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# PROJECT MEDSAT

## THE UNIVERSITY OF MICHIGAN

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### INTRODUCTION

During the winter term of 1991, two design courses at the University of Michigan worked on a joint project, MEDSAT. The two design teams consisted of the Atmospheric, Oceanic, and Space System Design and Aerospace Engineering 483 (Aero 483) "Aerospace System Design." In collaboration, they worked to produce MEDSAT, a satellite and scientific payload whose purpose was to monitor environmental conditions over Chiapas, Mexico. Information gained from the sensing, combined with regional data, would be used to determine the potential for malaria occurrence in that area. The responsibilities of AOSS 605 consisted of determining the remote sensing techniques, the data processing, and the method to translate the information into a usable output. Aero 483 developed the satellite configuration and the subsystems required for the satellite to accomplish its task. The MEDSAT project is an outgrowth of work already being accomplished by NASA's Biospheric and Disease Monitoring Program and Ames Research Center. NASA's work has been to develop remote sensing techniques to determine the abundance of disease carriers and now this project will place the techniques aboard a satellite. MEDSAT will be unique in its use of both a Synthetic Aperture Radar and visual/IR sensor to obtain comprehensive monitoring of the site. In order to create a highly feasible system, low cost was a high priority. To obtain this goal, a light satellite configuration launched by the Pegasus launch vehicle was used. The Pegasus is a recently developed launch vehicle designed by Orbital Sciences Corporation and the Hercules Aerospace Company. It uses the advantages of unique air launch to lift small payloads into orbit for a cost of approximately \$8 million.

### THE PEGASUS LAUNCH VEHICLE

Produced by the Orbital Sciences Corporation and the Hercules Aerospace Company, the Pegasus is a small launch system designed to place small payloads (136 to 410 kg) into orbit. Using the unique approach of an air-assisted launch, the system is able to accomplish its mission relatively inexpensively, at \$8 million for the entire launch cost. The Pegasus is fired from a special pylon under the wing of a B-52 or other similar size airplane. At launch, the airplane is in cruise flight conditions, flying at about Mach 0.8 and at an altitude of 12,000 m. The first stage ignites about 90 m below the B-52 and lasts 75 s. During this stage, the vehicle quickly accelerates to supersonic speed and then undergoes a 2.5-g pull-up maneuver. After coasting for a short time, the second stage burns for 75 s. The third-stage burn completes the orbital insertion. This occurs approximately 530 s after launch, 2200 km downstream.

### GROUND SEGMENT

The ground segment activities of the MEDSAT project have involved consideration of characteristics of malaria, site selection, data types, plans for ground station development, and the potential MEDSAT output.

Malaria is a generic term used to describe the pathological manifestations of a group of protozoan parasites of the genus *Plasmodium*. These parasites are known to cause a unique etiology in human hosts with distinct case fatality rates and patterns of symptoms. Aside from the human hosts, malaria parasites require an extrinsic period within a mosquito host in order to complete their life cycle successfully. The most common of these insect hosts are mosquitoes of the genus *Anopheles*. Although there exist approximately 400 species within this genus, only about a fifth of these are capable of actively transmitting malaria between human hosts. These vary widely in their geographical distribution, length of life cycle, and reproductive and feeding habits. A detailed study of the environment and life cycle of these vectors is essential to any program that seeks to reduce the incidence of malaria. The density of the insect vector population and their pattern of contact with infected and noninfected individuals are the main factors in determining the severity of the malaria problem in a specific area.

To select a primary site for the MEDSAT project, first a country was selected and then a specific site inside the country was chosen. The ideal country would be one with a stable government that would not only be receptive to the idea of participating in a project with NASA, but also one that possesses the necessary resources to enable both the collection of ancillary data and the useful application of the project output once it is produced. Of the nine countries selected for final evaluation, Mexico was the one that came closest to fulfilling the conditions stated above. Mexico currently accounts for 14% of all the malaria reported in the Americas. According to 1986 estimates, approximately 43 million people in Mexico live in malarious areas, resulting in 131,000 new cases annually.

