4.0 Operational Tasks and Their Related Sensor Needs

4.1 Introduction

The Air Force faces critical roles in modern warfare, but the transition of thinking from the NATO versus Warsaw Pact Nation conflict to the regional conflict anywhere in the world presents yet a greater responsibility within the Global Reach—Global Power nature of the Service. The levels of conflict, with a near-continuous spectrum from peacetime to war, present challenges to sensor developers that are technically global.

The information needs of the various levels of command vary greatly for the major conflict and the buildup to that stage. Translated to sensor terms, the information need is for a continual, near-real-time, near perfect picture of the battlefield. This need is all-pervasive and spans the situation assessment, master attack planning, air tasking order preparation, mission planning, mission execution, battle damage assessment, and mission re-tasking. Figure 4-1 depicts the range of functions.

- **Peacekeeping**
  - – Treaty Verification/Violation Detection
  - – Diplomatic Leverage
- **War on Drugs**
  - – Land & Sea Surveillance
  - – Land Vehicles, Boats, Low/Slow Aircraft
  - – Downlink to Enforcement Agencies
- **Surveillance**
  - – World-wide Deployment
  - – Precise Detection & Location
  - – Individual Targets Presented in Overall Context
- **Situation Assessment**
  - – Early Indication & Warning
  - – Discern Intentions
  - – Flag Mobilization/ Deployment
  - – See and Understand the Situation
  - – Diplomatic Leverage
- **Warfighting**
  - – Low/Medium/High Intensity Conflicts
  - – Contingency Operations
  - – Precision Target Detection, Acquisition, Location
  - – Surprise Attack Negated
  - – Battle Management
  - – Dramatic Shift in Loss Exchange

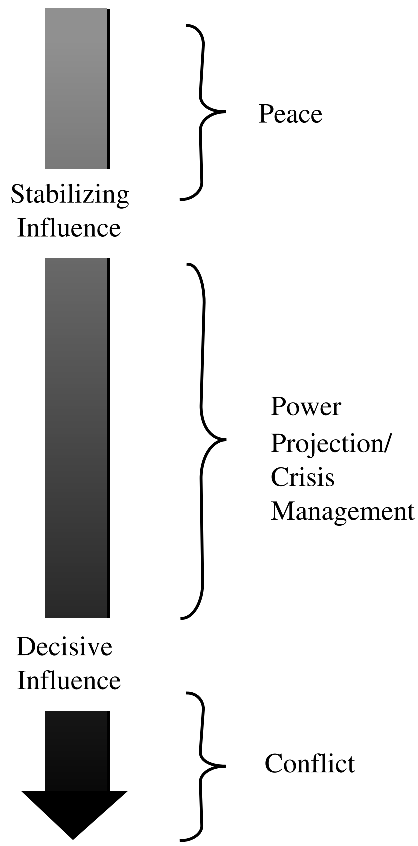

Figure 4-1. Range of Military Operations

A wide range of sensors is needed, though improved performance in cluttered and urban environments represents a more important capability enhancement than new sensor phenomenologies. Cost is of great importance in the current environment, not only the cost of the sensor itself but the cost of employing and maintaining the sensor system, whether it be on the ground, in an aircraft, or in space.

The targets of the future will be better hidden in the background in which they operate (stealthy), smaller, faster, and operating in all weather. Our sensors must be effective in such an environment, must be capable of identifying the target, and must be reliable. Table 4-1 matches the key missions and the associated general challenges.

Table 4-1. Mission to Challenge Mapping

Mission	Challenges
Counterair	Low Observable Aircraft and Cruise Missiles Long Ranges
Interdiction	Long Ranges Denied Territory Underground Targets
Close Air Support	Target Friend or Foe Large Target Densities
Surveillance and Reconnaissance	Wide Areas Denied territory Underground Facilities Low-Observable Ground Targets Perishability/Latency Dissemination
Special Operations	Denied territory Perishability/Latency Maintaining Survival/Covertness

Sensors will operate in the various classes of Air Force aircraft in use today (fighters, bombers, reconnaissance, transports) and the unmanned air vehicles (UAVs) of the future (reconnaissance and, perhaps, attack platforms). The UAVs will pose particular design challenges due to their constrained cost, size and weight, and perhaps the need for ATR to make up for limitations on data transfer rates. On the other hand, UAVs will provide unique capabilities of self-deployment world-wide, and very long on-station times.

Not every problem is solved by new sensors. We (the military in general) certainly have not learned to effectively extract information from the sensors, or combinations of sensors, we have now. Multisensor systems offer a tremendous potential, but only if we learn to effectively select the sensor combinations for the information they might provide, and properly combine data to derive useful information from these selected sensors. ATR techniques can include accessing or requesting additional data for the target identification decision and drawing on supplementary information sources.

For the purposes of identifying appropriate sensor concepts and the related enabling technologies, a set of representative operational tasks associated with the Air Force missions are selected. The operational tasks are not all-inclusive but suffice to develop a context that spans the range of Air Force sensor functions. The selected representative operational tasks are:

- Acquire, maintain, and disseminate a full, near-real-time situation awareness picture of the battlefield.
- Maintain continuous world-wide surveillance of NBC weapon manufacture, storage, and transfer.
- Locate, observe, and target assets and activities in hardened/underground facilities.
- Acquire, locate, track, and identify ground targets to deliver munitions with high accuracy.
- Detect, track, intercept, and destroy theater ballistic missiles and cruise missiles.
- Acquire, maintain, and disseminate information to plan and execute special operations and military operations other than war (SO/MOOTW).
- Acquire information for force sustainment.

The use of these operational tasks as a framework for investigating sensor technologies does not suggest that the list is exhaustive. Rather, we have chosen these operational tasks to identify key sensor tasks which then define a range of specific sensor needs and approaches. Moreover, we recognize that there is overlap in the listed operational tasks. This overlap is to be expected, and the ensuing discussion will attempt to address the sensor concepts and technologies so as to serve all appropriate sensor tasks. Table 4-2 relates the operational tasks to the Air Force missions.

