similar to a hyperspectral sensor, except that it employs fewer spectral bands, on the order of 5-20. |
| Non-imaging spectrometer | A sensor that records the spectra of materials but does not create an image. |
| Radionuclide sampler | In this study, an instrument that scans an air sample for the presence of radioactive isotopes. |
| Real aperture radar | A radar that creates an image but does not use synthetic aperture processing techniques. |

| | |
|---|---|
| Resolution | The measure of the ability to portray small details in an image. |
| Synthetic aperture radar (SAR) | An imaging radar that uses the motion of a moving vehicle to duplicate the effect of a physically large antenna, thereby increasing its resolution. |
| Tiltrotor | An air vehicle that takes off by means of rotors like a helicopter, then tilts the rotors to act as propellers in horizontal flight. |
| Unmanned Air Vehicle (UAV) | An air vehicle with no human pilot on board. |

# 1. Introduction

The purpose of a cooperative monitoring system is to create confidence, reduce tension, and provide a mechanism for solving common problems. It fulfills this purpose by collecting, analyzing, and sharing agreed-upon types of data.

Unmanned Air Vehicles (UAVs) have been around as long as manned heavier-than-air flight. However, until relatively recently, they have had limited use. Recent advances in airframe technology, sensors, and controls have opened the possibility that UAVs might be used for cooperative monitoring. The purpose of this study is to examine the possible utility of UAVs for cooperative monitoring. The study will first identify the characteristics of UAVs that would affect their usefulness for cooperative monitoring. It will then briefly examine several example scenarios for the use of UAVs in possible security, environmental, and disaster response missions. Finally, a more detailed assessment of the utility of UAVs for monitoring a hypothetical force disengagement agreement will be performed, covering the Siachen Glacier area in South Asia.

## 2. Characteristics of Airborne Remote Sensing

Characteristics that make airborne sensing suitable for some remote monitoring applications include the following:

- Large area coverage
- Remote area coverage
- High-resolution imagery (compared to satellites)
- Long dwell times over areas of interest
- Readily available technology
- Flexibility in tasking
- Potentially low cost
- Ability to operate in hostile environments

A top-level comparison of airborne monitoring compared with some other types of monitoring systems is shown in Table 1.

The table shows that airborne monitoring compares favorably with other types of monitoring in several areas. The remainder of this study will examine how well UAVs can perform airborne monitoring.

**Table 1. A Comparison of Airborne Monitoring with Other Technologies**

| Technology | Area Coverage | Data Detail | Flexibility | Technical Availability | Intrusive-ness | Cost of System |
|---|---|---|---|---|---|---|
| **Airborne Monitoring** | Medium | Medium | Medium/ High | High | Medium | Medium |
| **Satellite Monitoring** | High | Low | Low | Low | Low | High |
| **On-Site Technical Monitoring** | Low | High | Low | Medium/ High | Medium/ High | Medium |
| **On-Site Inspections** | Low | Very High | Medium | High | High | Medium/ High |

## 3. The Characteristics of UAVs

UAVs have been designed in a wide variety. The only characteristics that all unmanned air vehicles share is that they fly and that they are unmanned. Even the latter characteristic must be qualified. Some jet fighters have been converted to target drones. These may be flown remotely or human pilots can use the cockpits to ferry the aircraft. Current UAV designs may be fixed-wing, rotor-borne like helicopters, or tilt-rotors. Piston engines, gas turbines, or electric motors may power them. Figure 1 presents pictures of four different current UAVs.

Source: General Atomics Aeronautical Systems

Source: Pioneer UAV

Source: Aerovironment Unmanned Air Vehicles

Source: Bell Helicopter Textron

*Figure 1. Examples of UAVs*

UAVs vary widely in size and performance. They range from hand-launched vehicles with a few minutes' flight duration to large systems with global ranges. They tend to fall into two classes: small, short-range systems under 500 kg in maximum gross takeoff weight (MGTOW), and large, "endurance" UAVs that can have an endurance of more than a day and approach manned aircraft in size and weight. The system chosen will depend upon the mission contemplated.

To illustrate the range of characteristics of UAVs, Figures 2, 3, and 4 show where a selection of currently operational UAVs fall in a number of important characteristics.[1,2,3,4,5,6] The UAVs are coded by country. The following country codes are used in Figures 2, 3, and 4:

**Country codes for Figures 2, 3, and 4.**

BE – Belgium
CH – China
FR – France
INT – International effort
IS – Israel
RU – Russia
SA – South Africa
SW - Switzerland
UK – United Kingdom
US – United States

