Iowa Satellite Project

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Abstract

With a few exceptions, satellite systems to date have been large and expensive. Over the past decade, there has been a growing interest in small, inexpensive satellites built and operated by universities to provide students with a 'hands on' engineering experience. It was decided that the university would design, build, and operate a satellite called ISAT-1. The primary mission of ISAT-1 is to provide a broad educational experience to Iowa citizens of all age groups and educational backgrounds. The requirements of the project are that ISAT-1 must be a small, inexpensive satellite that can be launched by mid-1996, have an operational lifetime of five years, and can be designed, constructed, and operated by university students.

This satellite will have a mass of 50 kg and will be shaped as a hexagonal cylinder 34.0 cm wide and 64.3 cm tall. ISAT-1 will be launched into a circular, low Earth orbit as a secondary payload aboard a Delta II rocket in late 1995. The satellite will be stabilized using an extendible gravity-gradient boom with tip-mass and magnetic torquers. The body-mounted solar panels and rechargeable batteries will provide approximately 25 watts of continuous power. A variety of onboard payloads are designed to accomplish the educational goal including a CCD camera with a small telescope, particle detector, Earth Radio Frequency Experiment, and a robotic arm with a miniature CCD camera to examine the exterior of the satellite. Also, a network of weather stations positioned across Iowa will send weather and soil conditions to ISAT-1 for relay to the ground station. The entire project is expected to cost $2 million. The report gives an overview of the design effort of ISAT-1 and a detailed description of the bus, payload, and ground systems.

Introduction

Satellite systems to date have been mainly scientific, commercial, or military in nature. There are very few systems that provide students and ordinary citizens with a 'hands on' experience. The goal of the Iowa Satellite Project is to design, build, launch, and operate a satellite for a minimum of five years. The primary mission of ISAT-1 is to provide a broad educational experience to citizens of Iowa at all levels of education. The Project will provide products, services, and activities that will be practical and useful for a large number of people. The emphasis will be on public awareness, 'space literacy', and routine practical applications.

Background

The Iowa Space Grant Consortium was established in 1989 to facilitate space education and cooperation between business leaders and the three universities in Iowa: Iowa State University, University of Iowa, and University of Northern Iowa. It was decided that the state should embark on a project that would promote space activities and provide a 'hands on' experience to university students as well as the general public. One fairly inexpensive way of doing this was to design, build, and operate a small satellite in Earth orbit. It was decided that Iowa State University would take the lead in this project.

During the spring semester of 1992, the Spacecraft Systems class at Iowa State University started the conceptual design phase. This class decided upon the mission objectives and general requirements for the project. Several configurations and payload sets were studied. A small team of undergraduate and graduate students, funded by the Iowa Space Grant Consortium and the Institute of Physical Research and Technology (IPRT), furthered the design during the summer and fall of 1992. Also during the summer, Iowa State started taking part in the University Student Researchers Association Advanced Design Program (USRA/ADP). In December 1992, a non-profit corporation called the Iowa Satellite Company was formed to be responsible for financial and legal issues. During the spring semester of 1993, the Spacecraft Systems class selected an overall configuration and payload set and also furthered the preliminary designs for the major subsystems.

Requirements

The requirements for the ISAT-1 mission were decided to be:

- have an operational orbit lifetime of at least 5 years
- have a mass less than 100 kg

- be as 'user-friendly' as possible
- total cost over 5 years, including launch, less than $10 million
- to be launched by 1997
- to pass over Iowa at least 4 times per day

Payload

A number of experiments and applications that meet the design requirements and objectives comprise the payload set:

- CCD camera with a telescope
- Earth Radio Frequency Experiment
- Weather station network
- Micro meteoroid detector
- Solar cell experiment

A complete description of the purpose of each experiment and the work completed to date are discussed below. Other payloads such as a Global Positioning System receiver, seed growth experiment, robotic arm with CCD camera, and material solidification experiment are also being considered.

CCD Camera

One of the most common uses for a low Earth orbit satellite is taking pictures of the Earth. Pictures are one thing that everyone can understand and feel enthusiastic about; therefore, a color CCD camera will be included in the payload set. A small telescope, perhaps 10 cm in diameter, will be used to gain a greater resolution for the camera.

Earth Radio Frequency Experiment

The Earth Radio Frequency Experiment (ERF) will measure the intensity and spectrum of terrestrial communications signal 'leakage' through the Earth's ionosphere over the frequency range of 1.5 - 34.5 MHz. This experiment will collect data that, when analyzed on the ground, will help determine the spectrum, intensity, and temporal characteristics of this signal leakage. This data will be used to determine whether low frequency radio astronomy is feasible from Earth orbit.