Table 4-2. Representative Tasks to Missions

Representative Operational Task	Air Force Mission
Maintain Situational Awareness	Counterair Interdiction Surveillance and Reconnaissance Special Operations
Find Weapons of Mass Destruction (Nuclear, Biological, Chemical)	Interdiction Surveillance and Reconnaissance Special Operations
Surveillance of Underground Facilities	Interdiction Surveillance and Reconnaissance Special Operations
Kill Air and Ground Targets	Interdiction Close Air Support Special Operations
Find Theater Ballistic Missiles and Cruise Missiles	Interdiction Surveillance and Reconnaissance Special Operations
Conduct Special Operations and Military Operations Other Than War	Interdiction Surveillance and Reconnaissance Special Operations
Gather Information for Force Sustainment	All

The following discussion of the selected operational tasks is a top-down approach to identifying the sensor concepts and technology needs for the Air Force of the year 2025. It identifies the functions associated with each operational task, establishes the critical challenges for the future, then formulates sensor concepts and technology solutions to achieve the needed capabilities.

4.2 Battlefield Situational Awareness

Operational Task: Acquire, maintain, and disseminate a full, near-real time situation awareness picture of the battlefield.

4.2.1 Description of Operational Task

Tasks that support the acquisition, maintenance, and dissemination of a full, near-real time situation awareness picture of the battlefield include:

- Collect and fuse data from all available civil, diplomatic, and military sources including surveillance, reconnaissance, intelligence and operational information on order of battle and own force status, as well as history, economics, culture, geography, geology, trafficability, weather, hydrology, and so forth.
- Maintain multiple copies of the database, each containing appropriate information relevant to the scope of the intended user community, for example, from the President to the Private.
- Extract data on short notice from the national level system that is relevant to an anticipated potential crisis area and route it to a suitably equipped crisis management center or operational user.
- Index, organize, cross-reference, and distribute data for storage and use at multiple locations (from a national crisis center to a theater command center, to a squadron command post, to an on-aircraft data terminal).
- Perform dynamic distributed “truth maintenance” functions across databases at all levels.
- Detect and reject incorrect data inserted by enemy information warfare.
- Flag for further analysis specific items of interest and changes that exceed user specified bounds or historic norms.
- Present appropriate “views” of the information for users, highlighting changes and specific items of interest and enabling the user to rapidly gain an up-to-date mental model of the situation.

4.2.2 Sensor Challenges

The United States has enjoyed a long period of military and commercial sensor dominance that is now eroding as other major powers improve their capability and supply smaller countries with very capable information-gathering systems. There is a need to develop technologies that maintain or regain the advantage over our potential adversaries.

Of particular importance are the challenges associated with detecting and locating:

- Targets in hides, such as berms, tunnels, underpasses, caves, and canyons.
- Targets concealed in foliage and camouflage.
- Targets with highly reduced observables (radar cross section, infrared signature, acoustic noise, electromagnetic radiation, and visual image).
- Targets for which there are non-military objects that have a strong resemblance such that determining military targets is very difficult.

4.2.3 Applicable Sensor Concepts

There is a critical need to structure a global surveillance architecture that capitalizes on the attributes of satellites (GEO, LEO); unmanned air vehicles (high, medium and low altitude and endurance); manned aircraft; and ground/surface sensors in an affordable, yet capable way. The architecture would include the following concepts:

- Space based sensors will provide wide area coverage with active monostatic and bi-static radar, laser sampling, and passive hyper-spectral optical instruments.
- Unattended sensors will report measurements of interest spontaneously or when asked.
- UGS and minidrone/robotic (bumblebee) sensors will be implanted in advance or in response to crisis and provide detection, classification, ionization, hypothesis formation, and communications through appropriate readout/relay platforms.
- All useful information will flow to the master distributed database and in parallel to all interested users. Fusion of multisensor data will refine and clarify fuzzy hypotheses initially derived from single sensor data.
- National and theater databases provide storage, archiving and retrieval services. Generation of database queries, with fusion of data from multiple independent sources and partially fused intermediate results will take place at all levels that have access to outside data and the necessary processing assets.

4.2.4 Enabling Technologies

Many of the technologies that enable this vision of global situation awareness are communications and information technologies. Among the most challenging are:

- Fast, large, ultra reliable secondary and tertiary mass storage devices with built-in processing for indexing, cross-referencing, and retrieval.
- Fuzzy hypothesis formation and intelligent agents for distributed truth maintenance.
- Low cost, moderate power, tunable, coherent lasers.

- For space based radars: high efficiency, light weight solar cells and power conditioning; high efficiency RF conversion, light weight, high gain antennae; and low power, ultra-reliable spaceborne processors.
- Analog-to-digital converters with both higher sample rates and higher linear dynamic ranges.
- Database fusion, correlation, storage, and query techniques to quickly access data or task sensors to collect further data.

4.3 Surveillance of Weapons of Mass Destruction

Operational Task: Maintain continuous worldwide surveillance of NBC weapons manufacture, storage and transfer.

4.3.1 Description of Operational Task

The objective of this operational task is to maintain continuous world-wide surveillance of sites that manufacture, store or transport NBC weapons. This includes the requirement to:

- Reliably detect and characterize each manufacturing site, including having knowledge of the volume and type of NBC material being produced; understanding the relationship of the NBC material and its "cover" production material; and completely describing the factory production process.
- For storage sites, determine the location of the sites, the amount and type of material or weapons stored, and the relationship to other "cover storage " materials. Any movement in or out of the site, and even relocation within the site should be monitored, with particular attention given to those observables that might indicate intention.
- The transport information includes a description of the location, time, and means of transport of the material to other sites for storage, or to the weapon delivery system (such as a ballistic missile launcher).
- An additional information need occurs after attack of a site. In this case it is desired to know if the material in question was destroyed and, if not, where it is being dispersed.

4.3.2 Sensor Challenges

Since many of the NBC sites are intentionally hidden, the sensor challenges are driven by a lack of direct observables. Direct signatures of production process byproducts such as gas effluents, thermal energy imbalance, nuclear events, and so forth are rarely available or are ambiguous, are available too late for desired counter action, or are very weak so that they are easily confused or masked by other natural events. Weak signatures also make detection via remote sensing techniques difficult for all but very small areas because of the long integration times needed to achieve reliable signal measurement.