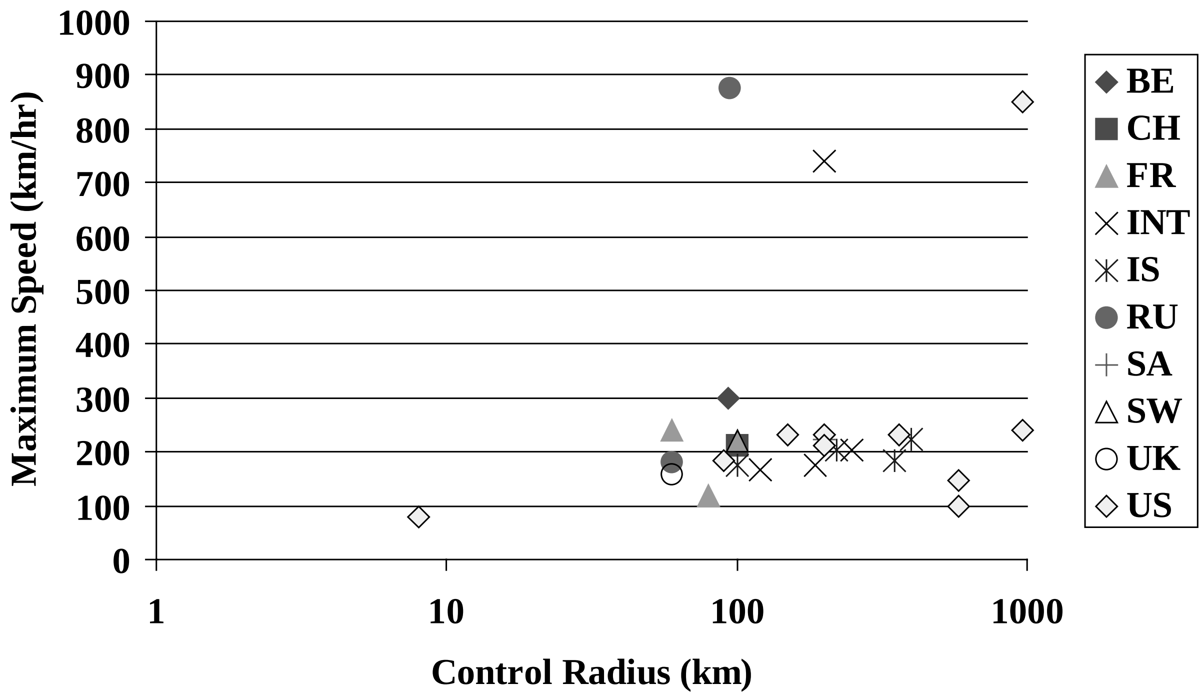



*Figure 2. UAVs Classified by Control Radius and Maximum Speed*

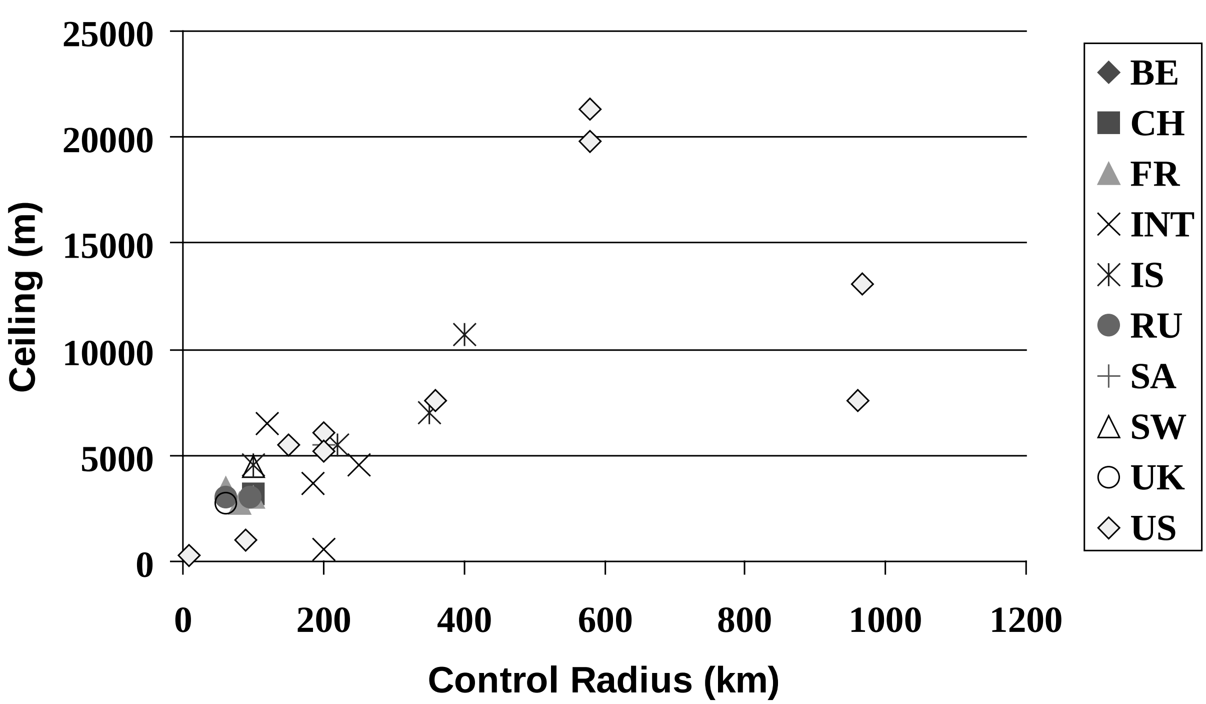



*Figure 3. UAVs Classified by Control Radius and Ceiling*

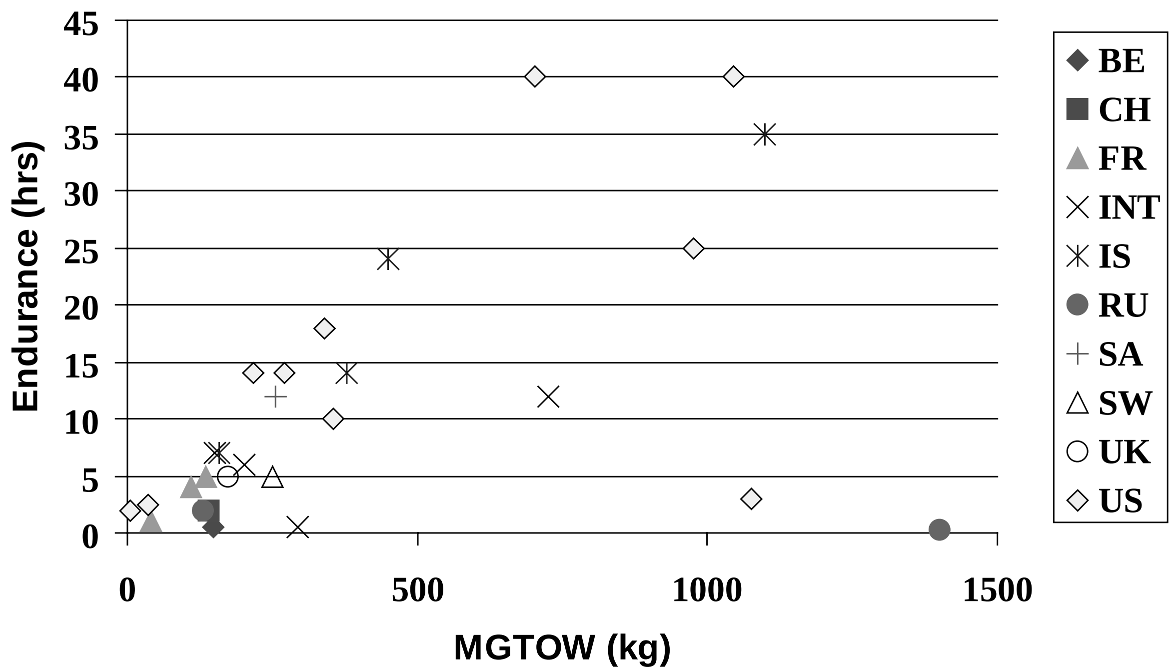



*Figure 4. UAVs Classified by MGTOW and Endurance*

A UAV system includes more than just an air vehicle and may be highly complex. Figure 5 illustrates some of the possible features of a complete UAV system. Not every system will be this complex, but a capable system carrying out a difficult mission could resemble this.

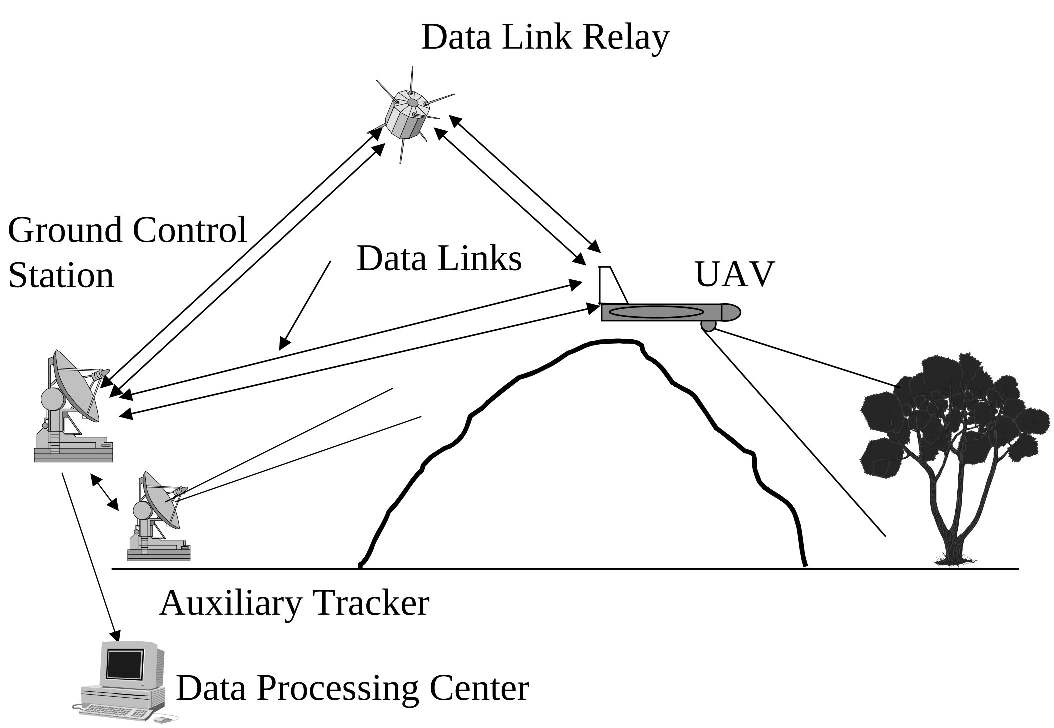



*Figure 5. Elements of a UAV System*

At least two of the components shown in Figure 5 would be present in every system: the air vehicle and the ground control station (GCS). The GCS sends commands to the air vehicle and receives data on the operation of the vehicle. It also can receive data from any sensors on board. The size of the GCS can range from a small, hand-held unit to a 10-m trailer, depending upon the system.

The presence of the other components would depend upon mission need. The UAV will usually depend upon a constant data link. Because of the large amount of information passing along the links, these links are usually limited to line-of-sight distances. If long-range operation is needed, then a data relay must be established. These can be ground-based, based on airborne platforms, or satellite-based.

An auxiliary tracking radar may be used to perform fine tracking of the UAV to give accurate position information.

Complex data or imagery may be processed at a separate location from the ground station. The data may be relayed from the GCS to a data processing center, or the center may receive data directly from the UAV.

The number of people needed to operate a UAV system will depend upon the complexity. One or two people may suffice for a simple UAV. A complex UAV on a long-endurance mission might have the following crew: a team leader, three to four pilots (for 24-hour missions), one to two electronics technicians, and two mechanics. In addition to these, there may be several people involved in data exploitation.[3]

The type of UAV chosen will depend upon the mission. In some situations, the use of UAVs is more complex than the use of commercially available aircraft. For example, a manned aircraft may be able to deploy itself to a distant region, carrying itself and all necessary personnel and equipment for a mission. In contrast, a UAV's GCS, personnel, and any auxiliary equipment would all have to be transported to the region, if the UAV could not be controlled from the home base. Also, the UAV may have to be disassembled and shipped to the region, then reassembled. In that case, the UAV must present sufficient advantages to compensate for the added complexity.

# 4. Advantages and Limitations of UAVs Relative to Manned Aircraft

UAVs are designed according to the same aeronautical rules that govern the design of manned aircraft. They therefore share many of the characteristics of manned aircraft. The major difference is, of course, the absence of human pilots and the substitution of remote and/or automatic flight control. These differences account for both the advantages and limitations of UAVs relative to manned aircraft.

## *4.1 Advantages of UAVs*

***No Pilot Equals Fewer Constraints*—**Manned aircraft must have a certain minimum size in order to carry the weight of a pilot. UAVs have no such constraint. The control system and data link can be smaller and lighter than a human pilot, so the weight saved can be used to increase performance or decrease the size of the UAV. In addition, a small UAV may not need a conventional runway for launch and recovery, which can be very useful for monitoring a remote area. Some UAVs are so small that they can be hand-launched.

Another advantage of not having a human pilot is that there is more flexibility available for the design. UAVs can have features that are not practical for manned aircraft. For example, the control components could be spread throughout the airframe, if necessary, which is not possible with a human pilot. UAVs can be more streamlined than manned aircraft, as the requirement for good visibility from the cockpit is not present.

The greatest advantage of eliminating a human pilot is that his safety is no longer a consideration. The direct predecessors of UAVs are target drones. They are used in preference to manned aircraft for gunnery and missile training for obvious reasons. Military airborne reconnaissance missions are typically very dangerous, especially if the aircraft must loiter over hostile territory for a significant length of time. For this reason, the defense forces of many countries are investing in reconnaissance UAVs.

UAVs can also be designed for extreme flight regimes that are dangerous or just unattractive to human pilots. Extreme altitudes and very long endurance flights (up to days) are examples of flight conditions where UAV use is increasing. Forty-hour flights and 24-km altitudes have been demonstrated.[6] Twenty-four-hour flights are not exceptional[3] for some UAVs. Long flights over water or remote, rugged terrain are also relatively dangerous missions where UAVs could be used.

***Cost Advantages Over Manned Aircraft*—**For a given level of technology, the smaller the aircraft, the less the cost, so small UAVs will cost less than manned aircraft. For long endurance missions, where multiple crews would be needed, the cost savings are considerable. A manned aircraft would have to carry all the crews needed for the entire flight, which would rapidly drive up the size and cost of the aircraft. As an example, the large Global Hawk UAV costs around \$14.8 million.[7] The manned aircraft closest in characteristics is the U-2, which would cost more than \$40 million in 1999 dollars, and has less range and endurance.[8,27]

## *4.2 Limitations of UAVs*

To date, UAVs have had relatively limited use. Some of these limitations have to do with the relative immaturity of UAV technology; others are more inherent in the nature of UAVs.

- ***Preprogrammed Missions vs. Data Link Control*****—**Because of the lack of a human pilot, UAVs must either be sent on preprogrammed missions or must be controlled by a data link. This condition imposes certain limitations. A purely preprogrammed mission without a data link robs the UAV of any flexibility. In addition, there is no way of knowing whether a mission is successful until the UAV does or does not return. Use of data links for real-time control of the UAV provides flexibility in missions. Data can also be returned in real time, if the data link has sufficient capacity. Use of data links has limitations, however. In order to provide sufficient bandwidth for significant information flow, the data link usually is limited to line-of-sight capability. If the data link is broken, the UAV may crash. Some UAVs can revert to emergency programs that carry out preprogrammed maneuvers.[3] This can save the aircraft, but will force at least a temporary interruption in the mission. The data link range imposes a maximum control radius for the UAV, which may be less than the radius that the UAV air frame endurance would allow. In addition, mountain ranges or low-altitude flight may impose further restrictions on where the UAV can fly. It is possible to extend the control radius of the UAV by using a relay station, which can be ground-based, airborne, or satellite-based. This adds complexity to the system and if a satellite relay is used, there must be space for the large satellite antenna.