To select our primary research site, a more detailed evaluation of the pattern of malaria incidence and prevalence within the selected country was completed. The final decision to select the county of Soconusco in the state of Chiapas was based upon several factors that determine a unique and urgent malaria problem in this region. Soconusco is located along the Pacific ocean, at the southernmost tip of Mexico, along the Guatemalan border. A demand for labor in this area has resulted in the large-scale influx of Guatemalan migrant workers into the region. The high number of cases of malaria in this area is most likely due to this population of migrant workers. By concentrating

surveillance and control efforts on the localities in Soconusco where these migrants are concentrated, the foci of this growing problem can be effectively targeted. In this particular study, it is hypothesized that there may be correlations between mosquito habitats and human population areas, particularly regarding vegetation and regions of standing water. However, such hypotheses need to be tested. In the research phase, ground data in the form of known mosquito habitats and actual malaria cases will be collected and used in collaboration with remotely sensed data to generate a model that can be used to map and predict those areas that are most prone to malaria outbreaks. A mobile ground station requires that only the most pertinent data be received and directly applied towards the production of a malaria risk map. Hence, the application phase will involve combining very specific predetermined data types, both ground and remotely sensed, and feeding them into the MEDSAT Geographical Information System (GIS) to be modeled and mapped. The output is envisioned as an accurate prediction device supplied to public health officials in Mexico as often as every day. The malaria risk map may for instance provide the ability to predict where and when mosquito populations will reach their maximum density allowing for the effective allocation of malaria control measures. In the long term, more and more data will be gathered and mathematically manipulated. From this process we will learn more about the behavioral and habitation characteristics of malaria transmitting mosquitoes as well as the people they infect.

#### THE SYNTHETIC APERTURE RADAR SENSOR

In order for MEDSAT satellite to be an effective tool used in determining areas of high malaria risk in the region of Chiapas, Mexico, it must possess a sensor capable of remotely sensing mosquito habitats and human habitation through rain and clouds independent of solar illumination conditions. The all-weather and day/night operational attributes of a Synthetic Aperture Radar (SAR), coupled with the ability to utilize the output imagery in identifying, classifying, and measuring the terrain parameters that are of key importance to this project, make the SAR ideal for the MEDSAT sensing platform.

Fundamental to the success of the MEDSAT project is a detailed knowledge of the spatial distribution of population densities of the malaria transport vector, the mosquito, to enable efficient implementation of appropriate disease control methods. The mosquito habitats of interest will consist primarily of wet grasslands in coastal regions to areas of partially or heavily shaded water in forest regions further inland. In addition to knowledge of the mosquito habitats, spatial distribution of migrant worker camps is also highly desirable.

#### Frequency Band

Ideally, one would like to combine the advantages of multiple frequencies into one instrument. However, due to the constraints of a small satellite, MEDSAT will employ only one microwave frequency band in the SAR design. Based on MEDSAT's remote sensing requirements, the optimum frequency band for the SAR has been determined to be the L-band (1.275 GHz/0.23 m). A radar system operating at a frequency below 5 GHz is necessary

to penetrate the crop canopy to measure soil moisture under a dense vegetation cover. L-band can accomplish that task, and can also be used to successfully identify and distinguish among various target classes such as crops, forests, swamps, and flooded forests. Another advantage of the L-band is that it requires an angle of incidence less than 20°. This is desirable for remotely sensing soil moisture to minimize both the backscattering by vegetation and the effective attenuation loss related to the two-way transmission through the vegetation canopy.

#### Geometric Imaging Requirements

Geometric imaging requirements consist of altitude and range to target, image ground-swath size, resolution cell size, incidence angle, and polarization of the transmitted microwave radiation. All these parameters are interrelated and all are ultimately constrained by the restrictive volume, mass, power, and data rate allotments of the MEDSAT project's small satellite design.

Because the antenna radiating power is directly proportional to the cube of the range to target, a substantial saving in power can occur by simply having as low an operational altitude and range to target as possible. The restrictions in power and data rate limit the SAR sensor's maximum ground-swath size range dimension, or width, to 50 km, and the maximum ground-swath azimuth dimension, or length, to 250 km.