4.3.3 Applicable Sensor Technologies/Concepts

A world-wide "map" database should be developed with a risk (likelihood that NBC materials are at the site) assessment for each candidate site. This risk index includes a confidence level and is continuously updated as new information is made available.

Several new sensor information sources can contribute to the overall NBC information fusion and collection tasking capability. They are described below:

- **Economic, Supply and Development Information**. This information deals with the equipments and raw materials purchased by companies/countries (perhaps obtained from world-wide delivery companies like Federal Express, etc.), the plans for construction of new facilities, the support infrastructure for new sites (energy, water, waste removal), and the energy balance and product (material) output of a site (including waste byproducts).
- **Ground and Near-Ground Based Microsensors**. This class of sensors are micro-machines and point measurement/sampling sensors that can support a wide variety of measurement phenomenology, including acoustics, seismics, thermal radiometry and imaging, spectroscopy, tilt, magnetics and vibration. The sensors can be delivered by air or through covert implantation via agents or special operations. Point sampling can also be accomplished by airborne sampling via miniature UAVs or ground-based crawling machines (from insect- to rat-sized).
- **Enhanced Active/Passive EO/IR (Spectral) Sensing**. This sensor concept utilizes advanced focal planes and tunable filters to support passive hyper-spectral remote sensing. Tunable lasers are used for narrow-band active spectroscopic sensing of gas and materials. Technology growth will support increased sensitivity, larger search rates and reduced false alarms. The sensors can also be miniaturized for man portable units to be carried by Special Operations personnel.
- **Supply Chain Tagging**. This sensor concept is related to the above in that special materials/devices are used to mark materials or vehicles with unique signature generation devices or coatings. Many tagging materials can provide unique spectroscopic signatures that can be measured hyper-spectrally by systems as discussed above. The techniques allow sensing and tracking of supply materials and final products as they relate to specific production facilities.
- **Stimulated Response**. Because the candidate site are well hidden and the observables are well controlled, alternative means are needed to confirm the site purpose. One approach is a "closed loop" measurement scheme whereby specific misinformation about the site is publicly released to cause the adversary to take action to further protect/deny/cover its existence. For a specific site, the strategy is to stimulate a new observable which is not consistent with the alleged factory purpose and thus would provide a cue of covert NBC activity.

4.3.4 Enabling Technologies

Many of the sites are intentionally hidden and masked where possible. Only indirect indicators were identified to characterize each candidate site. The detection of candidate sites without collateral information is an open (unsolved) problem. The observables identified are only partial indicators of site purpose. The optical remote spectroscopy and ground sensor, coupled with tagging devices, are the only viable means to gather the partial indicators of site activity. Fusion of site information and process models are the only methods identified to accurately characterize a site.

Specific enabling technologies include:

- Small, tunable lasers support active spectroscopy to detect and analyze effluents from the sites.
- Low cost focal plane arrays, tunable filters to support passive spectroscopy.
- Femtosecond lasers and laser radar systems to provide molecular identification.
- Micro-electromechanical systems required for covert point unattended ground sensors.
- Tagging materials that can be covertly embedded in materials to support material tracking.
- Adaptive tasking algorithms to support information gathering strategies based upon confidence levels.
- Information fusion stations for supporting multiple information source fusion for NBC sites data.

4.4 Surveillance of Underground Facilities

Operational Task: Locate, observe, and target assets and activities in hardened/ underground facilities.

4.4.1 Description of Operational Task

Countries (developed and developing) are, on an increasing basis, constructing and relocating their critical military complexes and facilities for production of weapons of mass destruction (WMD) underground. The reasons are twofold: the facilities are more difficult to detect and monitor, and they are much more difficult to neutralize/incapacitate/destroy.

The functions of air power in reference to UGFs for which sensors would have an important role are:

- **Surveillance of Underground Facilities**. Collecting information about a UGF, its characteristics, and any associated activities to:
  - Verify that an underground facility is present in the area
  - Determine the geographic location of the facility
  - Determine the function of the facility
  - Determine the characteristics of the UGF
  - Determine and measure operating signatures and monitor activity at site

- **Mission Planning and Targeting**. Providing information about critical components, meteorology, and the positioning of aim-points; identify and locate equipment and LOCs critical to site operations.
- **Strike**. Support fusing and verifying a weapon's performance, including real-time battle damage assessment.
- **Post-Strike Battle Damage Assessment**. Providing data about the effectiveness of the strike, weapon performance, collateral effects, and repair activities, including:
  - Assess the damage caused by the strike and its environmental effects
  - Monitor the reconstruction and the activity levels of the facility

4.4.2 Challenging Sensor Needs

The challenges associated with underground facilities are related to the fact that these facilities are designed to be undetectable. Therefore, we must employ sensors that can "penetrate" earth to detect a void or man-made structure or employ indirect means of detection such as observing collateral activity, effluents, machinery vibration, and so forth.

The phenomenology determines how and which UGF features are observable with certain kinds of sensors. Table 4-3 is a representative example of features, their observables, and the associated parameters of observation.

4.4.3 Applicable Sensor Technologies/Concepts

Because mission requirements involve the detection and monitoring of almost all UGF features, potentially useful sensors include virtually all types: electromagnetic, photographic, seismic, acoustic, chemical, biological, and so forth. Table 4-4 lists some of the more promising kinds of sensors for detecting and monitoring UGF features.

4.4.4 Enabling Technologies

Since the UGF task is so encompassing and may require all forms of sensors in performing the associated functions, a wide variety of enabling technologies are also relevant. Some of the enabling technologies associated with the specific sensor concepts indicated above are summarized here:

- **Arrays of Seismic and HF EM Sensors With Tomographic Processing**. The key technology to be developed for this concept is the seismic and HF tomographic processing technique for dealing with both amplitude and phase over a band of frequencies of a decade.
- **LIDAR for Effluent Analysis and Vibration Detection**. Small, tunable, solid state laser sources suitable for UAV operation are needed.
- **Unattended Ground Sensor (Chem/Bio, Acoustic, Electromagnetic)**. The development of small, near-real time chem/bio sensors is the key technology challenge for this class of sensors.