- ***Space and Carrying Load Capacity*****—**Another limitation is the space and load-carrying capacity for payloads. To date, most UAVs are designed to carry small, single-sensor payloads. The lack of capacity limits sensor type, size and resolution, and onboard data or sample storage.

- ***Airspace Control*****—**Airspace control is another issue. While some UAVs carry TV cameras specifically for navigation and piloting, they do not have the all-around view that human pilots have from a cockpit. In addition, small UAVs are hard to see. As a result, special care will need to be taken when operating in the same airspace with other aircraft. Because of a lack of experience with UAVs, air traffic regulators are uncertain how to deal with them and are inclined to be very cautious. In the U.S., chase aircraft are often used when UAVs are tested. This is not practical for operational UAV use, as it negates all the advantages of using UAVs instead of manned aircraft. High-altitude operations above the standard airline routes are easier, as the airspace there is empty.

- ***Lack of Operational Experience*****—**Finally, UAV technology is still relatively immature and there is a lack of operational experience. Maintenance schedules tend to be overcautious, which drives up projected costs. Production is still in limited quantities, which also maintains prices at relatively high levels. The limited number of experienced operators tends to produce a high crash rate. These drawbacks will be ameliorated as more experience is gained and more UAVs are produced. Currently, however, there is still a strong tendency to treat UAVs as research and development projects, rather than operational systems.[3]

## 4.3 Advantages and Disadvantages of UAVs for Cooperative Monitoring Missions

Some of the characteristics of UAVs have specific consequences for cooperative monitoring missions. The specific advantages and disadvantages of UAVs for cooperative monitoring are discussed here.

**Advantages:**

- ***No risk to pilots*—**UAVs will not risk human pilots and crew. This can be important in the early stages of an agreement where suspicion may abound. Incidents of mistaken identity or overzealousness, which could trigger a major international crisis if humans are involved, are much less liable to escalate if only a machine is involved.

- ***Real-time data dissemination*—**Many sensors available for UAVs allow real-time data dissemination. This permits simultaneous reception of information by all parties to an agreement.

- ***Dual control possible*—**Once suitable people are trained, then control of UAVs can be shared. It is possible to have multiple ground control stations, and to hand over control even while the UAV is in flight. This permits a close level of cooperation and can give all parties to an agreement a sense of having a share of control.

- ***Possible to tailor UAVs to mission*—**It is possible to tailor UAVs so that they can perform only the mission desired and no other. This can reduce resistance to cooperative monitoring, as it makes it less likely that the monitoring system could be used for unauthorized purposes. For example, a UAV sensor package can be designed so the sensors would scan only the desired geographical area. They would be turned off in transit.

- ***Low cost, compared to many alternatives***

**Disadvantages:**

- ***Resemblance to cruise missiles*—**UAVs may be mistaken for cruise missiles. This is unavoidable, as some of the same technologies are used both in cruise missiles and UAVs. This can reduce the acceptability of UAVs.

- ***Inexperience*—**UAV technology is still immature. This can lead to a high accident rate, unreliability, and higher-than-expected operating costs.

- ***No onboard human observer*—**This can lead to fears that the UAV can be diverted to an unauthorized use.

- ***Long missions may reduce operator alertness*—**Operators have fewer stimuli to foster alertness than human crews. Very long missions may induce fatigue and lack of alertness that could jeopardize the operational mission.

- ***Narrow field of view could limit images***—Human observers looking from an aircraft would have a wider field of view than most UAV imaging sensors. In addition, the three-dimensional images that human vision can acquire may convey more information than a two-dimensional sensor image.[18] While this could reduce the risk of unauthorized information gathering, it could limit confidence in the system's monitoring capability.

# 5. UAV Sensors

UAVs can carry most airborne sensors. Specific sensor models may have some limitations. For example, film cameras might require a crew to replace film cartridges, or experimental sensors might require frequent adjustment or operator actions. Some sensors might have size and power requirements that preclude their placement in present UAVs. For example, it might not be possible to use large aperture optical sensors or powerful long-range radars unless a special UAV was specially built to carry them. However, UAVs can carry many sensors that are useful for cooperative monitoring.

It is possible to divide potential UAV sensors into three classes: imaging sensors, non-imaging remote sensors, and air samplers. Some specific sensors are listed below:

**Imaging Sensors**

- Film cameras
- Digital cameras
- Electro-optical (EO) cameras (TV)[3]
- Low-light-level TV cameras
- Infrared (IR) imagers[3]
- Multispectral imagers
- Hyperspectral imagers
- Real aperture radars
- Synthetic aperture radars (SARs)[25]
- Laser radars

**Non-Imaging Instruments**

- Non-imaging spectrometers[9]
- Radiation detectors
- Global Positioning System navigation systems for position reporting
- Gravimeters
- Electromagnetic induction sensors

**Air Samplers**

- Chemical samplers
- Radionuclide samplers

# 6. UAV Missions and Sample Scenarios

## 6.1 Demonstrated UAV Missions

To date, most UAV missions have been military in nature. There has been relatively little civilian use of UAVs. Civilian flight is typically less dangerous, so manned aircraft can be used. Extreme flight regimes are less common. Demonstrated UAV missions include:

- Military reconnaissance[10]
- Atmospheric composition monitoring[11]
- Decoy against air defenses
- Target for air defense training
- Border monitoring for illegal crossings

To date, the most widespread uses are as targets and for reconnaissance.

## 6.2 Potential UAV Missions

As UAV technology advances and UAVs become more reliable and capable, more applications will undoubtedly appear. Some potential military and civilian applications of UAVs include:

- Communications relay[13,14]
- Weather reconnaissance[12,15]
- Pollution monitoring[16]
- Navigation aid[14]
- Forest fire detection[17]
- Land mine detection[14]
- Civilian or military mapping
- On-site inspection support[18]

## 6.3 Sample Scenarios for UAV Monitoring

There are numerous possible scenarios for UAV monitoring. Three sample scenarios are discussed briefly below. Later, in Section 7, another scenario will be developed in detail.

- ***Border Monitoring*—**One possible scenario for UAV applications is border monitoring. The ability of the UAV to cover large areas of remote terrain would be useful in this situation. A small UAV would be less noticeable than a manned aircraft, so there would be more chance of surprising border violators. In this scenario, UAVs equipped with imaging sensors would follow the line of the border. Imagery would be linked either to a joint monitoring center or simultaneously to border security centers of both countries.

- ***Forest Monitoring*****—**Monitoring the state of health of a forest that lies in the territory of more than one country is another possible UAV application. The ability of airborne assets to cover large areas is helpful here. UAVs would make regular surveys of the forest area, gathering data to be sent to a binational forestry center. The sensors to be used would depend upon the type of data desired; different sensors could be installed for different missions.

- ***Disaster Response*****—**Lack of timely information has been a severe handicap to disaster relief efforts in the past. In some disasters, UAVs could be used to gather information that could be used to guide rescue and relief efforts. For example, knowing the status of transportation networks can be of great use when planning delivery of relief supplies. UAVs could be dispatched and arrive in the impacted area before relief personnel arrive. The information could be sent back to a central relief coordination center or directly to the relief units en route to the scene.

Table 2 examines UAV applications in the three sample scenarios described above.

**Table 2. UAV Evaluation for Three Sample Scenarios**

| | **Border Monitoring** | **Forest Monitoring** | **Disaster Response** |
|---|---|---|---|
| **Concept** | UAVs will monitor both sides of an international boundary for security and economic purposes. | UAVs will monitor forest that extends into two countries for vegetation health and deforestation. | UAVs will respond after a disaster to aid in relief efforts. |
| **Operations Plan** | UAVs will fly along the border at random times.<br>Known crossing points will have near-constant surveillance. | UAVs will survey the entire forest area several times a year.<br>High-risk areas will be monitored more often. | UAVs will fly to the disaster area to perform advance reconnaissance of the affected area. |
| **Observables** | Vehicles trying to cross border, small groups of people trying to cross border, military buildups in border region | Vegetation stress, clearings, plant species change, road and trail emergence, logging and construction equipment | Extent of affected area, damage to roads and bridges, number and location of refugees, extent of damage to crops |
| **Sensors** | EO cameras, IR cameras, SARs | EO cameras, multi- and hyperspectral imagers | EO cameras, IR cameras, SARs |
| **Strengths** | Large lengths of border can be covered by a few units.<br>Individuals can be detected and identified.<br>There is no risk to crews. | Large area coverage is possible.<br>Remote areas can be covered.<br>Cost may be less.<br>There is no risk to crews. | Quick response is possible.<br>Long endurance over the affected area is possible.<br>There is no risk to crews. |
| **Weaknesses** | The entire border cannot be observed simultaneously.<br>Weather may limit operations. | Penetration of forest canopy by sensors may be difficult. | Range from control station may be limited.<br>Weather may limit operations. |

# 7. The Siachen Glacier Scenario

In order to examine in detail the utility of unmanned air vehicles for cooperative monitoring, a potential monitoring scenario was examined in detail. This scenario examines a hypothetical military disengagement agreement in the Siachen Glacier region of the Himalayas, in a disputed region between India and Pakistan. The general area of the Siachen Glacier is shown in Figure 6, and a more detailed image of the Siachen Glacier itself is shown in Figure 7.

## 7.1 The Siachen Situation

Since Pakistan and India gained their independence in 1948, they have been involved in a dispute over the territory of Kashmir in the Himalayas. Each controls part of Kashmir and the line between the two is not a recognized international boundary. After the first conflict, the location of what was called the Cease-Fire Line was laid out. Unfortunately, it was not clearly marked all the way to the Chinese border.