The MEDSAT SAR design incorporates a ground resolution cell size of 75 m by 75 m. This cell size has been determined as a trade-off between achieving the maximum possible system resolution and keeping within the power and data rate constraints. Higher system resolution, and thus smaller resolution cell size, corresponds to better target detection and classification in the resulting images.

The MEDSAT SAR will employ a small incidence angle. The major reason for going to a small incidence angle radar system is the correspondingly lower antenna radiating power requirements as compared to larger incidence angle systems. Another advantage of a small incidence angle radar system is in the ability to discriminate various types of target classes, especially vegetation types. The only disadvantage of a smaller incidence angle radar system is the increase in amount of image layover for tall vertical targets like mountains and skyscrapers. Since the primary target area is the coastal plain area of Chiapas, Mexico, this disadvantage should be negligible for the present imaging interests of the MEDSAT project.

The MEDSAT SAR sensor will be fully polarimetric in order to gain an increased ability to distinguish various target classes from each other in the resulting imagery. A fully polarimetric SAR is a synthetic aperture radar system that has the ability to measure all the possible multipolar returns from the target/ground. The polarimetric information will help to fill the image interpretation gap created by having to use only one frequency band in the SAR design.

#### System Design Specifications

The determination of the SAR design parameters is not only influenced by the geometric imaging requirements and the power, size, and data constraints of the small satellite design, but also by the image quality requirements. The six design

specifications are: pulse repetition frequency, pulse length, system losses, noise temperature, signal-to-noise ratio, antenna area, and noise floor.

The pulse length was chosen as 20  $\mu$ s, and the pulse repetition frequency was determined to be 5047.95 Hz.

The MEDSAT SAR will employ burst mode operation, in order to reduce the operational data rate and power draw of the sensor. This technique works by simply turning the radar on and off in specific timed bursts during the imaging time over the target. The duration of the "burst on" time is calculated to create a synthetic aperture of sufficient length to satisfy the azimuth resolution specification. The reduction in the number of transmitted pulses for the MEDSAT SAR results in a lower operational power draw and a smaller amount of data per image.

The MEDSAT SAR will also incorporate an adaptive quantization scheme. This quantization scheme provides a data compression to complement the data reduction obtained by the burst mode operation. Applying these two techniques to decrease the amount of SAR data means that the system will operate at a much lower data rate and require substantially less memory than traditional SAR systems.

The small satellite design of this project places severe limitations upon the antenna's size and mass. Therefore, the overall size of the MEDSAT's SAR antenna will be by  $6 \times 1$  m. Drawbacks of such a small antenna include decreased antenna gain, increased power requirements and larger bandwidths. To meet the payload specifications of the launch vehicle, the antenna will be subdivided into 10 identical panels, each  $51 \times 100$  cm. These panels will be separated by 10 cm and will be supported by a foldable epoxy-graphite truss. The minimum number of transmit/receive (T/R) modules (at 12 W) needed on the antenna was determined to be 226. By using multiple T/R modules, the SAR gains advantageous beam steering capabilities. This will allow for the optimization of the main and side lobes of the antenna.

### VISUAL AND INFRARED SENSOR

Since it is not yet possible to directly sense the regions of high mosquito density, it is necessary to indirectly infer how changes in vegetation may affect the mosquito population. Therefore, a visual and infrared sensing system (VIS/IR) will be included in the MEDSAT scientific payload. The VIS/IR sensor will have two main functions. First, to detect regions in Chiapas where habitats are ideal for mosquito production. Second, to track the location of migrant workers from Guatemala. In addition to these, other functions of the sensor will be to locate geographical indicators, both natural and man-made, which with ground truth observations can aid in specifying which portion of Chiapas is being portrayed.