Table 4-3. Representative Features, Observables, and Parameters

Example Features	Physical Observables	Observable Parameters
Effluents		
Gaseous	Vegetation, Rock Varnish, Chem/Bio Agents	Spectral Absorption, Emissivity, Luminescence, Microwave Reflectivity, Chem/Bio
Liquid	Vegetation, Rock Varnish, Chem/Bio Agents	Spectral Absorption, Emissivity/Reflectivity, Luminescence, Microwave Reflectivity, Chem/Bio
Communications Signals		
Electromagnetic Emissions	Electromagnetic Radiation, Vegetation Effects	Microwave Emissivity, Spectral Reflectivity
Antenna Complex	Antennas, Heating, Electromagnetic Radiation	Spatial Arrangement, Temperature Differences, Microwave Reflectivity
Size and Layout	Cavity, Structural Members	Gravity Gradient, Magnetic Gradient, Telluric Properties
Construction Materials	Shielding, Materials	Magnetic Gradient, Resistivity
Transportation		
Roads & Rails	Roads & Rails	Spatial Arrangement, Thermal Properties, Spectral Reflectivity, Microwave Reflectivity
Runways & Helipads	Runways & Taxiways, Water Channels	Spatial Arrangement, Spectral Reflectivity, Thermal Properties, Microwave Reflectivity
Electrical Power	Power Lines, Transformers, Heat Production,	Spatial Arrangement, Thermal Differences, Microwave Reflectivity
Heat Exhaust	Heat Dissipation, Vegetation Effects, Snowmelt	Thermal Properties, Spectral Reflectivity, Microwave Reflectivity
Air Handling Components	Intake & Exhaust Ducts	Thermal Properties, Vibration
Operations Machinery	Surface and Air (Sound) Vibration, Electromagnetic Emissions	Vibration
Process (Raw) Materials	Materials, Storage Areas/Containers, Vegetation & Soil Effects	Spatial Arrangements, Spectral Absorption/Emissivity, Spectral Reflectivity, Luminescence
Location		
Far From Population Centers	Context	Spatial Arrangement
Near Military Facilities	Context	Spatial Arrangement

- **HF/VHF Interferometric SAR**. This involves the development of narrow notch filters and processing techniques involving adaptive apodization to produce image point spread functions with low sidelobes to reject interference. Other enabling technologies related to this concept are ultra-wideband airborne antenna structures (approaching 100 percent bandwidth), high power, ultra-wideband components, for example, switches, and analog-to-digital converters, to deal with the very large dynamic range of signals associated with this application. Coherent change processing allows the detection of very small (few mm) subsidences and subtle surface disturbances. The development of improved image registration algorithms is important to permit the application of this concept.

- **Weapon-Borne BDA Sensors**. These sensors will accomplish battle damage assessment (BDA). High “g” forces must be endured, and a method must be found to communicate the assessment to the delivery aircraft, or to our forces, to determine if re-strike is required.

Table 4-4. Sample Features Versus More Capable Sensors

	Sensor Type								
Example Features	**VIS**	**M/H**	**US**	**TIR**	**SAR**	**GPR**	**LAS**	**GEO**	**NBC**
Effluents									
Gaseous		X	X				X		X
Liquid		X	X				X		X
Communications									
Electromagnetic Emissions		X		X				X	
Antenna Complex	X			X	X				
Size & Layout						X		X	
Construction Materials						X			
Transportation									
Roads & Rails	X	X		X	X				
Airports & Helipads	X	X		X	X				
Electrical Power	X			X	X				
Heat Exhaust		X		X	X				
Air Handling Components				X	X		X	X	
Operations Machinery					X		X	X	
Process Raw Materials	X	X	X				X		
Location									
Far From Population Centers	X								
Near Military Facilities	X								

X	Likely the better class (maybe more than one) of sensor for observing the feature based on phenomenology
VIS	Visible and near infrared sensors (photo/electro-optical)
M/HS	Multispectral/Hyper-spectral sensors
US	Ultraspectral sensors
TIR	Thermal infrared semsprs (single/multiple band)
SAR	Symthetic aperture radar sensors
GPR	Ground-penetrating radar sensors (maybe similar to SAR, but designed for sub-surface imaging)
LAS	Laser sensors including molecular absorption, scattering, vibrometry, luminescence
GEO	Geophysical sensors, includes seismic, acoustic, magnetic, gravimetric, EM sensors
NBC	Nuclear, biological or chemical sensors

4.5 Accurately Deliver Munitions

Operational Task: Acquire, locate, track, and identify ground targets to deliver munitions with high accuracy.

4.5.1 Description of Operational Task

Targets to be attacked include theater ballistic missile transporter-launchers, aircraft parked in revetments, enemy command posts, bridges, weapon storage sites, manufacturing plants, enemy tanks, personnel carriers, and troops. Mobile or relocatable targets require different weapons targeting strategies than fixed targets. The effective destruction of targets requires successive steps:

- Wide area search and localization of the target, or of a target rich area so as to cue the attack.
- Target acquisition to provide accurate identification and location of the target such that a weapon can be directed to the target aimpoint.
- Flyout and midcourse guidance of the weapon.
- Terminal guidance of the weapon/munition, either as a continuation of a precision midcourse guidance, or as a terminal seeker acquisition and guidance to the aimpoint.
- Observation of the munitions effects for the purpose of BDA as required to determine whether re-attack is necessary.

4.5.2 Sensor Challenges

Successful destruction of air and ground targets requires a number of sensor-related challenges:

- For an uncued air-to-ground (A/G) situation, search up to 15,000 square km per hour (a 750 km by 20 km area), with no more than one false weapon release. A targeting sensor may be cued by some other sensor, but in some cases it will not be cued. For those cases, we need a search capability.
- For the air-to-air (A/A) situation, sense all targets within an elevation of 60 degrees and an azimuth of 360 degrees.
- Weapon release should be available at maximum weapon range. This means target detection, recognition, ID, and identification friend, foe, or neutral (IFFN) has occurred. In addition, target priority has been determined and a firing solution has been achieved—all prior to reaching maximum weapon release range.
- Targets should be acquired in all weather conditions, day and night. Targets obscured by CCD or foliage, inside revetments or bunkers, or otherwise concealed must be located and classified.
- As the weapon approaches the target, the location of the weapon relative to the target must be determined more accurately and at a higher update rate until impact.