Weather Station Network

The weather station network will be a network of ground transponders that will uplink stored and current weather and ground data collected by a variety of sensors connected to the transponder. The data from the entire network will then be down-linked to the receivers on the ground. The data will be analyzed and be available to anyone that requests it. The goal is to have at least one weather station and transponder in each of Iowa's 99 counties.

Micro meteoroid Detector

While in orbit, ISAT-1 will be in an environment filled with meteoroids and orbital debris. Within 2000 km of the Earth's surface there is about 200 kg of meteoroid material, most of it smaller than 0.1 mm in diameter. While larger meteoroids and orbital debris will most likely render ISAT-1 useless upon impact, smaller meteoroids may only cause a small disturbance or vibration. The micro meteoroid detection system will be used to count the number of impacts on ISAT-1, determine where the impact occurred, and obtain an estimate of the momentum of the meteoroid before impact.

Solar Cell Experiment

A solar cell's performance degrades due to radiation, thermal stresses, and surface degradation caused by impacts with micro meteoroids. This experiment will compare the performance of gallium arsenide cells and silicon cells covered by different material films and thicknesses.

Launch Vehicle

Several launch vehicles were considered for orbiting ISAT-1, including the Space Shuttle, Ariane, Atlas, Pegasus, and Delta II. The shuttle was rejected because the shuttle could not deploy ISAT-1 in an orbit with the minimum required altitude and inclination. Because Atlas does not currently have a designated secondary payload accommodations and the primary payload cost is prohibitively high , the Atlas booster was rejected. Pegasus was summarily rejected because of the high cost. Ariane was rejected because the launch apparatus and secondary payload configuration were not compatible with the proposed ISAT-1 design. Therefore, launch on a Delta II as a secondary payload was chosen.

Configuration

ISAT-1's bus will be a hexagonal cylinder 64.3 cm in height and 34.0 cm in width. The satellite will use gravity-gradient stabilization augmented by magnetic torquers. To increase the inertia of the longitudinal axis a 6 kg mass will be attached to a 3 m long boom.

Most interior components will be placed in boxed-shaped modules. This will allow standardization of most module components and provide thermal and radiation protection. There will be two modules for the flight computers, two modules for the two communication systems, one module for the Earth Radio Frequency Experiment, two large experiment modules, two medium experiment modules, and six small experiment modules.

The interior components will be mounted on three load - bearing shelves. The six batteries at the base of the satellite, telescope, and the two medium size experiment modules will be mounted to Shelf 1. The Earth Radio Frequency Experiment, CCD cameras, two small experiment modules, two large experiment modules, and boom will be mounted to Shelf 2. Shelf 3 will support the two flight computer modules, four small experiment modules, and the two communication modules. The bus configuration is shown in Figures 1 and 2. Table 1 shows the mass and peak power consumption of each of the components.

Orbit

The final orbit for ISAT-1 has not been finalized at this time; however, there are a few requirements that have been determined. The orbit must be near circular so that gravity-gradient stabilization can be used. To meet the 5-year lifetime requirement, the orbit must have an altitude of at least 600 km. The inclination of the orbit must be greater than 55 degrees for ISAT-1 to pass over Iowa.

Structure

The structure of the spacecraft provides the necessary physical support for all subsystems. The structure not only contains the payload and bus systems while on-orbit, but must withstand launch conditions and ensure that all of the payload and bus systems will arrive on-orbit in an operational condition.

Previous work on the ISAT structure included the selection of a hexagon shape based on solar cell power calculations. In addition, the maximum dimensions of the exterior were based on the launch vehicle payload envelope. In addition, the internal configuration was provided by the integration group.

Design Considerations.

Several design criteria for the ISAT structure were developed. These included: accommodating the internal payload arrangement as specified by the integration group, providing access to internal payloads, supporting the launch adapter, providing for attitude control mechanisms, and using as little internal volume as possible. Total structural mass, cost, and ease of fabrication were also considered.