Remote sensing of vegetation depends greatly upon reflectance characteristics over the solar spectrum. In order to determine the malaria habitat, one must use the relationships between the mosquito habitat and vegetation, moisture, and temperature on the ground. Thus, detectors in four wavelength bands (A, B, C, and D) were considered to sense the desired characteristics. Considering each of these wavelength bands, there are advantages and disadvantages regarding the amount of valuable information given, feasibility and cost. In Band A (0.62-0.69

$\mu$ m) the reflectivity of green vegetation is very low. In Band B (0.77-0.9  $\mu$ m) the reflectivity varies dramatically among different types of vegetation, as well as in different stages for a certain type of vegetation because the reflectivity of this band indicates leaf cell structure. From this information, we can classify different vegetations and therefore find the potential malaria habitat. From Band C (1.55-1.7  $\mu$ m) one can get the vegetation moisture content information. Band D (4.0-5.6  $\mu$ m) can remotely sense the temperature.

### DATA MANAGEMENT AND PROCESSING

Data management and communication is integral to the operation of any satellite system. For the MEDSAT, large amounts of data must be collected from the SAR and the VI/IR sensors. To be of any use, these must be transmitted to a station where they can be decoded and processed into a final image. As a final step, these data may be distributed to the users and/or archived in some manner to be of further scientific use. Therefore, data management and communications must function in an efficient and timely manner.

Design constraints that limit the functionality of data management and communications are power requirements, size, weight, and time. Data management and communications must consume the least amount of power possible to afford the operation of the SAR and VI/IR sensors. Its size must be small to ensure available hardware space; its weight must also be limited to allow the maximum amount of scientific payload. Finally, the data management and communications hardware must operate quickly to ensure that data can be transmitted to a ground station. Given all these constraints, five subdivisions were considered: data handling, data processing, communications path, data compression, and data storage.

The data handling system is controlled by a customized microprocessor. This onboard computer will also control the scientific instruments and direct the flow of data collected. Raw SAR data needs to go through a great deal of processing to generate an image from the radar backscatter data. The best approach to this problem is to collect the sensor data, process the information for downlinking, and subsequently generate the image at a ground facility. The extent of onboard SAR data processing and handling would include conversion of the analog signal to digital signal, data compression, error correction coding, and storage prior to downlinking. The raw SAR sensor data is steered into an analog/digital conversion unit to be converted to a digital format. In the next step, the information is compressed by a data compression unit. After this has been completed, the error correction coding system adds correction bits to the bit stream and organizes the data into packets for transmission. The resulting data is stored by the optical disk storage system and awaits transmission to the ground receiving station.

The VI/IR data is converted into a digitized form when it is collected by the sensors. Hence, only compression and storage are required before transmitting the data to the ground for image registration. The VI/IR sensor data is handled in a similar way as that of the SAR. However, the analog/digital conversion is excluded since the sensor has already accomplished this step.

The sensor image generation and correction is performed on the ground. Once the data have been downlinked to the

receiving ground station, the information is transferred to two sites via the NASCOM system. One dataset will be transmitted to the NASA Ames Research Center while the other set will be sent to the field site in Mexico. NASA Ames will then be able to do extensive and more sophisticated imaging using the SAR data. Ames may also want to archive the generated images since the field station will be physically limited in its ability to store the large volume of information. The field station will be equipped with the hardware and software needed to process the SAR and VI/IR data.

An important aspect of MEDSAT is its data collection capabilities. In order to minimize the time required for the enormous amount of data to be transmitted, the collected data need to be compressed as much as possible. This will greatly increase the efficiency of the operation of MEDSAT. The compression method best for this design is the vector quantization method. The compression ratio of vector quantization can be specified by the designer, thus easing design constraints. The MEDSAT design team also suggests that vector residual vector quantization be used to reduce error. For decompression, the computer compatible tape is the method of choice because of the reduction in processing time required for a final image.

### COMMUNICATIONS

A satellite's communication subsystem is the link between Earth and the satellite. This allows new commands to be sent to the satellite for the sensors and the attitude control mechanism. In turn, the satellite can return the data collected by the sensors to stations on Earth where the data can be analyzed and sent to the appropriate authorities. The onboard equipment and the uplink/downlink sites make up this subsystem.