- Bomb damage assessment is essential to determine if a target has been killed, or must be attacked again.

4.5.3 Applicable Sensor Technologies/Concepts

Target attack capability depends on a mix of EO/IR and microwave systems for affordability, accuracy, weather resistance, and jam resistance. Some of the more important elements are:

- Multispectral EO/IR sensors for wide area A/G search.
- Determination of local weather/environment to establish selection or delivery of weapons.
- High bandwidth (high range resolution) microwave A/G sensors to reduce pixel size such that clutter within a pixel is within the limits that can be handled by later stages of the targeting process, but without the long dwell times associated with synthetic aperture derived angle resolution.
- Laser radar for target identification. Preferably, the same system does laser designation.
- Modulatable corner cubes on the target for covert handshake and IFFN determination.
- Covert radar approach to target identification handshake. This could employ a modulatable corner cube similar to the idea put forward for laser radar.
- Low cost three-dimensional laser sensors for use as seekers. With microwave radar or GPS coordinates as an initial targeting source, and then GPS/inertial to put the weapon in the basket, even a short range three-dimensional laser radar can do the final correction, especially if the weapon has a “high g” maneuver capability.
- SAR with 0.3 meter resolution and 10 meter target location accuracy for the weapon-carrying aircraft, and some method of locating the weapon to 10 m accuracy, so we can use command guidance to reduce weapon cost.

4.5.4 Enabling Technologies

The enabling technologies for the target attack operational task include:

- Affordable modular, integrated, multifunction EO/IR sensors.
- Modular, integrated, multifunction RF sensors.
- A very low cost, lightweight, three-dimensional laser radar for missile seeker use—with as much atmospheric penetration and smoke penetration capability as possible. A baseline would include a 32 by 32 high bandwidth imaging laser radar detector array at about 1.5 μm, with an alternate wavelength at 3.5 μm for smoke penetration. This is possible using an optical parametric oscillator, and a 1.06 μm laser as the drive laser.

- A low cost, but very accurate, inertial measurement unit (IMU) to allow the weapon position to be known, even after GPS is jammed. The better the IMU, the more accurate the weapon is. If we have a final seeker guidance correction, such as with a three-dimensional laser seeker, a better GPS means less correction is required.
- 1 GHz bandwidth microwave radar (probably at X-band) for high range resolution SAR. Bandwidths of 2 or 3 GHz would provide for even greater range resolution.
- A multispectral passive imaging IR sensor for wide area target detection.
- A tunable laser radar for target detection and identification of partially obscured targets.
- ATR techniques for rapid target identification.

4.6 Find Theater Ballistic Missiles and Cruise Missiles

Operational Task: Detect, track, intercept, and destroy theater ballistic missiles and cruise missiles.

4.6.1 Description of Operational Task

The United States can expect to face a theater ballistic missile (TBM) and cruise missile (CM) threat in future conflicts. In addition to the political disruption like that caused by the Scuds in the Gulf War, we are likely to face more accurate TBM/CM systems that can pose a meaningful threat to military systems, including NBC warheads. Our options begin with preventing use by destroying the equipment on the ground before the missiles are launched. Sensors for this role are discussed in Section 4.5. The next option is to deter use by holding the launch sites at risk when they launch. To do this requires sensors to find the sites and to guide munitions to attack them.

We will also attempt to destroy any missiles that are in flight. This can be done either in the terminal phase or in the boost phase for theater ballistic missiles. In the first of these cases, because the re-entry vehicle (RV) is on a ballistic trajectory, the debris (which may include chemical and biological warfare agents) will land in the defender's territory. Boost phase intercept, on the other hand, will deposit the debris in the shooter's country. In addition, if the missile has multiple warheads, boost phase intercept will kill them before they can be separately deployed (warhead fractionation). For terminal defenses, the missiles are ground based, and the seekers and FC systems will be developed and fielded by the Army and Navy. They will need sensors for warning and cueing, and these are likely to be airborne or spaceborne sensors fielded by the Air Force. Boost phase intercept will require airborne FC sensors to meet the stressing engagement timeline.

Destruction of cruise missiles in flight is difficult due to the small size (in both physical and signature senses) and the typically low altitude ingress. If the enemy is using cruise missiles to saturate our air defenses, multiple simultaneous engagements will be required. Cruise missiles may employ electronic countermeasures (ECM) such as terrain bounce jamming or towed decoys.

4.6.2 Sensor Challenges

To detect and locate a missile launcher before it launches a weapon is extremely difficult. Large areas, many hide locations, and frequent movement offer significant and, as yet, unresolved challenges to the Air Force.

After a launch, the launcher can be localized for counter-battery attacks to some extent by tracking back on the missile trajectory. If there is a weapon that can attack the launcher before it is able to move, it can be engaged; this requires either a very fast weapon, a weapon platform that can maintain fast PGMs close to the launch site, or both.

The major challenges in cueing for terminal defenses lie in the rapid acquisition and dissemination of information; the basic sensor requirements can be met with current systems, or evolutionary improvements, although improvements in IR sensors may ease this challenge by allowing small cheap satellites that can be under the control of theater commanders (see 5.2.7).

For boost phase intercept, the hardest challenges are in the weapons. The nature of the sensor challenges depends on whether directed energy (laser) or a missile is used as the weapon. For the case of the laser, the biggest challenges are aiming the laser to a fraction of its 0.5 micro-radian beam, and compensating for atmospheric distortions over a long path. In addition, if the laser cannot be maintained in a ready state, the launches must be detected before cloud break.

To attack cruise missiles in flight, we need novel seekers that can cope with the very small signatures. Techniques that can place the sensors close to the flight path are important. For the possibility of saturation attacks, high firepower surface-to-air missiles and fighters capable of multiple long range engagements are needed, with accompanying surveillance and missile guidance sensors.