Table 1: Mass and Power Consumption of Components

Quantity	Component	Mass (kg)	Peak Power (W)
1	Structure	3.6	n.a.
1	Boom	7	n.a.
2	Communications	3	7
2	Flight Computer	3	7
2	Large Experiment Module	3	4
2	Medium Experiment Module	1.1	1.5
6	Small Experiment Module	0.9	1.1
1	Large Torquers	0.45	2
2	Small Torquers	0.1	0.25
2	Boom Tanks	0.1	n.a.
1	Earth Radio Frequency Experiment	5.4	7
1	CCD Camera	0.4	5
1	Telescope	3	n.a.
6	Battery	0.6	n.a.
6	Battery Mount		n.a.
2	Magnetometer	0.22	0.04

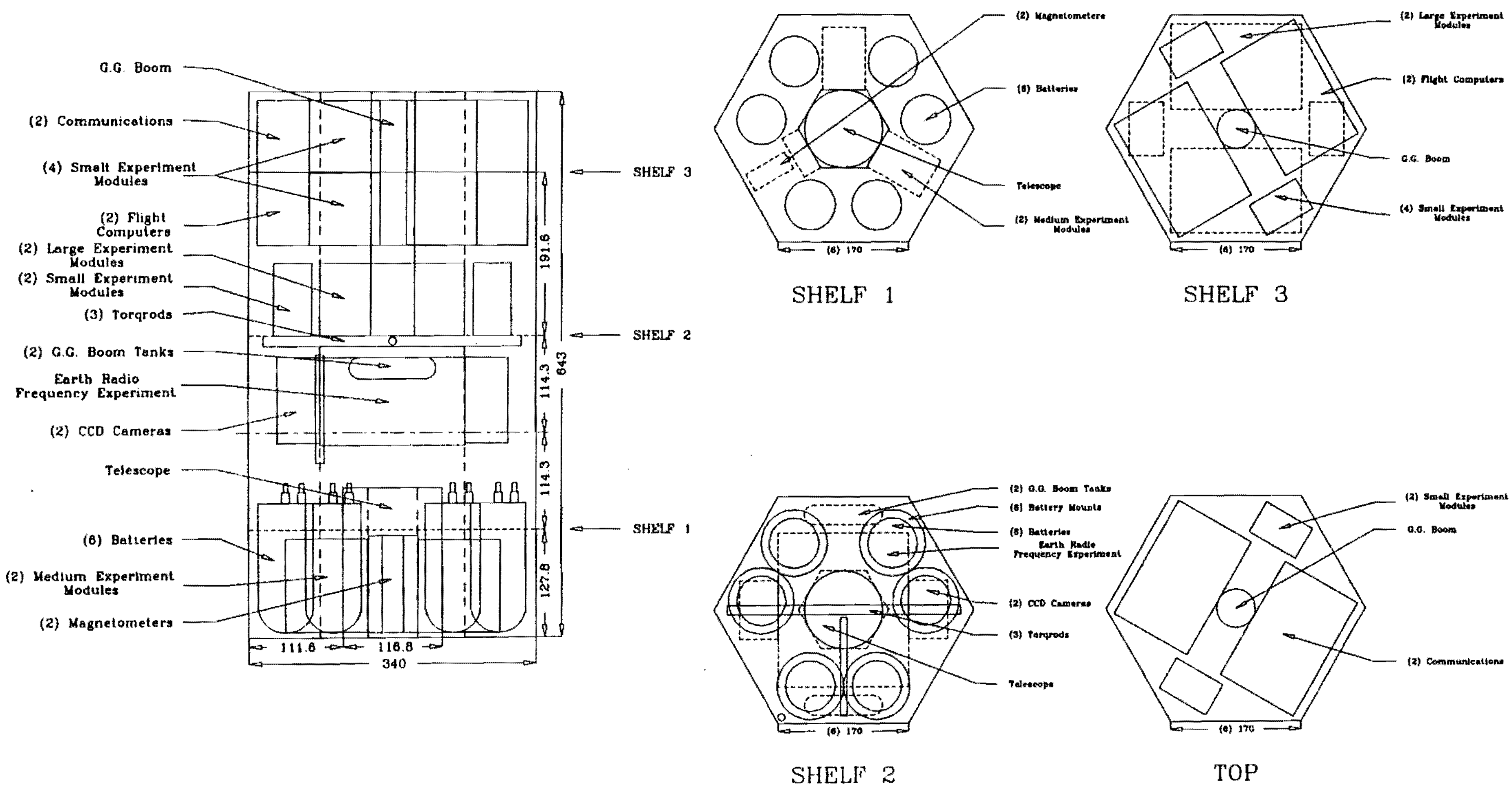
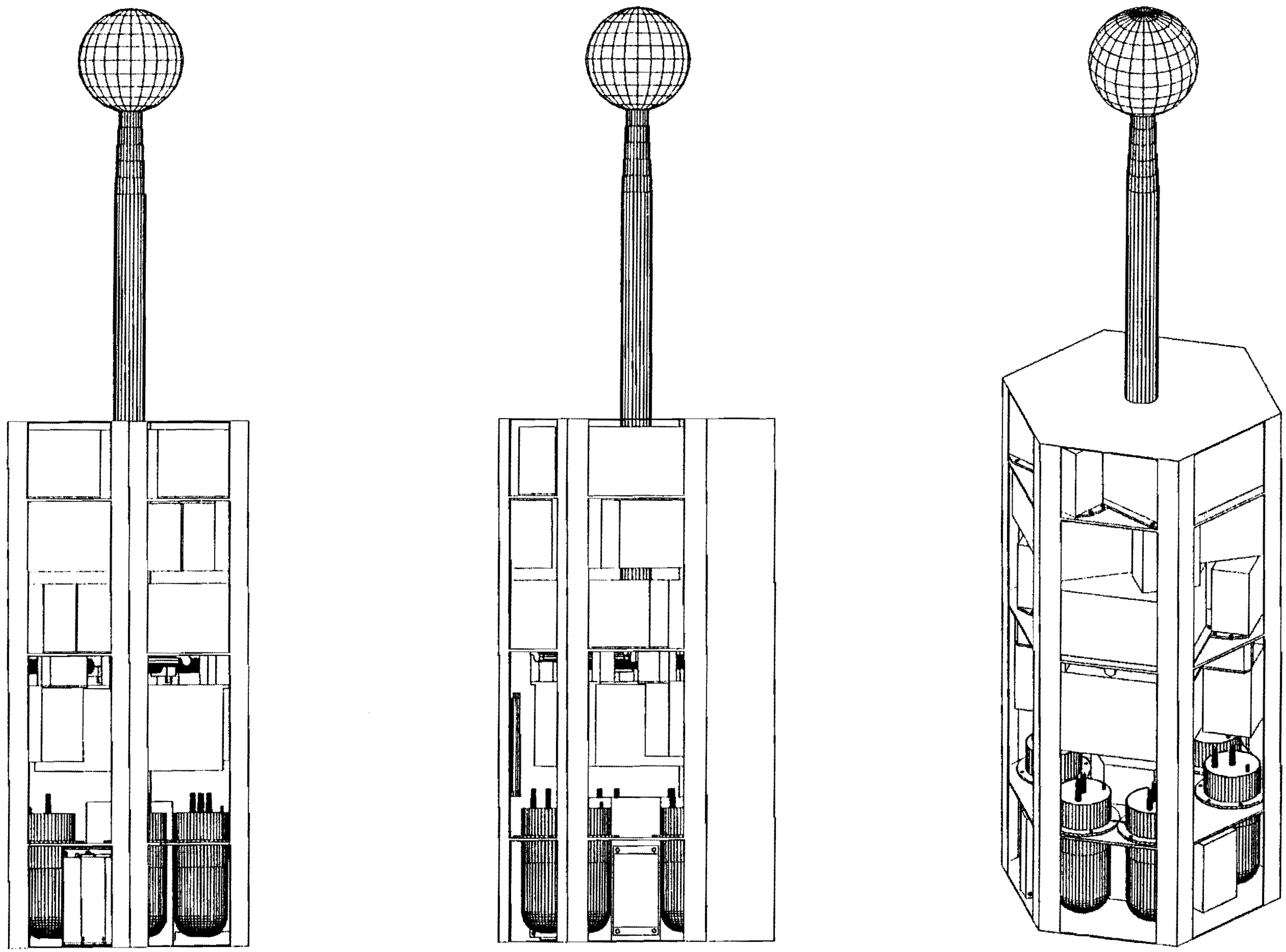