MEDSAT's onboard subsystem is made up of the offset-fed parabolic antenna, a diplexer, and two transponders for transmitting and receiving the information. The antenna dish is constructed of a 78 sq cm (2.5 cm thick) plate. It is made from a graphite composite and lined with a thin layer of reflective material. The feed is a corrugated circular horn 9.2 cm in diameter and 8.6 cm long. It is also made of graphite composite.

In determining the uplink/downlink capabilities of the satellite, the limited amount of power available was a large concern. The sites for uplinking and downlinking information with the satellite were also constrained by the inclination angle of the satellite's orbit. Hawaii was finally chosen as the site for the ground station because it fulfilled several criteria. First, it allows a sufficient amount of time between sending and the downlink to build up power. It also lies within the  $21^\circ$  inclination restraint and it is part of the U. States so that fewer political problems would be faced in establishing the site.

### MISSION ANALYSIS

The objective of the mission analysis group was to design the optimal orbit that would satisfy the sensing and launch vehicle requirements. The specific requirements that the orbit must satisfy are: daily sensing of Chiapas, a four-year life time, a low altitude, the ability to communicate with a suitable groundstation for efficient uplinking and downlinking, and good equatorial coverage.

The main concern for the design of MEDSAT is the payload weight capability of the Pegasus. As the weight is increased, the altitude that can be reached with the Pegasus decreases. Taking these limitations into account, the capabilities of the Pegasus launch system will enable the 340 kg MEDSAT to be inserted into a 477-km circular orbit with a  $21^\circ$  inclination. In calculating these parameters, the precession of the nominal orbit as a result of the oblateness of the Earth was taken into account.

A circular orbit was chosen over an elliptical orbit in order to prolong the lifetime of the satellite. The period corresponding to an altitude of 477 km is 94.1 min. This period and altitude will allow the satellite to cover the target site twice every day. This will allow almost continuous daylight sensing, thus obtaining the maximum benefit from the VI/IR sensor. However, because the precession was taken into account when determining the period, the time of day of coverage will vary. Each day, the satellite will pass over Chiapas 27.74 minutes before the previous day's pass.

One of the major effects on a low Earth orbit satellite during its mission is the atmospheric drag. The drag force acts in the opposite direction of the motion of the satellite and gradually lowers the satellite's altitude by decreasing its energy. As the energy decreases, the altitude will decrease and the orbit will decay until the satellite eventually reenters the atmosphere and burns up. As a result, thrusters will be employed to occasionally boost the satellite and offset the drag. By using thrusters, the required four-year lifetime is obtained. This will be accomplished through a Hohmann transfer maneuver consisting of two burns, one to transfer to the higher orbit and one to recircularize the orbit. This is the lowest energy transfer maneuver and consumes the least amount of fuel. The thrusters used for these maneuvers will be the same as those used for attitude control.

The airborne launch of the Pegasus from beneath a B-52 offers considerable flexibility without the launch window restrictions of ground-based launch facilities. The only restriction on the launch is that it must be over open water with a clear downrange to allow for reentry of the first and second stages. For the launch of MEDSAT the most advantageous launch site is the east coast of Florida. This will allow the Pegasus to be launched due east at  $21^\circ\text{N}$ , thus gaining the most advantage of the Earth's rotation.

### SPACECRAFT INTEGRATION AND STRUCTURES

The primary responsibilities of the spacecraft integration and structures group are developing the configuration and thermally controlling the satellite. The first and most important goal is to develop both the internal and external configuration that integrates various subsystems of the satellite into a single operating system. The basic subsystems are the SAR, the infrared sensor (IR), the power system, the attitude control, the launch interface, and the thermal control.