4.6.3 Applicable Sensor Technologies/Concepts

For missile detection above the cloud deck, we can use space-based infrared sensors, either in GEO or, with LIGHTSATS, in LEO. The principal challenges here are to process and distribute the information. It will also be challenging to make the low earth orbit satellite system affordable in the required quantities.

An EO/IR sensor system on an aircraft could be used to precisely and rapidly locate missiles above the cloud deck. Such a system could be placed on surveillance assets normally flying in-theater such as AWACS or Joint STARS, on HAE UAVs, or on such aircraft sensor systems as Cobra Ball.

To detect a launch below the cloud deck requires either a network of ground based IR sensors deployed around the potential launch areas or radars, which may be airborne or space-based. The radars would seem to be a better choice since they can perform other missions, such as air surveillance, at the same time they look for TBM launches. The choice between airborne or space based radars will depend on the technology and the nature of the other uses desired from the system. If the system must hand off to an optical system, it may be necessary to have the radar located near the optical system to deal with the effects of atmospheric refraction. It may also be necessary to switch from a low frequency search radar to a higher frequency tracker to get sufficient accuracy for handover to a fine optical tracker.

To direct a laser weapon to the required accuracy will require an optical FC system, like the one planned for ABL. This will probably be a passive IR sensor, although an active sensor with a sensitive detector (like an APD array) might also be possible. Sensors to allow atmospheric compensation have been developed, and the technical challenge posed by compensation for long propagation paths is being investigated. An interceptor missile would likely have midcourse guidance from the radar that found the launch with handoff to an IR homing seeker.

Tracking a launcher for the time it takes to bring a weapon to bear can be accomplished by several approaches. One is a spaced based radar that can provide continuous coverage. It could be cued by the launch detection system to an accuracy limited by the accuracy of trajectory tracking. It would probably need both SAR to find the launcher and MTI to track it, and it may need to penetrate foliage. Such a sensor could be placed aboard airborne platforms, including UAVs and Joint STARS. Another choice is a collection of sensors deployed in the launch area, which could be acoustic or optical, that can track the target and respond to interrogation by the attacking aircraft. Alternatively, the launch vehicle might be tagged in some way to allow an attack aircraft to follow its track, perhaps with some material on the tire that leaves a trail that can be detected.

The detection of cruise missiles in flight requires high power-aperture product radars on air or space platforms, as well as novel seekers proliferated on the ground to detect low flyers. The use of HF and VHF radars capitalizes on the fact that the size of the target is on the order of the wavelength of the radar, such that normal RCS reduction techniques are less effective. Proliferated ground sensors employing acoustic and infrared detection will be effective. Detection sensors must be closely coupled with the FC and kill systems because of the time sensitivity of the solution.

4.6.4 Enabling Technologies

Many of these sensor needs can be met by current technology or incremental improvements. Providing the constant surveillance and rapid communications required for boost phase intercept and counter battery missions will require improvements in the information technology employed. The technologies associated with the detection and neutralization of cruise missiles are further discussed in the 1993 AFSAB Summer Study, “Options for Theater Air Defense.”

Wide area surveillance sensors coupled with techniques for area delimitation may help in the search for launchers.

To provide nearly continuous space-based radar coverage for counter battery operations will require several SAR sensor systems in low earth orbit (LEO).

Optical FC systems with passive or active IR sensors are important to this task, including development of the sensor, optics, and pointing subsystem for an airborne boost phase intercept laser.

Ground based unattended IR and acoustic sensors with processing and communications may be useful for missile track reporting and transporter-erector-launcher (TEL) tracking.

High power-aperture product high frequency (HF)/very high frequency (VHF) and ultra high frequency (UHF) radar components, such that these sensors can be carried aboard such aircraft as AWACS and some HAE UAV, are promising approaches to detection of concealed targets.

4.7 Special Operations and Military Operations Other Than War

Operational Task: Acquire, maintain, and disseminate information to plan and execute SO/MOOTW.

4.7.1 Description of Operational Task

The special operations mission, more than any other military mission, must be carried out successfully the first time. As history has shown, the failure of such a mission, usually a one-of-a-kind mission carried out by small elements, becomes a national embarrassment and international news at a minimum. Thus the forces must be fully equipped, very well informed, completely trained, and thoroughly rehearsed. In an age of many rapidly evolving technologies on both sides, this is a significant challenge. As an example, the Special Operations forces typically had the night as their friend. That is, they could operate with relative impunity at night. Advances in night vision equipment and in radar have given our adversaries the capability to detect special operations at night and in poor weather, threatening the success of those operations and the lives of the special operations forces (SOF).

The SO/MOOTW mission area includes an ever-increasing series of roles in the modern world. The Air Force missions include:

- Successfully, survivably, and perhaps covertly infiltrate and exfiltrate personnel, equipment, and supplies in denied territory.
- Apply precise firepower in small areas to support military entry/exit, and combat or non-combat rescue.
- Support counter-terrorism operations.
- Provide counter-drug surveillance and intercept.
- Assist in humanitarian operations.

In fact, SO/MOOTW is the “now” war, “fought” every day in many locations around the world. In the future, SO/MOOTW will have an increasing role in the world, with particular emphasis on counter-terrorism and counter proliferation. One-of-a-kind missions will be the rule, rather than the exception.

4.7.2 Sensor Challenges

The sensors envisioned for the SO/MOOTW missions vary from small, covert unattended sensors up to airborne (on-board and off-board) sensors and even space-borne sensors with a wide range of capabilities. Concentrating on the SO/MOOTW unique sensors, the needs tend to be peculiar to a particular mission, rather than the broad applications associated with other Air Force elements. Table 4-5 depicts the key sensor challenges.