Figure 4

ALL DIMENSIONS IN (mm) UNLESS NOTED

Iowa Satellite Project ISAT-1	Packing Arrangement	Drawing File: PACK.DWG
Drawn By [redacted]	Delta II Secondary Payload (SPE1)	Iowa Satellite Company 5/12/93

Figure 2



Iowa Satellite Project	3-D Packing Arrangement	Drawing File: 3DSTRUCT.DWG
ISAT-1	Delta II Secondary Payload (SPE1)	*Iowa Satellite Company*
Drawn By: Mike		5/9/93

The internal configuration of ISAT-1 is shown in Figure 2. This arrangement shows the payload and bus systems arranged on three internal shelves. The location and arrangement of attitude control mechanisms is also shown. Most notably, the structure must be capable of transmitting control torques from the three torque-rods and from the gravity-gradient boom attached to Shelf 2.

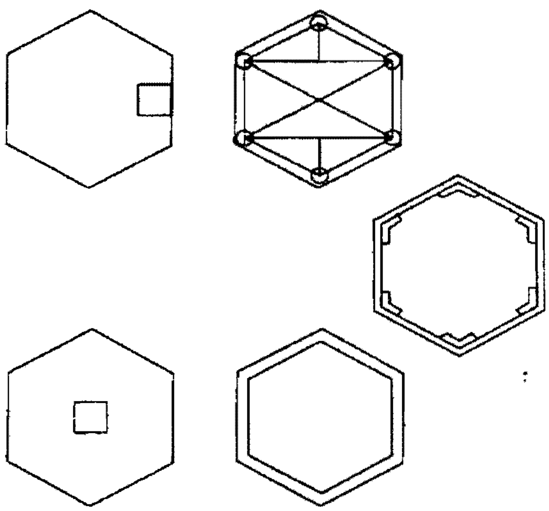


Figure 3: ISAT Structure Concepts - End View

Internal Structure

Concepts Five concepts for the internal structure of ISAT were considered. They included central support, modified central support, full monocoque, semi-monocoque, and truss. These five concepts are shown in Figure 3. These structural concepts were considered prior to determination of the internal payload arrangement.

The semi-monocoque concept would consist of skin panels attached to longitudinal stringers. The design would reduce the panel thickness while transferring more structural material into the corners of the hexagon. One panel would have to be designed to accommodate launch loads.

Selection Criteria One of the major considerations in the final selection of a structural concept was the amount of internal volume that would be required. It was felt that the semi-monocoque structure would best fulfill this criteria, as it would make the best utilization of previous unused space in the corners of the hexagon shape.

Another consideration was the ability of the structure to be adapted to the unique launch interface. The placement of the launch interface on the side of the satellite, requires that non-uniform loading be a consideration. It was felt that the semi-monocoque structure would again adequately meet this consideration. The semi-monocoque structure can be adapted to the launch adapter by varying the stringer and panel thickness on the side of the launch adapter.

Fabrication and assembly of both the structural components and the integration of the payload was also considered. The semi-monocoque concept provides for greater flexibility in fabrication and assembly sequences than the other concepts. It should be possible to design the structure such that all segments of the payload are accessible even with the launch adapter in place.

Preliminary Structure Sizing Analysis A preliminary analysis of the structure was conducted for sizing purposes. For this case, each payload was considered to be of uniform mass, and its mass would act at its center of mass on each shelf. These loads were then transferred to the six stringers for each shelf. The details of the this analysis are presented below in Table 2.

Table 2: Static Shelf Load Estimates

Bottom	0.0 N
Shelf 1	92.4 N
Shelf 2	138.5 N
Shelf 3	156.0 N
Top	t.b.d.

These loads were then used to conduct a stress evaluation of the stringers and the shear stress in the panels. A computer program was written to calculate the axial stress in the stringers and the shear stress in the panels due to the maximum shelf loading case.

Preliminary Finite Element Analysis The results from the preliminary sizing analysis were used to construct a finite-element model. The model was fixed in rotation and translation at the four launch adapter attach points. The model was loaded with the estimated shelf loads.

Structural Elements

Boom Section Selection A circular, closed-section design was chosen. This section was chosen for its torsional properties and its uniform bending stiffness. The simplicity of the deployment mechanism was also a consideration. The magnetic torquers of the attitude control system will be able to re-invert the satellite with the boom deployed, so the boom will only be deployed once.

A locking, pressure tight joint for the boom segments was developed. The design provides for a forward stop collar located on the inner wall of the outer boom section, and a series of forward segmented stops located on the outer wall of the inner boom section. A segmented stop collar is also located on the inner wall of the outer section. A rear stop collar is located on the inner section. When pressurized, the boom extends until the forward stop collar on the outer section comes into contact with the segmented collar on the inner section. The segments on the inner section slide through the gaps in the collar on the outer section, and are then rotated to lock the boom in its deployed state. The joint design also provides for the placement of three gaskets: one each at the base of the inner section, the top and base of the rear stop collar to provide a gas seal for the pressurized deployment of the boom.