From a spacecraft integration standpoint of MEDSAT, the main design parameters taken into account are subsystem safety, volume, mass, and cost. There were four primary design constraints that shaped the design of the satellite. The first was the OSC/Pegasus launch vehicle, which has a total of  $7.2\text{ m}^3$  usable volume in its payload fairing. During launch, the satellite must fit within the dynamic envelope of the payload fairing

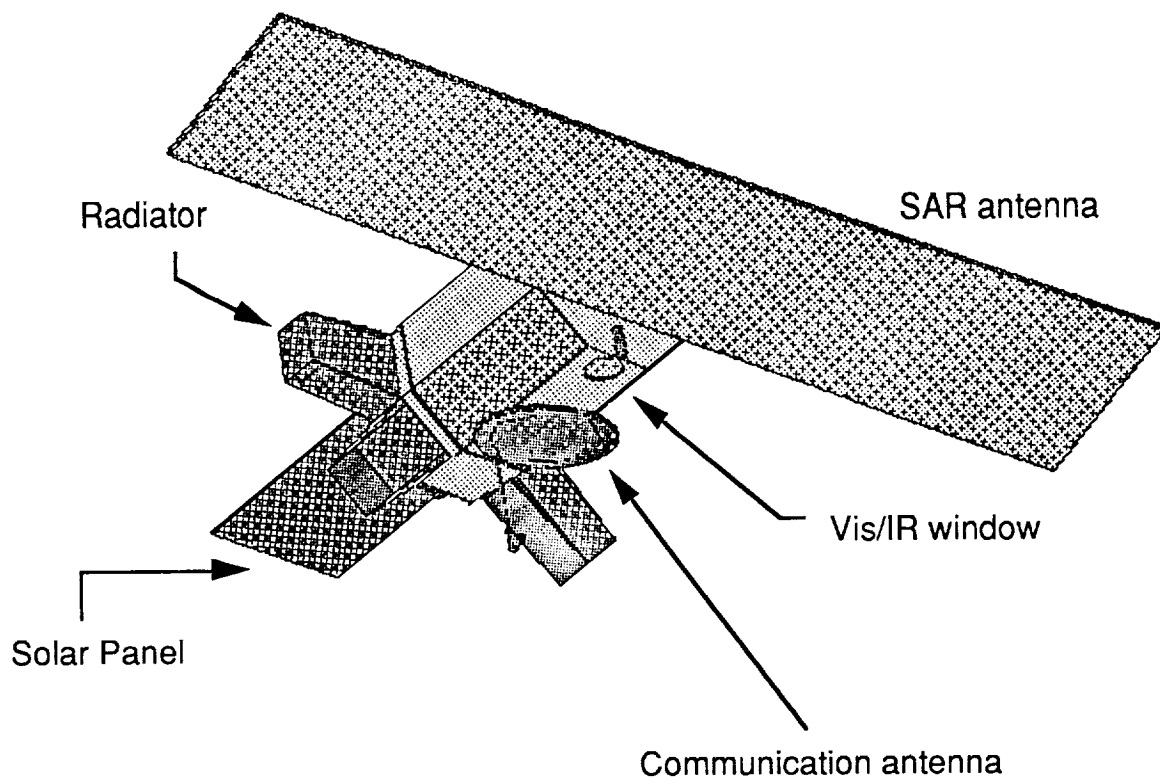


Fig. 1. Exterior shape of MEDSAT.

to avoid contact with the inner wall of the payload bay. Upon reaching orbit, subsystems will deploy into their operating configurations. Second, the combination of the orbit altitude and the launch capability of the Pegasus determines the mass of MEDSAT to be 341.8 kg. Since the total mass of the satellite is limited, the mass of each subsystem must be minimized. Due to the modern technology and the efficiency of the supporting subsystems, MEDSAT allows 28% of the total mass to scientific payloads. Third, each subsystem requires adequate safety, so that the malfunction or failure of any system does not hinder the performance of the other systems. Fourth, the low cost requirement of MEDSAT dictates that each subsystem be built with reasonable cost.