Table 4-5. SO/MOOTW Sensor Challenges

Capability	Challenge
Infiltrating and exfiltrating personnel, equipment and supplies	Maintaining covertness and/or survivability of relatively large aircraft
Detecting, locating and tracking humans in buildings	Penetrating walls, shields, rubble Low signature of humans
Locating and identifying electronic equipments	Low emissions levels Equipment in standby
Inspecting containers for contents	Penetrating containers Identifying contents
Tracking illegal cargo movement	Penetrating containers Wide search/track area Small signatures
Establish intent of humans	Small signatures
Determine and monitor underground activity	Earth/facility penetration
Locate and monitor weapons caches	Foliage penetration
Identification of objects	Sub-pixel resolution

4.7.3 Applicable Sensor Technologies/Concepts

Specific technologies that might aid the SO/MOOTW mission area include some that are unique, and many that are common with other mission areas. The SOF need many of these sensor technologies to conduct day-to-day operations now. Their missions, and the accompanying sensor requirements, will grow with time.

The general requirements include building penetration and foliage penetration radars, as well as radars and LADARs associated with target identification. These sensors must be packaged for use in transport-class aircraft, or for easy transport and air drop. In general, however, there is the need to develop small, lightweight sensors for easy and, perhaps, covert deployment and employment. Table 4-6 depicts the sensor technologies/concepts more specifically.

4.7.4 Enabling Technologies

The enabling technologies supportive of the Special Operations and Military Operations Other Than War operational tasks include miniaturized versions of many of the conventional technologies.

- Miniature focal plane arrays combined with acoustic/seismic/tilt transducers, and GPS in very small packages.

Table 4-6. SO/MOOTW Sensor Needs

Sensor Type	Sensor Concept
Building penetration radar	MTI range gated radar RF/Seismic Sensor with Tomographic Processing
Advanced sensors	Laser Radar Femtosecond Laser Radar Induced Fluorescence Tunable Laser Radar Differential Absorption Laser
Multispectral imaging	Multispectral infrared focal plane arrays
FOPEN radar	Low frequency, wideband synthetic aperture radar Gated laser radar
Building implantable sensors	Miniature spectrometers inserted with food supply to detect chemicals and effluents Miniature seismic, audio, and radio frequency sensors inserted covertly
Tags and detectors	Optical corner cubes with controllable/variable phase shift Electronic tags inserted in food supply Electronic tags implanted in friendly personnel Sensor/tags inserted in equipment manufacturing process
Personal (anxiety, stress, etc.) sensors to detect adversary's intentions	Temperature, heart rhythm, eye movement sensors implanted with food supply Miniature spectrometers inserted with food supply to detect chemicals and effluents
Effluent detection	Differential absorption laser Femtosecond Laser Radar Miniature chemical sensors

- New technologies for UGS, including new transducer fabrication and integration methods such as the MEMS technology.
- Chemistry lab on a chip technology to produce a micro-miniature effluent and agent detector-reporter.
- Tags made even smaller than current designs (micro-tags) could map water, sewer, and air flows which, in turn, could help map areas and buildings, and even help locate humans and equipments.
- Multispectral apertures (e.g., infrared (IR) with millimeter wave (MMW) and multicolor IR) are required, as are low cost, moderate power, tunable, coherent lasers, and analog-to-digital converters with both higher sample rates and higher linear dynamic ranges.

- Micro-miniature radio frequency sensors, perhaps square-law detectors on a chip to detect even LPI radiations using unattended sensors placed close to LOCs.

4.8 Information for Force Sustainment

Operational Task: Acquire information for force sustainment.

4.8.1 Description of Operational Task

A major application of sensors in Air Force operations concerns maintenance, system inspection, quality assurance, and other aspects of providing a combat-ready force. The overall vision is of a force structure in which weapon systems have high intrinsic reliability through design for long failure-free lifetimes and are essentially self-supporting under operational conditions with little or no external infrastructure required beyond replenishment of consumables. For example, diagnostics built into a combat aircraft returning from a sortie should be able to determine and report the status of the aircraft and its systems in enough detail to enable a decision on whether to send the aircraft to an integrated combat turn or to a repair point. Important elements of this task include:

- Fast, accurate, and precise diagnosis of failures and damage.
- High throughput, thorough, and affordable inspection of aircraft and other equipment for wear, corrosion, damage, or other problems.
- Maximum system autonomy, resulting in minimum requirements for specialized equipment and technicians.
- Rapid, high fidelity inspection of procured or fabricated parts and materials to ensure compliance with specifications.

4.8.2 Sensor Challenges

Better sensing capabilities are important across the spectrum of system support (see also 1994 Air Force Scientific Advisory Board Summer Study, “Life Extension and Mission Enhancement for Air Force Aircraft”). Some key sensor challenges include:

- Embedded diagnostics with the ability to accurately determine the status of hidden aircraft structures, hydraulic/pneumatic systems, electrical systems, engines, and avionics.
- Continuous and automatic maintenance sensor calibration, lubricant, and filter monitoring.
- Current nondestructive inspection/evaluation/testing (NDI/NDE/NDT) techniques for corrosion, cracks, leaks, and other problems are manpower intensive and generally require cumbersome equipment and long inspection times, restricting much of this surveillance to periodic depot visits.
- Determining the condition of parts, assemblies, and materials in storage (dormant reliability) without installing those items in weapon systems.

4.8.3 Applicable Sensor Technologies/Concepts

In general, the key to success in meeting these challenges is the deployment of small, cheap, intelligent sensing devices for a wide range of mechanical and electrical properties, backed up by data processing to extract the required information. Specific concepts include:

- **Advanced Built-In Test/Fault Isolation Test (BIT/FIT)**. BIT/FIT can employ information from a wide variety of sensors, especially using machine reasoning in onboard processors to interpret the indications. Techniques and standards (e.g., IEEE 1149) for digital avionics are well advanced. Analog, RF, and EO electronics can be monitored both with dedicated sensors such as power meters on transmitters and by analysis of output data to assess performance. RF and EO sensors can be calibrated using reference patterns that are either printed on the inside of radomes or moved into the field of view (FOV). Engines are already heavily instrumented for performance optimization, and additional sensors for such things as vibration and oil contamination could enable very thorough health checking. For example, an acoustic monitor might detect changes in the frequency content of engine noise associated with incipient blade cracks, and external engine oil monitors like the spectroscopic oil analysis program (SOAP) might be replaced by built-in contamination monitors.