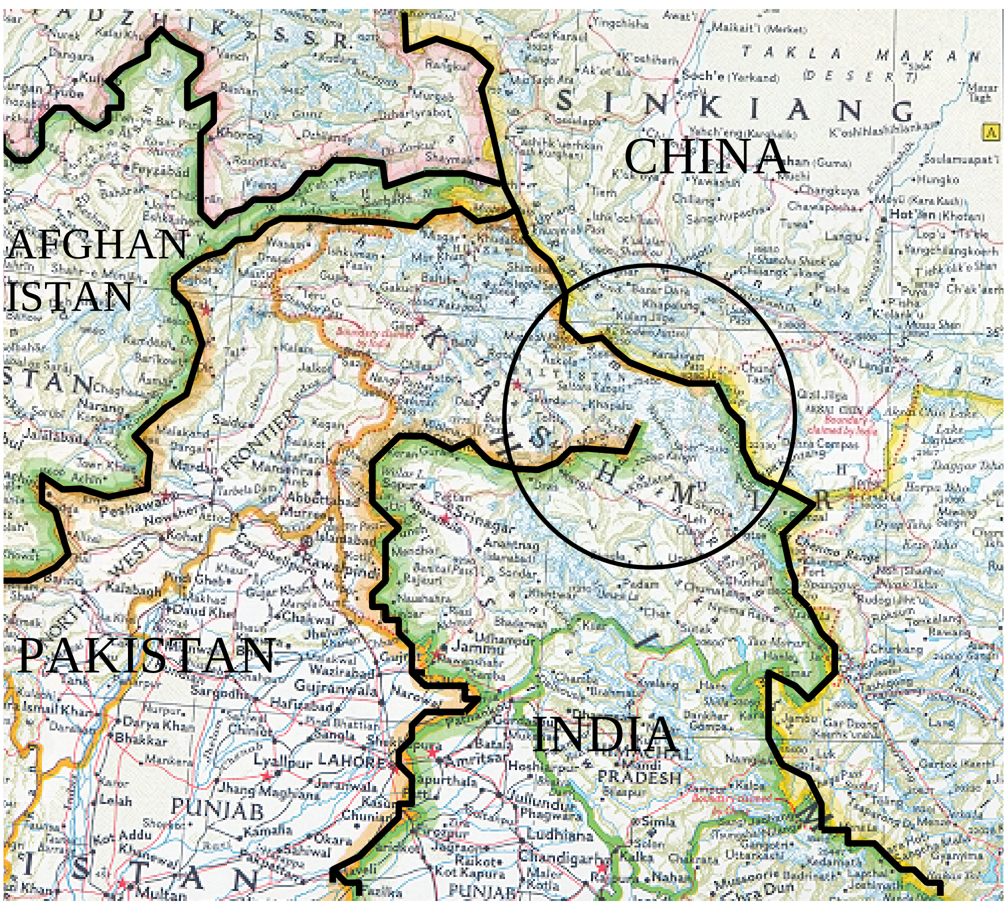



*Figure 6. India, Pakistan, and Kashmir*

Instead, it proceeded to the control point NJ9842, at the base of the Saltoro mountain range, and from there, the agreement merely stated that it proceeded "north to the glaciers." Pakistan interpreted the wording to mean that the line proceeded northeast to Karakorum Pass, while India interpreted it as meaning northwest along the Saltoro Range. The territory between the two lines is the site of the Siachen Glacier, the longest non-arctic glacier in the world. After the 1971 India-Pakistan war, the Cease-Fire Line was replaced with a "Line of Control." Nothing was done to more clearly define the boundary in the Siachen region. For a long time, no action was taken by either country to occupy the area and resolve the question, because of the remoteness of the region. In the 1980s, however, a growing number of mountaineering parties visited the region. They generally came from the Pakistani side because the access was easier. India became aware of this and felt that Pakistan was acquiring de facto sovereignty over the disputed region. In 1984, to forestall this, India sent mountain troops and occupied the Siachen Glacier and three of the four significant passes over the Saltoro Range. Pakistan succeeded in occupying the fourth pass. Since that time, repeated efforts by both countries to dislodge the other from the passes and the outposts along the Saltoro ridge have failed. The military stalemate has existed for over 14 years. The extremely high altitudes (from 3600 to 7000 m) and harsh weather have combined to inflict more casualties on both sides than the actual fighting. The situation constitutes a steady drain on the resources of both countries. A military disengagement agreement would halt the loss of life and large expenditures for both sides.

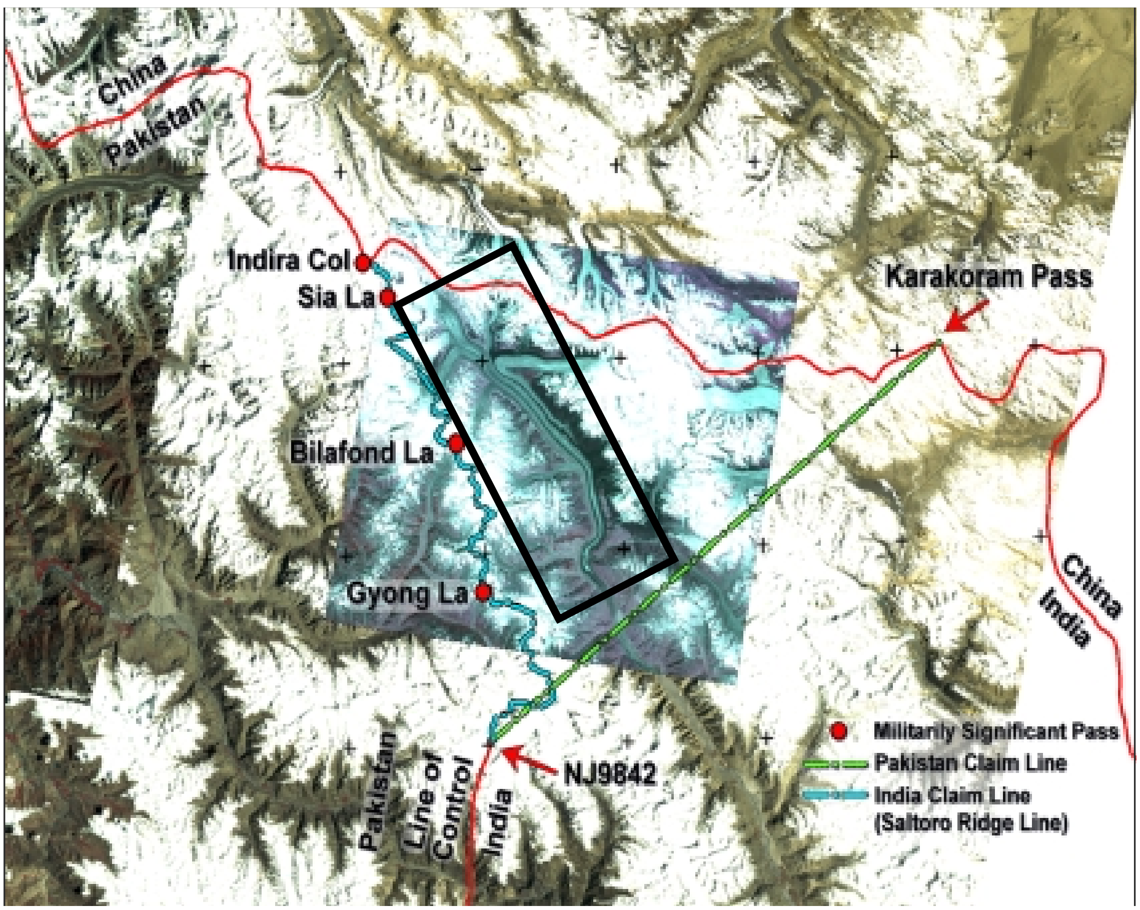



*Figure 7. Siachen Glacier Region and Disputed Territory*

## 7.2 Hypothetical Disengagement Agreements

There have been several proposals made to stop the fighting and disengage the military forces. The scenarios used in this study will build upon proposals made in *Freezing the Fighting: Military Disengagement on the Siachen Glacier*, by Samina Ahmed and Varun Sahni.[19] They outlined three possible agreements that could be made to ameliorate the Siachen situation. They were, in order of increasing effect, 1) a cease-fire in place, 2) a military separation and the establishment of a Zone of Separation, and 3) complete disengagement and withdrawal from the glacier. Specific details have been added to the proposals to permit an analysis of different monitoring systems.

***Cease-Fire in Place*—**This could be the first step in the process to end the conflict in the region. The object would be to halt the fighting and maintain the forces at the present level. Sniping, artillery attacks, and infantry assaults would be forbidden, as would the construction of new outposts, the enlargement of old outposts, and the introduction of more troops and increased heavy weaponry, such as artillery. This agreement would have the advantages of preventing increased hostilities and saving lives, while avoiding the difficult question of the ultimate sovereignty over the glacier. As such, it might be a good first step towards further disengagement.

***Military Separation*—**This agreement would not only include a cease-fire, but would also create a Zone of Separation a few kilometers wide. Outposts in the zone would be dismantled and no troop movements within the zone would be allowed. This agreement could help reinforce the cease-fire by depriving both sides of targets for small arms fire. It could also remove troops from some of the more dangerous, exposed outposts.

***Complete Disengagement*—**This agreement would bring the maximum benefits of a military disengagement. All troops and outposts would be removed from the glacier, the Saltoro ridgeline, and the approaches. The Indian and Pakistani base camps would be demolished. This agreement would get the troops out of the most dangerous environments and would eliminate the financial burden of supporting the high-altitude outposts. Pending a final agreement on the issue of the border location, this would produce the greatest savings of people and resources.

## 7.3 Monitoring Requirements

The terms of the hypothetical agreements and the harsh environment create exacting requirements for monitoring systems. A list of monitoring requirements follows.

- The size of the disputed territory is about 2000 to 2400 $km^2$. While a fair portion can be eliminated as being impassible and thus not necessary to monitor, this still indicates that large area coverage is necessary.

- It would probably require at least a day for a significant reoccupation of the critical passes. To detect this, this area must be covered once a day at a minimum.

- In order to cover the passes, the system must have an altitude capability of at least 5700 m. To clear all peaks in the area, the altitude requirement is 7600 m.
- The system must detect and identify the signs of military operations (small units of infantry, camouflaged outposts, and light artillery) against a backdrop of snow or rock.
- The system must cope with weather conditions that include high winds, heavy snowfall, frequent ground fogs, and uniformly low temperatures.
- The system must be maintainable in a very remote region of the world.