With the above design considerations and parameters, the final external configuration of the MEDSAT main body is an octagonal cylinder attached to a conical section. The satellite body is constructed with 8-mm-thick aluminum honeycomb with two 1-mm-thick aluminum face sheets. Aluminum honeycomb is chosen for its high strength-to-weight ratio. Once in orbit and separated from the Pegasus third stage, the satellite's attitude control system orients itself so that the cylindrical section points along the north pole axis of the Earth and the conical section points along the south pole axis of the Earth. The SAR consists of an antenna with deployed dimensions  $6.0 \times 1.0 \times 0.0254$  m and the supporting electronics. It is constructed with aluminum honeycomb and truss structures and it is mounted on the north

side of the satellite body. The antenna is stored in a box of dimensions  $1.0 \times 0.6 \times 0.38$  m in the octagonal section of MEDSAT. The exterior shape of MEDSAT is shown in Fig. 1.

When the satellite reaches the desired orbit and orientation, the SAR antenna slides out of the side of the satellite, unfolds its panels, and locks into a stable and rigid position facing the northern hemisphere of the Earth. All the supporting electronics are located inside the satellite body.

The IR sensor contains optical lenses, visual and thermal IR detectors, readout and interface electronics, and supporting frame. It utilizes a window opening positioned between the communication antenna and the SAR antenna allowing alignment with the axis of the SAR.

The power subsystem consists of two major components, the solar array and the battery. Driven by the power requirements of MEDSAT, the size of the solar array is 1 sq m in area and 1 cm thick. During launch, the solar array is folded and stored on top of the conical section of the satellite.

The 0.78-m-diameter communication antenna, which is constructed of graphite composite, is located on the cylindrical section of the satellite. During launch, the antenna is hinged at two points and wrapped around three sides of the satellite.

A thermal control system is used to regulate the temperature of each component. The main components that require cooling are the IR sensor and the batteries. The system includes three radiators and three heat pipes. Two radiators are used to maintain

the IR charged-couple device at 90 K. These radiators are located on each side of the communication antenna on the conical section. The third radiator is used to regulate the battery and the IR optical lenses. Because the radiating surface temperature of the radiator is higher, it is located on the trailing side of the satellite, which receives significant amount of solar radiation. All radiators will be folded during the launch. The deployed radiators will be normal to the satellite surface and point towards the south pole. Since the solar incidence angle varies with respect to the time of the year, the radiator must be shielded from both the Earth and solar radiation.

The interior components of the spacecraft also need to be insulated from the temperature extremes generated on the outer wall surface. The insulation consists of a 1-cm-thick blanket made up of 30 separate layers of Kapton. As the outer surface temperature of the satellite drops due to the Earth's shadow, the Kapton insulation is not sufficient. As a result, heaters need to be turned on to keep the payload within its operating temperature.

### ATTITUDE CONTROL

The Attitude Determination and Control System (ADCS) of the MEDSAT satellite must correctly position the satellite upon orbit insertion, maintain the nadir orientation of the spacecraft, point the scientific instruments to within  $0.3^\circ$  of the target, and provide a reference to keep the solar array pointed toward the Sun. The ADCS will have to measure and counter disturbance torques while in orbit. For a satellite in low Earth orbit, these torques will consist primarily of gravity gradient, aerodynamic drag, and solar radiation. The two main jobs the system will perform are sensing changes in position, and correcting these changes. Accordingly, the main subsystems of the ADCS are the position sensing subsystem, the attitude sensing subsystem, and the actuator subsystem. The data from any of these systems will go through the microprocessor to the other subsystems that rely on it. The positioning subsystem plays two roles. It must determine when the satellite is positioned over a particular area to know when to turn on the scientific instruments and it must determine the attitude. The positioning subsystem will utilize the Global Positioning System (GPS).

The attitude sensing subsystem is necessary in order to determine the orientation of the satellite. These sensors have two jobs: to provide orientation information to keep the scientific instruments pointed accurately and to provide a reference to the Sun for the solar array. To perform these two duties, the attitude sensing subsystem will have an inertial sensor (TRILAG gyro) and a Sun sensor.