  An intriguing possibility for both metallic and composite aircraft structures is the use of embedded strain gauges to monitor structural integrity; changes in strain patterns under well characterized flight loads could provide valuable fatigue and damage information. Cooperative sensing among aircraft might be a convenient means of evaluating RCS degradation. A host of other possibilities exists, including:

  - Measurement of voltage and transients on aircraft electrical power circuits.
  - Differential pressure measurements to determine when filters need replacement.
  - Position sensors for actuators to check on such things as flap rigging.
  - Contamination sensors in fuel tanks.

- **Portable, Automated Inspection Instruments (PAIINs)**. Some aspects of health and status monitoring are probably impractical to implement entirely with embedded instruments. However, we see great potential in the replacement of current inspection techniques with smaller, cheaper, faster, less manpower-intensive methods. Extensions and combinations of known sensor phenomenologies, especially those that require no disassembly or chemical treatment of the structure, are important here. Airframe fatigue and corrosion might be detected with a set of lightweight ultrasonic instruments that stimulate an airframe or other structure and measure the resulting signatures at carefully chosen points. Manual engine borescoping might be replaced by an automated instrument. There is great potential in the use of small, highly intelligent robots that crawl over and through structures to make a variety of measurements.

- **Multispectral Robotic Vision**. A substantial body of technology exists for automated inspection of objects, for example, to determine orientations on a conveyer belt. Sensing with higher degrees of dimensionality has great potential in the overall area of materiel handling and inspection as a component of highly automated and adaptive handling and shipping systems. Such instruments could perform physical mensuration, assessment of coatings and preservatives, and even verification of constituent materials, at least in the sense of comparing measured signatures to stored calibration patterns. Both in complex depot inspection stations and in portable instruments for deployed operations, such techniques could improve logistics management and reduce manpower requirements.

4.8.4 Enabling Technologies

Achieving the vision for embedded system monitoring and diagnosis depends mainly on the availability of inexpensive microsensors with high sensitivity and selectivity for the variables of interest. Silicon and other semiconductors offer a wide array of sensing mechanisms for temperature, mechanical displacement, stress, chemical species, voltage and current, and other variables, combined with the ability to embed signal conditioning and data processing functions in the sensing unit and the potential for low cost batch fabrication.

BIT/FIT for digital avionics can achieve performance on the order of detection of 99 percent and isolation of 98 percent of naturally occurring failures with a modest level of additional hardware and software. Progressively lower, but still highly effective, levels of diagnostic precision are possible for analog and RF/EO hardware using embedded calibration and test signal generation and computer monitoring of outputs. The value of these methods is multiplied by small, highly integrated multifunction sensors for environmental variables (temperature, g-forces, supply voltage, etc.).

Table 4-7 lists candidate sensor phenomenologies for structural integrity monitoring. Techniques with great promise to yield significant improvements include swept frequency eddy current measurement, high resolution real-time radioscopy (HR-RTR), and advanced pattern recognition algorithms, including neural networks, to extract precise problem diagnoses from the complex signatures produced by such instruments.

Complementary data processing techniques, mainly using artificial intelligence, can extract the maximum information from patterns of sensor outputs. Micromachines and robotics will enable the replacement of large, fixed external instruments with small, mobile, and highly portable surveillance platforms. The synergistic application of these technologies will make practical a philosophy of system design and support in which aircraft, munitions, and other assets contain the means for status monitoring and diagnosis of failures and damage, greatly reducing the requirement for external test equipment and maintenance technicians.

Table 4-7. Typical Phenomenologies Applied to NDI/NDE/NDT

NDI/NDT/NDE Category	Applicable Phenomenology
Corrosion	Eddy Currents Ultrasonics Thermal Imaging Shearography Acoustic Emission Enhanced Visual Inspection
Cracks	Magneto-Optical Imaging Radiography Enhanced Visual Inspection
Disbonding/Delamination	Ultrasonics Radiography

4.9 Summary of Operational Tasks and Sensor Concepts

The operational tasks and the sensor concepts have been presented in a mission-to-task-to-concept structure. The operational tasks are meant to establish a framework for consideration of the sensor concepts and technologies. The enabling technologies show a great deal of commonality across the various operational tasks. Table 4-8 summarizes the key enabling technologies that emerge from this analysis.

Table 4-8. Enabling Technologies

Operational Task	Enabling Technologies
Battlefield Situational Awareness	RF Conversion Moderate Power Tunable Lasers High Efficiency Solar Cells Mass Storage Devices Intelligent Agents High rate, Highly Linear Analog-to-Digital Converters Fusion/Correlation Techniques Automatic Target Recognition
Surveillance of Weapons of Mass Destruction	Multispectral Laser Radar for Effluent Detection Low Cost Focal Plane Arrays Micro-Machinable Electromechanical Systems Materials Tagging Adaptive Tasking Information Fusion/Correlation Femtosecond Laser Radars Unattended Ground Sensors (Acoustic, RF, IR, Seismic)
Surveillance of Underground Facilities	RF/Seismic Sensors With Tomographic Processing Multispectral Laser Radar for Effluent Detection Unattended Ground Sensors (Acoustic, RF, IR, Seismic) HF/VHF Synthetic Aperture Radar Weapon Borne Battle Damage Assessment Sensor
Accurately Deliver Munitions	Multifunction EO/IR Modular, Multifunction RF Components 3-D Laser Radar Miniature, High Accuracy Inertial Measurement Unit Imaging IR Sensor Multispectral Laser Radar Automatic Target Recognition Weapon Borne Battle Damage Assessment Sensor
Find Theater Ballistic Missiles and Cruise Missiles	Space Based Radar High Energy Lasers Optical Fire Control System Unattended Ground Sensors (Acoustic, RF, IR, Seismic) HF/VHF Radar
Special Operations and Military Operations Other Than War	Miniature Focal Plane Array Chem Lab On a Chip Multispectral Apertures RF Sensors Multispectral Laser Radar for Effluent Detection Unattended Ground Sensors (Acoustic, RF, IR, Seismic)
Force Sustainment	BIT/FIT Sensors Corrosion Sensors Crack Detection Sensors Disbonding/Delamination Sensors