## 7.4 Candidate Systems

Several systems might be applied to the Siachen monitoring scenario. In keeping with the overall purpose of this study, only airborne systems (manned fixed-wing aircraft, helicopters, UAVs, and the sensors they carry), will be considered, as follows:

***Manned Fixed-Wing Aircraft*****—**A manned aircraft would need a ceiling of at least 7600 m in order to clear the mountain peaks. It would have to carry at least three crewmembers: a pilot, a sensor operator, and at least one observer from a different country than that of the payload operator. It would also have to carry adequate sensors. Given these requirements, a commuter-airline-type turboprop aircraft would be the least risky choice. Examples of aircraft that might be suitable include the U.S.-built Fairchild Metro, the Brazilian Embraer Bandeirante, and the German Fairchild-Dornier 228.[4]

***Helicopters*****—**The requirement for high-altitude capability places a severe strain upon helicopters, which are generally designed for low altitudes**.** A military-type, turbine-powered aircraft would be preferable, such as the Eurocopter Cheetah, which is especially built for high-altitude operation and has been used extensively in the Siachen region by the Indian army.[4]

***UAVs*****—**The requirement for high altitudes rules out small simple UAVs. The most capable candidates are medium-altitude, long-endurance machines like the U.S.-built General Atomics Predator or the Israeli Heron.

***Sensors*****—**As stated before, the type of monitoring needed under these agreements would be similar to airborne reconnaissance. The most commonly used sensors for airborne reconnaissance are imaging sensors, among them TV cameras, IR imagers, and SARs. These three types of sensors will be considered in this analysis. Though they might be useful for detecting and characterizing military activity, signals intelligence sensors will not be considered because it would be very difficult to design a sensor system that would be useful for monitoring purposes and yet not collect unrelated intelligence data.

## *7.5 Operational Employment*

To examine operational issues, a notional operation deployment plan for each of the three agreements has been developed. The operational employment of the airborne systems would depend upon the details of an agreement. There are some common features, however.

To minimize the chances of unauthorized intelligence gathering, representatives of both parties would have to be present, either on board a manned aircraft or at the GCS of a UAV. The parties could take turns controlling the aircraft for different flights. If imagery was data linked back from the aircraft, dual data receivers might be used to ensure simultaneous reception of the data.

Available information on the Siachen conflict indicates that it would take at least a day to stage and move a significant number of troops from the base camps up to the Saltoro passes, which would be the most important military objectives in case of a violation of an agreement. To have timely warning of such a developing situation, daily flights would be necessary.

Helicopters could be based at a site close to the glacier, perhaps at the Indian and Pakistan base camps of Dzingrulma and Dansam. Fixed-wing aircraft would have to operate from runways farther away. The closest runway on the Indian side appears to be at Thoise, about 60 km from the glacier, while the closest runway in Pakistan appears to be at Skardu, 120 km away. The basing of the UAVs would depend upon the type of system. If a small UAV could operate in this environment, it might be possible to use a catapult launcher and base the systems close to the glacier. Present long-endurance UAVs, however, operate from runways, and would thus operate out of Thoise and/or Skardu. To preserve equity, airborne systems could operate alternately from the Indian and Pakistani side, or if multiple systems were used, they could operate from both sides simultaneously.

To deter military activities, either the glacier area must be covered sufficiently often that meaningful movement was impossible in the time between visits, or the aircraft must be able to pass over the glacier area at random times. Takeoff times should be random. The aircraft should either be capable of multiple passes in a day, or there should be sufficient aircraft available that several aircraft could cover the glacier. As the takeoff of the aircraft could be detected and communicated to the field, random approach paths to the glacier from the takeoff site could be used, so that the exact time of arrival of the aircraft over the glacier would be known only to the operators.

To ensure that the area would be monitored at least daily, at least two aircraft would be needed. This would allow time for scheduled maintenance, as well as provide a backup in case of breakdown or loss of an aircraft. In addition, because of the need for a continuous link between the UAV and the GCS, an additional unmanned aircraft to function as a relay may be necessary.

In the following sections, features of nominal operational plans for the different proposed agreements are discussed.

### 7.5.1 Cease-Fire in Place

Under this agreement, the Saltoro ridgeline would be the major area of interest, to ensure that outposts are not enlarged and that troop movements are not taking place. Flights would cover the ridgeline of the Saltoro Range. This does not imply acceptance of Indian territorial claims, but recognition of the current de facto situation.

Figure 8 shows a nominal flight path that an airborne monitoring system could follow. The thick line is the distance over which the monitoring sensors would be active. The system could either navigate by a GPS-based system, or a lower-resolution TV camera could be used, which would not have the capability to gather useful intelligence information. For this nominal flight path, the sensors would be in operation over a distance of approximately 100 km. The flight path from the system base of operations to the start of sensor operation is not shown.

Representative cruise speeds for manned aircraft, UAVs, and helicopters are 300 km/hr, 200 km/hr, and 180 km/hr. To follow the flight path shown in Figure 8 would require 20 to 40 minutes to monitor the ridgeline. The fixed wing systems would require about 20 to 30 minutes to fly from Thoise or 30 to 40 minutes from Skardu to reach the beginning of the required monitoring flight path, and up to 1 hour to fly back from the end of the path. Assuming 20 minutes for takeoff and landing, the total flight would require 1.5 to 2 hours. The helicopter could be based closer to the glacier, compensating for the lower cruise speed, and would also require 1.5 to 2 hrs. This assumes that the aircraft fly a straight line along the ridge. If they must deviate from a straight line to ensure complete coverage, more time would be required. The 1.5 to 2 hours per flight should be regarded as a minimum.

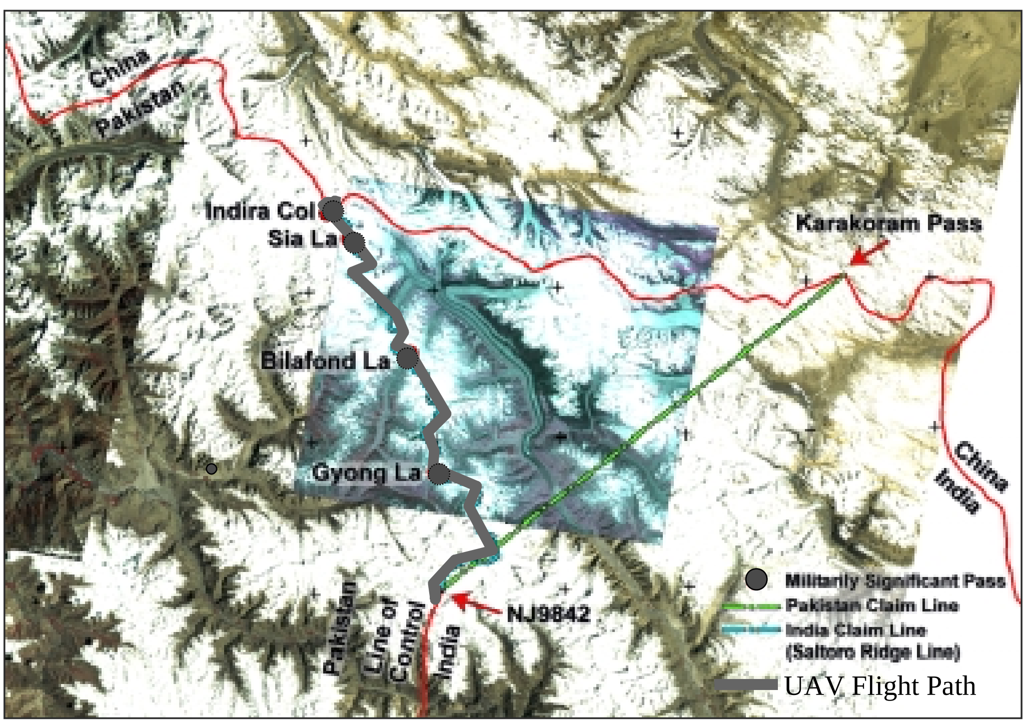



*Figure 8. A Nominal Flight Path under a Cease-Fire Agreement*

### 7.5.2 Military Separation

Under this agreement, a 2-km Zone of Separation would be monitored to ensure that no military reoccupation was taking place. A nominal flight would cover the Zone of Separation by flying down both sides of the Saltoro ridgeline.

Figure 9 shows a nominal flight path (the thick line) that an airborne monitoring system could follow. In this case, the sensors would be operating for a distance of about 220 km. This would add .5 to 1 hour to the flight time needed for the cease fire monitoring. In this case, one monitoring flight would require 2 to 3.5 hours. Again, several flights per day would be possible.

### 7.5.3 Complete Disengagement

All the terrain around the Siachen Glacier that would support military operations would be monitored under this agreement. Daily flights to cover the ridgeline of the Saltoro Range, plus both base camp sites and the entire length of all major approach routes, would be utilized.

Figure 10 shows a nominal flight path that an airborne monitoring system could follow. The sensors would be operating over a distance of 380 km. A complete monitoring flight would require 2.5 to 4 hours. This would still permit several flights per day, if that were considered necessary.