Boom Sizing A design sizing code with boom length and tip mass as control variables was written to determine an optimum length and tip mass for the satellite. The code allows the user to select the desired stability in terms of the stability criterion, σ_X as defined by the following equation

$$\sigma_x = \frac{(I_y - I_z)}{I_x} \quad (1)$$

The user also selects the desired range of boom lengths and tip masses. The code then iterates through these two variables, calculating the new mass moment of inertia I_X, and uses the new inertia to calculate the value of σ_X. The calculated value of σ_X is subtracted from the target value, and the absolute value of the difference is written to a data file along with the boom length and mass. This information can then be plotted on a contour plot. Several candidate designs meet the desired stability. The final boom size was selected to be 3 meters in length with a 6 kilogram tip mass. This represents nearly a fifteen fold increase in I_X.

Boom Section Sizing Stability considerations determined the boom length and tip mass. The diameter and thickness of each section would be determined according to the loads acting upon each section. Loads acting on the gravity-gradient boom were modeled as the Earth's gravitational force acting on the tip mass. This in turn caused forces and moments to be exerted on the boom. A sizing code was written to size the boom sections based on the known loads, the material properties of graphite-epoxy composites, and a selected factor of safety. It was not possible to accurately determine dynamic loads on the gravity-gradient boom due to insufficient source data so a large factor of safety was used.

The code was set up to allow the user to choose the desired tip mass and boom length for section sizing analysis. Once the user had completed the inputs of number of sections, minimum section thickness, gap between sections, and initial base section outer diameter, the code would size the boom sections. This entailed determining the necessary outer diameters, section thicknesses, and inner diameters corresponding to each boom section. If the section thickness needed was found by the code to be smaller than the minimum section thickness, the code would substitute in the minimum section thickness and continue the analysis.

Results of section sizing yielded necessary section thicknesses for a number of base section outer diameters. A base section having an outer diameter of 3.81 cm was chosen based on the limited volume fraction of ISAT-1 which would be required. Table 3 shows the section sizes in terms of outer diameters, thicknesses, and corresponding inner diameters. It should be noted that in all cases the thicknesses used are the minimum section thickness, and the gap between sections is constant for ease of fabrication.

Table 3: Boom Sections

Boom Section Number	Outer Diameter (cm)	Section Thickness (cm)	Inner Diameter (cm)
1	3.81	0.102	3.71
2	3.61	0.102	3.51
3	3.40	0.102	3.30
4	3.20	0.102	3.10
5	3.00	0.102	2.90
6	2.79	0.102	2.69

Fabrication Methods

The mandrels used for curing of the boom sections consisted of two sections of steel pipe, each 0.61 meters in length. These were complemented by three rubber hose sections of 0.76 meters in length. The hoses had outside diameters 2.62 cm, 3.15 cm, and 3.61 cm. Each section was fabricated from three plys of woven graphite-epoxy composite. The composite material was cut to a length of 0.56 meters and a width equal to the circumference of the desired section. The three plys were then debulked with the edges staggered prior to being placed in the mandrel.

To avoid the added complexity and difficulties involved with co-curing the joints along with the respective boom sections, joints from separate cure cycles were epoxied in at a later time.

Modeling

The boom was modeled using ANSYS finite-element analysis. The boom was modeled as cantilevered with the tip loads acting perpendicular to the boom length. A static analysis was performed. The boom was found to have a maximum deflection at the tip of 0.05 meters (1.969 inches).

Shelving

Design Considerations Each shelf must be capable of supporting all loads and payloads. In addition the shelves must accommodate the payload boxes, including any unique interfaces (radiator, electrical connections, etc.). The internal volume of the spacecraft and the payload requirements limit the allowable deflection for each shelf. Other concerns include thermal conductivity, vibration characteristics, cost, weight, ease of fabrication, and ease of access.

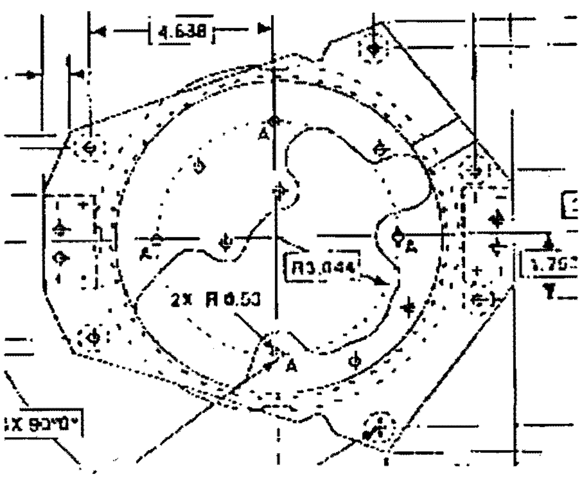


Figure 4: Payload Adapter Assembly

Launch Adapter

The launch adapter provided by McDonnell-Douglas for the SPE payload fairing on its Delta II rocket is shown in Figure 4. The launch adapter design is fixed by McDonnell-Douglas Space Systems. The adapter consists of a ring that is clamped to the launch vehicle. Six attachment bolts are provided to attach the launch adapter to the payload. The ISAT-1 structure must be designed to accommodate the given interface and be able to jettison the launch adapter when orbit is achieved. Two of the attachment bolts will not directly contact any side panel.