The attitude actuator system will consist of 3 reaction wheels, 1 along each axis, and a 10-thruster propulsion system. The reaction wheels will perform corrections as needed to maintain stability for the scientific mission. The thrusters will be used for orbit insertion, downloading momentum, providing redundancy for the reaction wheels, and performing the  $\Delta V$  maneuvers necessary to prolong the lifetime of the satellite. The thrusters will be positioned so that forces can be applied to cause rotation about each of the axes without causing translational motion, as well as a causing translational motion without rotational motion.

### POWER

To achieve the project goal of low cost, the power system of MEDSAT is designed to use mostly standard satellite equipment such as gallium-arsenide solar cells and nickel-cadmium batteries. However, the system includes a modern microprocessor to increase the power system efficiency, prolong the life of the batteries, and reduce the overall weight of the power system. MEDSAT's power system is faced with the unusual task of providing high power levels to the scientific instruments for short durations in the low Earth orbit environment. This requires a battery with a large charge capacity, and also a pulse modulator to feed the SAR with the required short pulses of peak power. The first step in providing power for the satellite is to harness the energy of the Sun. A solar array generates electrical power to be used by the satellite to run various components. The solar energy is converted into electrical energy by the solar cells. The solar cells used on MEDSAT will be gallium-arsenide-based cells. The main reason why gallium-arsenide cells were chosen over silicon cells is that they offer a reduction in array area. This significantly reduces the aerodynamic drag on the satellite, which in turn reduces the fuel required during MEDSAT's lifetime. In addition, the smaller array reduces the disturbance torques on the satellite, easing the problem of attitude control. Since MEDSAT has a limited available surface area, and also due to the high power requirements, the solar cells will be panel mounted. The solar array structure itself will consist of an aluminum honeycomb core sandwiched between aluminum facesheets. A layer of insulation is located between the actual cells and the aluminum. The array will have orientation control in only the axis that is stable.

Satellites in low Earth orbit, like MEDSAT, spend a considerable portion of their orbital period in the shadow of the Earth. During this darkness, the solar array cannot produce power for the satellite subsystems. Consequently, electrical energy must be stored to provide power during this eclipse period. To do this, nickel-cadmium battery cells will be used. The battery chosen for the satellite must provide power at nearly 28 V, the satellite's bus voltage. To achieve this voltage, the battery will consist of 23 of the 1.2-V cells connected in series. One goal of the energy storage system was to be able to fully recharge the battery in one orbit after a sensing session. The battery system designed for MEDSAT is almost able to fully recharge the battery before the next orbit begins.

With the advent of lightsats and improved computer technology, power control systems are becoming more flexible and efficient. The power conditioning and control system of MEDSAT is based on an independent microprocessor that resides in the central satellite computer module. This microprocessor continually monitors the satellite power system, including the battery voltage, array current, and battery charging rate, and it can also carry out instructions received from the ground.

### FIRST-ORDER COST ANALYSIS

To address the first-order cost analysis, the satellite system was divided into subsystems. For each subsystem, actual industry estimations were used. The overall system cost was then computed by summing the subsystem component costs. The

total estimated MEDSAT project cost was \$35 million dollars (in 1991 dollars). The purpose of a first-order cost analysis is to give a general estimate of the costs over the lifetime of the mission. A degree of uncertainty is always involved in estimates. Cost overruns, schedule restraints, and the inherent speculative nature of estimating will contribute to errors.

To obtain funding for a costly space mission, it is important to be able to demonstrate the anticipated benefits. Such benefits can take two forms. Humanity can be benefited through improvements in the quality of living, and science can advance through the development of new technologies. With over half the world's population living in areas of malaria risk, the benefits

of a project like MEDSAT that could help control this disease would be very significant. The MEDSAT satellite will also be breaking new ground in the area of compact lightweight remote sensing. Never before has a satellite contained both a SAR and an IR system. In this way, the technology gained from the MEDSAT project could be used in future endeavors in satellite design.

The design team of the MEDSAT project has made a conscious effort to make this project cost effective by using the Pegasus launch vehicle and by using already developed and tested technology. The design team has realized that it is very important in these times of economic hardship to propose a project that satisfies the mission goal while being cost effective.