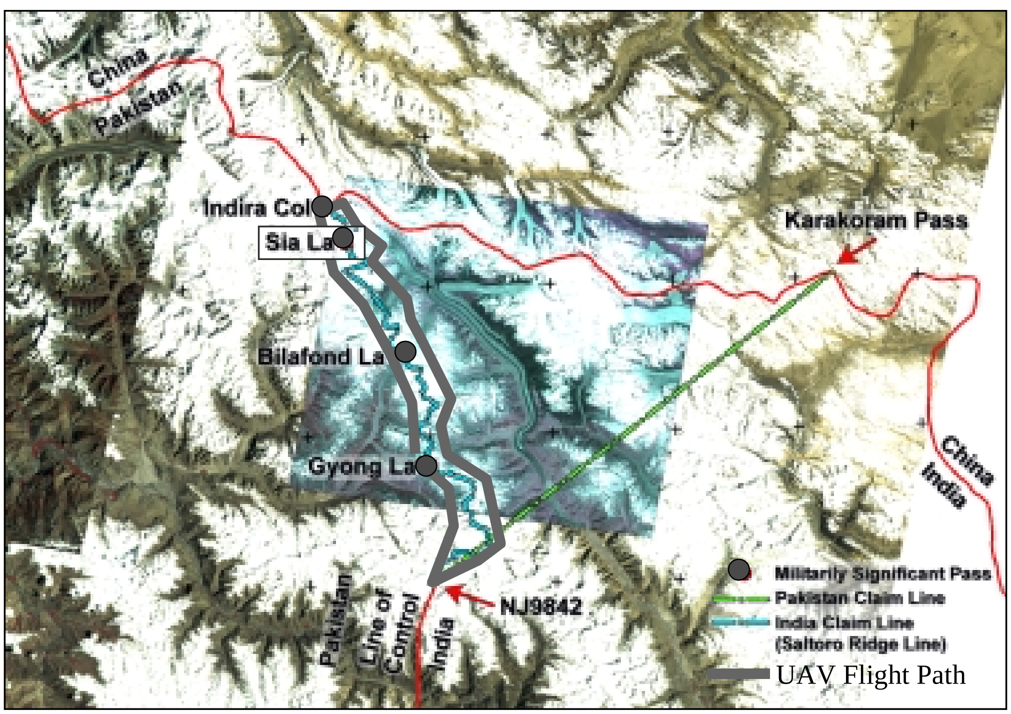



*Figure 9. A Nominal Flight Path under a Military Separation Agreement*

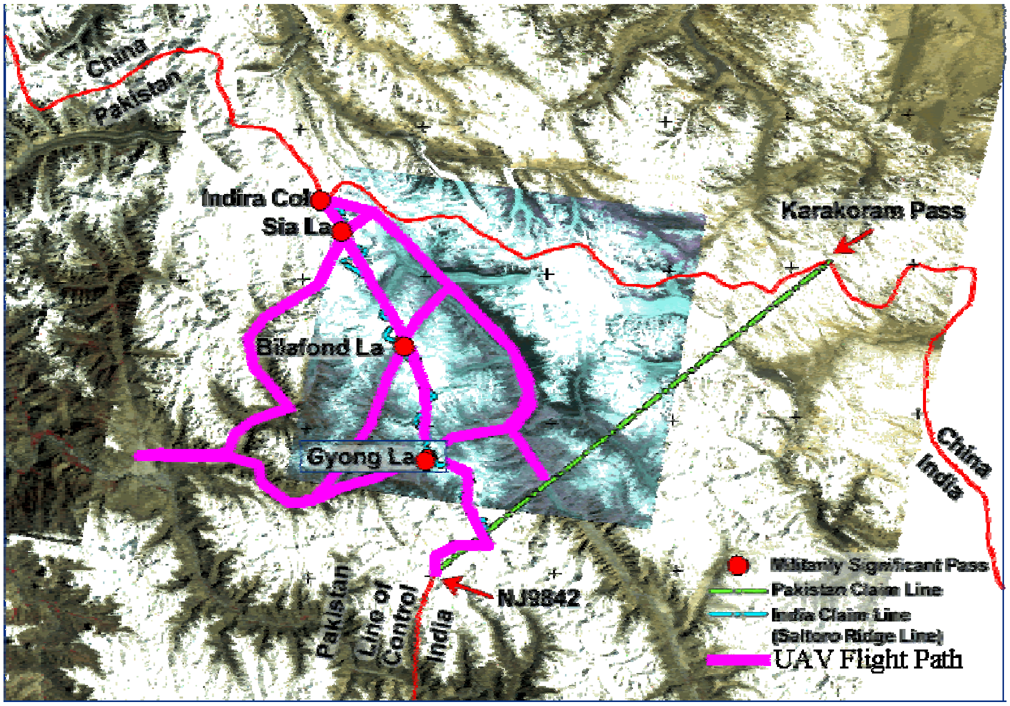



*Figure 10. A Nominal Flight Path under a Complete Disengagement Agreement*

## 7.6 Evaluation Criteria

In order to evaluate the candidate airborne monitoring systems, a common set of criteria must be established. For this study, a set of eight criteria will be used. A list of the criteria and a brief definition of each follows.

- ***Access to Observables***—Can the system be placed into position where the observables are visible to its sensors?
- ***Detection***—Are there observables it can see, and at what range and under what conditions?
- ***Identification***—Can it identify the targets that it detects?
- ***Robustness***—Under what range of conditions, including night and bad weather, can the system operate? Can it be fooled easily by countermeasures? What is the false alarm rate?
- ***Response Support***—Can the system support response teams? Can it track the detected targets for a useful length of time?
- ***Acceptability***—Will the concerned governments accept this system on their own territory? Is it too intrusive? Too dangerous? Politically or culturally unacceptable?
- ***Cost***—How much does it cost to procure and operate the system? Also, and equally important, what is the risk to human lives?

- ***Exportability—***If it is not available domestically, can it be obtained through the international market? Is a license required? How hard is it to obtain a license?

For each criterion, the candidate systems will be scored according to a high, medium, or low scale. A high score indicates that no significant problems exist and the candidate system appears to have favorable features for this criterion. A medium score will indicate that some challenges exist, but the system has at least the potential to satisfy this criterion. A low score indicates a significant problem in this area. After all the criteria are discussed, a table will present overall results

### 7.6.1 Discussion of Systems According to Criteria

***Access to Observables—***The greatest difficulty that aircraft will have in gaining access to the Siachen area relates to the altitude. The bottom of the glacier is around 3840 m, while the peaks of the Saltoro Range go up to 7600 m. This poses a challenge for all three systems. Figure 11 compares service ceilings of several examples of each type of platform with altitudes of important features in the Siachen Glacier area. As stated earlier, these platforms are military-type, turbine-powered helicopters; turboprop-powered commuter-airline aircraft; and medium-altitude, long-endurance UAVs.

Helicopters would have significant problems achieving the altitudes necessary to operate in the Siachen region. While helicopters commonly do fly at the glacier, available information indicates that these machines have special modifications for high altitude. The helicopters can carry only a small portion of a normal load.[20] While flights up to the level of the peaks have been recorded; these flights are without cargo, passengers, or a full fuel load. While it may be possible to monitor the passes with helicopters, the endurance would be brief. It may not be possible to carry a sensor load, observers, and a full load of fuel. A partial fuel load may be required that would limit the length of each flight. Numerous daily flights may be needed to cover the areas of interest. This could lead to a need for multiple machines and crews that would lead to increased costs.

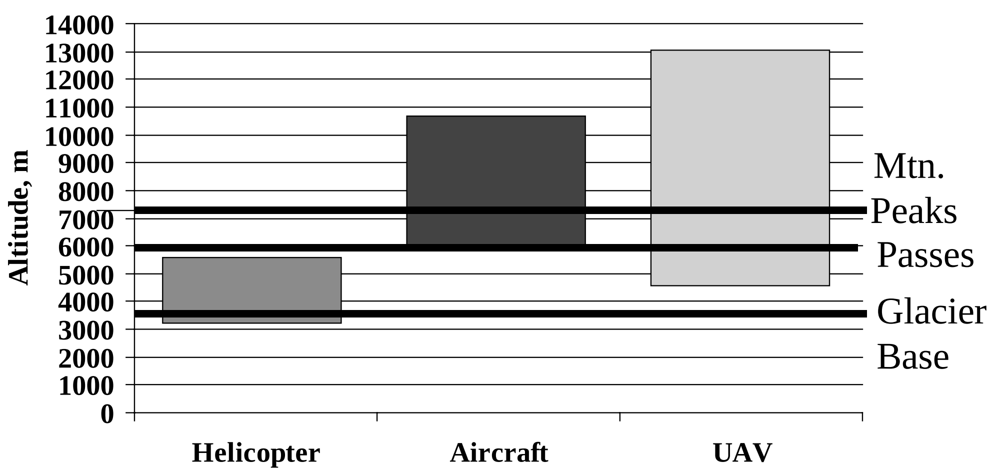



*Figure 11. Range of Aircraft Ceilings and Altitudes in the Siachen Region*

Manned aircraft are available that can meet the altitude requirements. They are turboprop or turbocharged piston, twin-engine aircraft. While there should be no difficulties obtaining these aircraft, the altitude requirement does drive up the cost. In addition, international flight safety rules specify minimum safe altitudes for fixed wing aircraft. While flights under visual, clear weather conditions only require a few hundred meters of clearance, under instrument flight conditions (night or poor visibility), fixed-wing aircraft must maintain an altitude 600 m above the highest peak within 8 km.[21] This adds an additional 600 m to the altitude that the aircraft must be able to fly. It also might mandate the use of large, expensive sensors to detect activity in the valleys, which can be several kilometers below the altitude of the peaks. While the governments of the two countries can waive this rule, use of lower clearances would increase risk to the crews.

UAVs are available to meet the requirements; however, they are not simple or inexpensive. Capable, relatively expensive UAVs are needed. Not only are these machines more costly, but they are also less available, and government licenses might be needed to obtain export approval. While UAVs can fly at the altitudes associated with the Siachen region, they do have problems with data links. The high peaks will tend to block the line of sight from the ground control stations to the air vehicles. Line-of-sight blockage will not only interfere with image transmission, but also with control of the UAV. Numerous UAV crashes have been attributed to loss of the data link between the GCS and the air vehicle. To avoid this, only three options are possible: autonomous action, data link relays, and manned airborne control stations. While autonomous action is possible, this reduces the usefulness of the UAV because imagery is only available when the UAV returns to base. It also reduces the acceptability of the UAV because there would be less confidence that the system was not being diverted to extraneous uses. A relay station appears to be a better solution. The relay station could be based on a satellite, a high peak, or another UAV or manned aircraft. There may be export problems associated with obtaining a satellite link. A ground station could be difficult and dangerous to install and maintain. For these reasons, an airborne platform operating as a data relay station or as a primary control station appears to be the best option. This will, however, add complexity and cost to the UAV system.

Other considerations should be taken into account. The approach routes to the critical passes are all in deep valleys. It would be useful to be able to go into the valleys to examine detections more closely. This may present a danger to manned, fixed-wing aircraft. Helicopters or UAVs would be freer to go into those valleys. Helicopters have one option that is not open to either UAVs or fixed-wing aircraft: they could land and the crews could personally investigate indications of human passage. This may compensate, to an extent, for their altitude limitations.

A final consideration would be weather. If the risk of losing the aircraft was considered acceptable, UAVs could be flown in marginal weather conditions where it would be considered too dangerous for manned aircraft. This could deter attempts to move troops on the ground in weather that is too dangerous for flying. Icing conditions are a hazard for all types of aircraft. Manned aircraft and UAVs should have anti-icing systems.

Both UAVs and fixed-winged aircraft are given high scores in this area. Significant problems exist for the helicopter, however, because of ceiling limitations, and it is given a low score.