Several designs have been considered to meet this challenge. One possibility is the reinforcement of the side panel facing the launch adapter by addition of stringer, increasing the size of existing stringers and/or increasing panel thickness. This design may make it possible to not use the two attachment bolts not directly in contact with the panel. Further study of this design will require consultation with McDonnell-Douglas and is recommended.

Attitude Control

Because ISAT-1 will have a camera used for imaging the Earth, the satellite will need to be stabilized and controlled in a Earth-pointing orientation. The pointing requirements were set to be less than 5 degrees on the pitch and roll axis. Spin and three-axis stabilization were not considered because the pointing requirements could not justify these relatively complex and costly systems. Momentum-biased systems were considered, but rejected because of the high cost and the internal volume constraints of the spacecraft. Therefore, ISAT-1 will use gravity-gradient stabilization augmented by magnetic torquers.

Sensors

Because gravity-gradient stabilization will not give pointing control better than a few degrees on each axis, attitude knowledge requirements for ISAT-1 are less stringent than more complex systems and cannot justify massive and costly attitude sensors. It was decided that with new advances in attitude determination with magnetometers and sun sensors, these lightweight and relatively inexpensive sensors would be adequate. Two 3-axis flux-gate magnetometers mounted orthogonal to each other will measure the Earth's magnetic field and at least two sun sensors mounted on the bus surface will measure the sun angle. This will give the three-dimensional attitude of ISAT-1 to within 1 degree on each axis.

Control Hardware

A 3 meter long boom with a 6 kg mass mounted on the end will give ISAT-1 a stability ratio of 0.98 defined by equation 1. This is comparable to the stability ratios of previous gravity-gradient satellites such as Uosat-2 and Polar Bear. Three magnetic torquers will use the Earth's natural magnetic field to damp out any oscillations and correct any residual errors in the attitude. Two 1 A-m^2 torquers will be mounted along the pitch and roll axis and a 10 A-m^2 will be mounted along the yaw axis. The larger torquer will be used for re-inverting the satellite. However, current work shows that an additional 10 A-m^2 torquer may be need along the roll axis.

Modes of Operation

There are four phases of attitude control to be considered:

- Despin after separation from launch vehicle
- Boom deployment
- Normal operation
- Inversion correction

Despin. Separation from the launch vehicle will induce a tumbling motion on the satellite. The magnetic torquers will be used to slow the tumble rate so that the gravity-gradient boom may be deployed. The torquers will follow the well-known control law

$$\bar{\tau}_m = -M_{sat}\left|\frac{d\bar{B}}{dt}\right| \tag{2}$$

By numerically integrating the equations of motion using this control law, it was found that tumble rates of up to 10 degrees per second on each axis can be damped out within four orbits.

Boom Deployment. Once the attitude rate has slowed sufficiently, the boom may be deployed. Assuming no roll or yaw motion, the satellite's motion can be described by the following equation

$$\left(\frac{d\theta}{dt}\right)^2 + 3\omega_c^2\sigma_y \sin^2\theta = c \tag{3}$$

where θ is the pitch angle, ω_c is the orbit rate for a circular orbit, and σ_y is defined by the following equation

$$\sigma_y = \frac{(I_z - I_x)}{I_y} \tag{4}$$

c is the constant calculated from the initial conditions. Using this equation and assuming boom deployment in zero time, one can find under what combination of pitch angle and pitch rate the satellite will be captured in the correct orientation, i.e boom-up, for given initial conditions. Current work is being done on the effect of roll and yaw on the capture phase.

Normal Operation. Once the boom is deployed and the attitude has been captured in the correct orientation, the magnetic torquers are used to damp out any oscillations and correct any residual attitude errors. The torquers will be controlled by the following control law

$$\tau_{m\theta} = k_p B_\phi \phi - K_n \frac{dB_\theta}{dt} \tag{5}$$

where k_p and k_n are the precession gain and nutation gain, respectively. Also being considered is a Linear Quadratic Regulator type of control law.