***Detection*—**To detect any exceptions to disengagement agreements, the likely features of these exceptions must be known. The concern of both parties in a Siachen disengagement scenario would be the reintroduction of troops into the Zone of Separation. A renewed military presence would have several characteristics that can serve as observables. People, shelters for the people, military equipment, and transportation systems are essential for any military operation. The following list shows some observables that are likely to be present in case of an exception to a disengagement agreement.

- Huts
- Helipads
- Supply dumps
- Artillery
- People
- Snowmobiles
- Helicopters

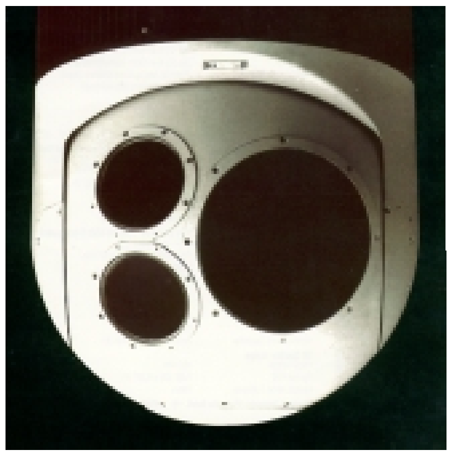
Pictures of some of these observables are shown in Figure 12.

Source: Sugarman, *War Above the Clouds*[22]

*Figure 12. Example Observables*

To detect an exception to an agreement, at least some of these observables must be detectable by whatever sensors are used on the aircraft. For this type of monitoring, imaging sensors would be the systems most likely to be useful. Candidate sensors are listed earlier in this report. For this scenario, the most appropriate sensors appear to be film and TV cameras, IR imagers, and SARs. Visible light cameras typically have the best resolution and can produce the most detail. IR imagers enable nighttime monitoring. In addition, as human shelters must be heated to be habitable, the heat could produce a noticeable IR signature. SARs could image through ground fog and metal objects tend to have very prominent radar signatures.

To determine the feasibility of detection, the capabilities of the sensor system must be examined. It is believed that all three candidate platforms could carry adequate sensors to accomplish the monitoring mission. For the purposes of this analysis, it will be assumed that all three platforms would carry the same sensors. To serve as a representative electro-optical sensor suite, the Wescam Skyball 14 system was chosen. This system is currently employed on the Predator UAV and it is compatible with helicopters and manned aircraft in terms of size and weight. A picture of the system is shown in Figure 13.



Source: Wescam

*Figure 13. The Wescam Skyball 14 System*

This system combines a daylight TV camera with an IR imager. Some relevant parameters of the system are shown in Table 3.[23]

**Table 3. Skyball Parameters**

| Parameter | TV | IR Imager |
|---|---|---|
| Spectral Range | visible | 3-5 micron |
| Resolution Elements | 768 x 494 | 512 × 512 |
| Field of View (degrees) | | |
| Wide | 23 × 17 | 40.9 × 31.3 |
| Medium | 2.3 × 1.7 | 5.4 × 4.2 |
| Narrow | 0.38 × .29 | 1.4 × 1.0 |

A representative film camera, the KA-91, was also examined. This is one of the sensors chosen for the U.S. Open Skies aircraft. The KA-91 parameters are shown in Table 4.[24]

**Table 4. KA-91 Parameters**

| | |
|---|---|
| **Spectral Range** | Visible |
| **Field of View (degrees)** | 93 |
| **Resolution** | ~.04 milliradians |
| **Film Type** | Plus X (3404) |

Figure 14 shows estimated ranges at which the observables listed above could be detected against the natural background. The narrowest fields of view for the TV and IR imager would probably not be used for normal surveillance, as the image area is very small. A very fast scan rate would have to be used to cover a significant amount of territory. This would give the operators very little time to examine the image. Alternately, the data would have to be stored and examined later.

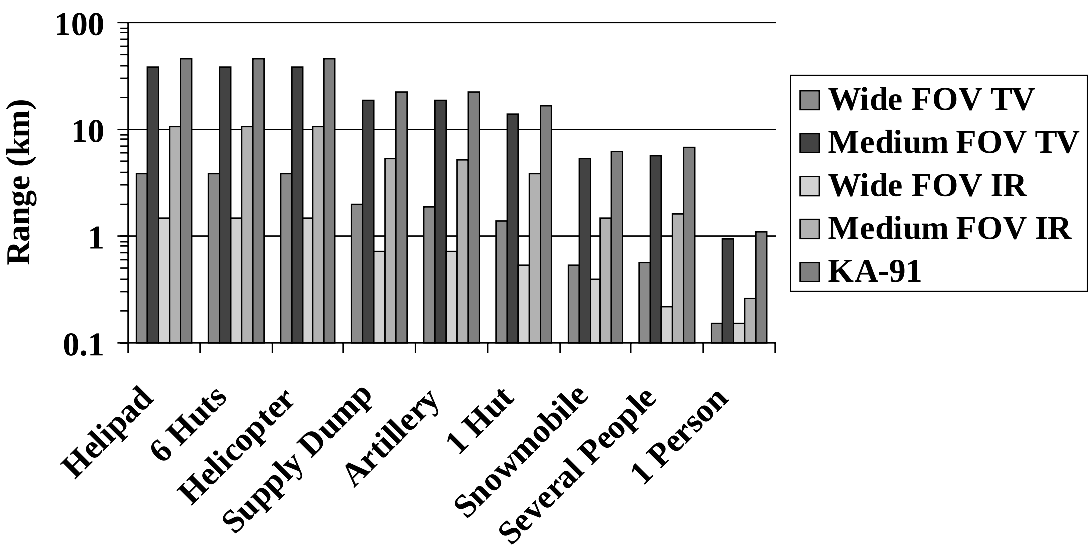



*Figure 14. Detection Ranges in km for Airborne Sensors*

It can be seen that the most difficult targets are lone humans. Using conservative detection criteria, the detection range is a kilometer or less. In order to reliably detect small groups of people, the platform using the TV or IR sensors must fly lower than the mountain peaks in order to get close enough to the valley floors. While the helicopter is well suited for this, there is more difficulty for the fixed wing platforms. The safety regulations can be relaxed for the UAV. The manned aircraft is more problematic. As stated earlier, under some conditions the aircraft must operate 600 m above the highest peak within 8 km. As there are 7600 m peaks in the Saltoro range, the manned aircraft would have to operate at an altitude of 8200 m or more. At this altitude, the distance to the passes can be as much as 2800 m, while the distance straight down to the glacier can range from 2500 to 4000 m. At these ranges, only the very largest observables would be detectable to the TV and IR sensors at the wide field of view. If the safety regulations were not relaxed, then the manned aircraft would have to operate with narrow fields of view or with the film camera in order to detect smaller objects. Also, the clouds, haze or fog that force the manned aircraft to fly higher will also come between the sensors and the ground. UAVs and helicopters may be able to fly beneath the weather.

SARs, until recently, had relatively poor resolution. Advancing technology has recently brought SAR resolution to where it is comparable to electro-optical resolution. While the Open Skies SARs are limited to 3-m resolution, recently resolutions as good as .1 m have been cited in product literature.[25] This is sufficient to detect the observables listed above. SAR has the advantage that the resolution is independent of range as well as lighting and weather conditions. The range of the Lynx SAR, which is currently being produced for the Predator UAV, is greater than 25 km. If such radars become exportable, they would be an attractive choice. Additional capabilities offered by SARs include the use of coherent change detection or interferometric SAR. These techniques could detect new outpost construction, even if it were very well camouflaged visually.

The UAV and helicopter were given high scores. Because of possible problems with resolution from safe altitudes, the manned aircraft was given a medium score.

***Identification*****—**An attractive feature of imaging sensors is that they have the inherent ability to perform identification as well as detection. Imaging sensors need a certain minimum resolution to recognize targets, which is more exacting than the resolution for detection. The resolution needed to identify the target is a function of the target size, contrast, shape, and orientation. Targets with a distinctive shape, for example helicopters, are much easier to recognize than targets whose shape is similar to that of nearby features. Figure 15 shows recognition ranges for the Skyball and the KA-91. It was assumed that once a target had been detected, then the sensor would be increased to maximum optical power to identify the target. For this reason, the maximum magnification of the TV and the IR imager were used. (It should be noted that the recognition ranges of the IR and the KA-91 are so close that the lines overlap.)

When compared with the detection ranges in Figure 14, it becomes apparent that for daylight conditions, detection is the stressing condition. If a target is detected, it is simple to switch to a high resolution, narrow field-of-view sensor to recognize the target. If a target can be detected, it can then be assumed that it will be recognized. However, if the manned aircraft must maintain a high altitude for safety reasons the smaller observables may not be recognizable by the IR sensors. This means that the usefulness of the manned fixed wing aircraft will be limited under night conditions.

As SAR resolution does not depend upon range, then the altitude restrictions of the manned aircraft would be less important. A possible problem is that SAR imagery does not resemble visible or IR imagery. Many man-made objects stand out against natural backgrounds on SAR imagery, which will enable targets to be recognized as intruders, even if exact identification is not possible.

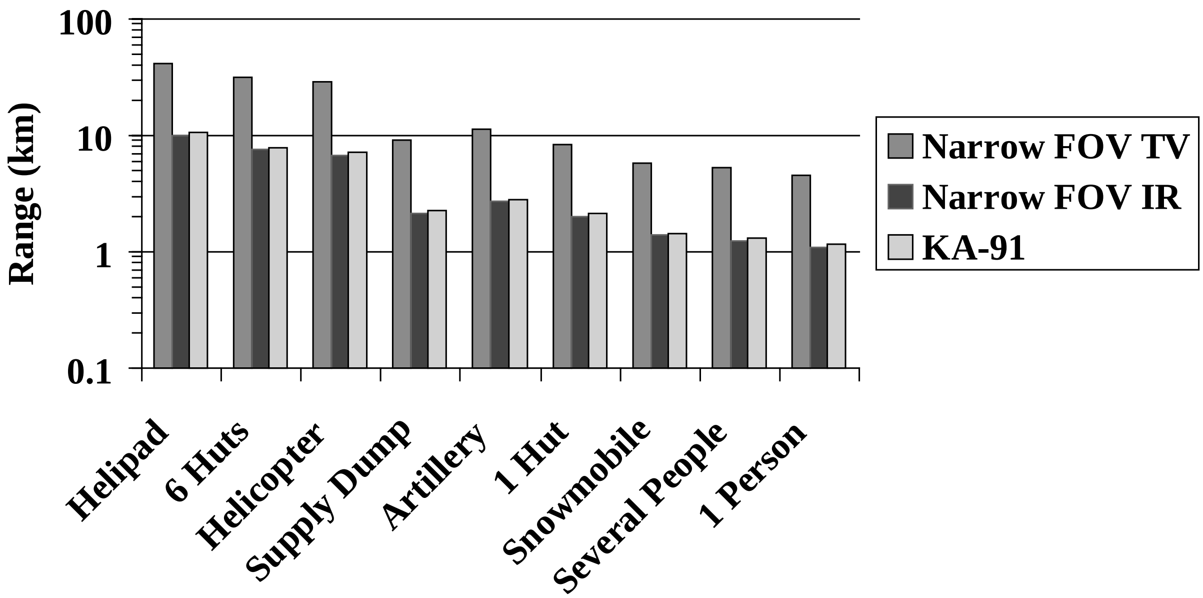



*Figure 15. Recognition Ranges for Optical Sensors*

It therefore appears that sensors are available that could be used to detect and recognize activity on the glacier and around it. All three candidate platforms could carry those sensors. However, manned fixed-wing aircraft may have some problems with recognizing the smaller observables, when flight safety requires a relatively high altitude. Helicopters and UAVs, with fewer restrictions, appear to have a potential advantage here. For these reasons, the helicopter and UAV were given high scores, and the fixed-wing aircraft a medium score.

***Robustness*—**Robustness concerns center around two questions. First, could troops evade detection by camouflaging themselves or digging into snow? Second, could troops move and dig in during weather that would ground aircraft?

No firm answer is possible utilizing the available resources. Some discussion of the issues is possible.

The possibility of evasion by camouflage or digging in could be minimized by frequent, random missions. Moving troops could be surprised if overflights were sufficiently random. Frequent flights could also lower the probability that troops would have enough time to conclude evasion efforts. Key needs are night and all-weather sensor capabilities. IR imagers would prevent the use of night as a time of activity. In addition, use of the IR spectrum provided additional phenomena that could be used to detect activity. It may be possible to detect camouflaged huts by detection of the heat signature. Some ventilation will be necessary to keep the occupants of outposts alive, and heating is another necessity. SAR would provide all-weather capability and makes additional signatures visible. Metallic objects such as artillery tubes are particularly visible to SAR.

SAR can also help counter weather problems. A frequent problem would be fog in the mountain valleys. People could move on the ground, while aircraft could not detect them. SAR might help with this, particularly if a moving target indicator mode could be added to the basic radar.

The remaining question is whether troops could move when weather precludes any flying at all. It can be argued that if the weather prevents flying, it would also raise the dangers of moving on the glacier, perhaps to a prohibitive level. It would seem that at the least bad weather would slow movement on the glacier. This would increase the chance that a troop unit would still be traveling when the weather cleared and the aircraft could fly again.

One final consideration is that monitoring with UAVs might be feasible in weather conditions that would be considered too dangerous for a manned aircraft. The limitation here would be the available money to replace UAVs that were lost because of bad weather.

All three systems have some challenges in meeting the robustness criterion. However, these challenges do not appear to be overwhelming, and all systems were given a medium score.

***Response Support***—An attractive feature of any monitoring system would be the ability to support whatever response is made to the data that it gathers. Most airborne systems have the ability to loiter in the vicinity of the detection and monitor the activity there over some period. In this case, a long-endurance-type UAV could have a significant advantage over a manned system. Long-endurance UAVs have demonstrated flight lengths of over 40 hours.[3] This endurance could be used to characterize whatever has been detected. It could track a moving object for a long period, and could even be used to guide a response party. In addition, the UAV may be less noticeable than a manned aircraft and therefore less likely to trigger evasion attempts or attacks against itself. However, the several hours endurance of the manned aircraft would be sufficient in most circumstances.

While having less endurance than a UAV, a helicopter could land at the scene of activity, which would enable further on-site investigation or even a confrontation with intruders.

For the reasons discussed above, all systems are given a high score.

***Acceptability*****—**For a monitoring system to be acceptable to both parties in an agreement, concerns about intrusiveness and controllability must be addressed. In this case, the most probable concern would be that the monitoring system could be used outside of the area of agreement in order to perform military intelligence missions.

With manned systems, agreement provisions mandating that personnel from both countries would be present in the aircraft whenever it flies could mitigate this concern. The observer would have to be able to ascertain if the aircraft departed from agreed flight paths, and would thus have to have access to navigational information. The aircraft would be subject to inspection to ensure that no sensors outside of the accepted suite are installed.

The novelty and potential long range of the UAV could work against its acceptability. Several measures could be taken to increase its acceptability. First, the UAV would be maintained jointly so that both parties could inspect it. Second, a system of dual-party control could be maintained, so that neither party could fly the UAV by themselves. A possible way to achieve this could be a dual key system to unlock the GCS. Finally, whenever the UAV was flown, observers from both parties would be present at the GCS so that the position of the UAV would be known at all times, and the imagery would be available simultaneously to both parties.

Because of the novelty of the UAV, it was scored somewhat lower than the manned systems. Acceptability was not seen as an insurmountable obstacle, however.

***Cost—***One of the great potential benefits of UAVs is in terms of cost, both monetary and human. A preliminary examination of costs indicated that for a system of the required capability, the annualized cost for a manned aircraft (which would include fuel, maintenance, and the procurement cost of the aircraft and sensors, amortized over 10 years) would be approximately US$1.2 million per year. The UAV system would cost substantially less, with annualized costs of approximately $700,000. The helicopter costs would fall between the two systems' costs, but would tend to be closer to the cost of the UAV than to the fixed wing aircraft. These costs would include an electro-optical sensor system. A SAR system would increase the price. The Wescam EO/IR system would cost approximately $400,000[23], while a high-resolution SAR would cost approximately $1-1.5 million.[3] Personnel costs would probably be similar for all systems, requiring, at a minimum, a crew of two to operate the system, plus at least one observer from the other party. The parties would take turns operating the system. Training costs may be somewhat lower for the UAV system.

The principal advantage of the UAV may not be in dollar costs but in human costs. No human lives would be at risk under the UAV option, while employing both helicopter and fixed wing aircraft would be dangerous. It must be remembered that a major purpose of a Siachen military disengagement agreement would be to save lives. For this reason, the UAV scored high in this category while the manned systems were seen as more costly and risky and given medium scores

***Exportability—***The availability of the monitoring system without restrictions is an important issue. The fact that relatively capable systems are needed to operate in the Siachen region and monitor the Zone of Separation with a reasonable probability of detection indicates that there may be problems with obtaining the needed technology without restrictions. As an examination of the export policies of every country that might conceivably supply the system is impractical, for this study, the example of the U.S. was used. An examination of the applicable State Department and Commerce Department regulations revealed the following salient points.

Daylight TV cameras are widely available and there do not appear to be any restrictions upon them.

Night-capable sensors, such as IR imagers and SARs, may have restrictions placed upon them, especially if they are capable of high resolution.

The situation with respect to platforms is mixed. While there do not appear to be restrictions on fixed-winged aircraft and helicopters of the type needed for the Siachen, there might be restrictions upon UAVs with the required capability. The commerce regulations state that systems with significant military potential may be restricted, and UAVs are among the list of technologies that may have significant military potential. In particular, UAVs with a potential range of 300 km or more could be considered by the U.S. government as potential cruise missiles and could be governed by the provisions of the Missile Technology Control Regime.[26]

When the term "restrictions" is used above, this does not mean that export is prohibited. It does mean that an export license must be granted. The U.S. government could put conditions upon the granting of such a license.

For these reasons, it seems that the cooperation of the U.S. government will be needed, if U.S.-source sensors and/or UAVs are desired. The desire of the U.S. government to see a lessening of the conflict between India and Pakistan may act as a counterweight to U.S. concerns about the transfer of technologies with military potential. It may be that the U.S. government would furnish the systems, but would require safeguards to prevent misuse or unauthorized technology transfer.

If an alternate source such as Israel were used, their particular export regulations would have to be consulted as well.

Because of these considerations, the UAV was given a medium score, while the manned systems were given high scores.

## *7.7 Evaluation Results*

The results for the evaluation of the three candidate airborne monitoring systems are shown in Table 5. For each criterion, each of the systems is scored with a symbol. A circle indicates that the system has a high score in this area. A square indicates that some questions or challenges exist in this area, or the system simply does not perform as well as the other systems. A diamond indicates that significant problems exist here.

## *7.8 Conclusions for the Siachen Scenario*

From this analysis, several conclusions can be reached, as follows:

- The Siachen monitoring mission would be challenging for any monitoring system.
- Airborne systems could be used to monitor a potential Siachen Glacier military disengagement agreement.
- UAVs have significant advantages for monitoring in this environment. They receive no low scores and more high scores than the other platforms.
- The chief uncertainties about using UAVs are whether they would be exportable without severe restrictions and whether the parties to an agreement would accept a new, unfamiliar system.

**Table 5. Evaluation of Airborne Monitoring Systems for the Siachen Glacier Scenario**

| | **UAV** | **Helicopter** | **Manned Aircraft** |
|---|---|---|---|
| **Access** | ● | ◆ | ● |
| **Detection** | ● | ● | ■ |
| **Identification** | ● | ● | ■ |
| **Robustness** | ■ | ■ | ■ |
| **Support of Response** | ● | ● | ● |
| **Acceptability** | ■ | ● | ● |
| **Cost** | ● | ■ | ■ |
| **Exportability** | ■ | ● | ● |

**Key**

● Suitable

■ Some concerns exist

◆ Significant challenges exist

## Overall Conclusions

The following overall conclusions about UAVs may be made:

- UAVs have not been used for cooperative monitoring to date and the technology as a whole is relatively new. Evaluations should be made on a case-by-case basis.

- UAVs can be useful in many applications requiring airborne monitoring or remote sensing. They are especially useful in situations that require difficult, long-duration, or dangerous flight regimes.

- UAVs are competitive with manned aircraft for cooperative monitoring.

- UAVs are not trivial to acquire and use.

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