Inversion. Due to thermal vibration in the boom or a meteoroid impact the satellite may become inverted. It will then be required to re-invert the satellite to its proper orientation; otherwise, the camera will be useless and there will be a reduction in performance of the communications system. The procedure to re-invert the satellite is currently being studied.

Power

The power system for ISAT-1 will consist of solar arrays, rechargeable battery made of six nickel-hydrogen cells, battery charge controller, and power conditioning and control unit.

Solar Array

ISAT-1 will obtain the necessary power to run the bus and payload systems by the use of solar cells mounted on the six lateral sides of the bus. The solar cells are to be arranged on panels, with each panel consisting of 32 cells each. Each panel will then have a surface area of 256 cm^2. Five sides will consist of 4 panels each, while the side with the launch adapter will have only 2 panels. Figure 5 shows the average power generation during one orbit as a function of sun elevation above the orbit plane and the efficiency of the solar array, e. Gallium-arsenide solar cells have beginning-of-life (BOL) efficiencies of 0.18 and end-of-life (EOL) efficiencies of 0.14. Silicon cells have BOL efficiencies of 0.14 and EOL efficiencies of 0.10. At the present time, gallium-arsenide cells have been chosen over silicon cells because of their greater efficiency; however, gallium-arsenide cells may be too expensive for this project. The results of a study in experiment scheduling will determine which cells will be used.

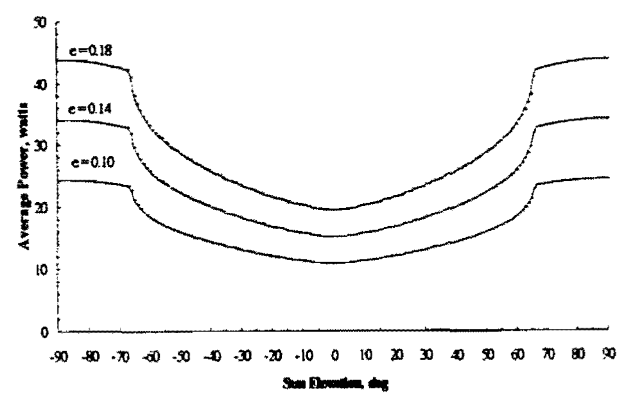


Figure 5: Average Power Generation

Power Regulation The power conditioning and control unit will have DC/DC converters to provide the required operating voltages for various satellite systems. In general, decentralized voltage regulation will be employed in order to avoid over-regulation and yet provide well- conditioned power to different systems. Control of power to various satellite systems will be handled by the flight computer software. The flight computer will monitor the battery status and will perform the power management function under the guidance of commands from the ground station.

Power Storage The satellite battery will consist of space-rated nickel-hydrogen cells. Six cells connected in series will provide a nominal unregulated voltage of 15 volts.

Table 4: Cell Specifications:

Rated capacity	6 AH
Nominal voltage	2.5 V
Cell mass	0.633 kg
Diameter	6.48 cm
Length	17.15 cm
Capacity	7.1 AH
Specific energy	28 WH/Kg
Energy density	39.20 WH/l
Operating pressure	400 PSIG
Safety factor	5:1 ratio

The battery charge controller will monitor the temperature and voltage of the battery and will control the flow of current from the solar arrays, thereby ensuring maximum power transfer on one hand and avoiding over-charging of battery on the other.

Communication

The communications system for ISAT-1 will be divided into two parts called Comm-1 and Comm-2. Comm-1 will be the main communications link between the satellite and the ground station. All command and control commands will be transferred through this link. Additionally, data for bus health, payloads, and software updates will be handled by this link. Comm-2 will serve as the data link for the Weather Station Network. Comm-2 will receive weather and soil data from the ground transponders and transmit the data to the ground station upon command. In the event of failure of Comm-1, Comm-2 can act as the primary communications link. Figures 6 and 7 show a schematic of the communications system.

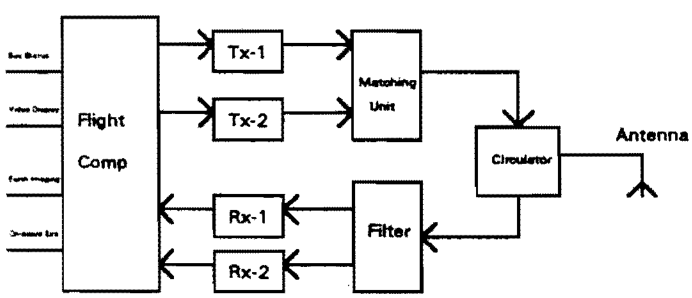


Figure 6: Onboard Communication Architecture

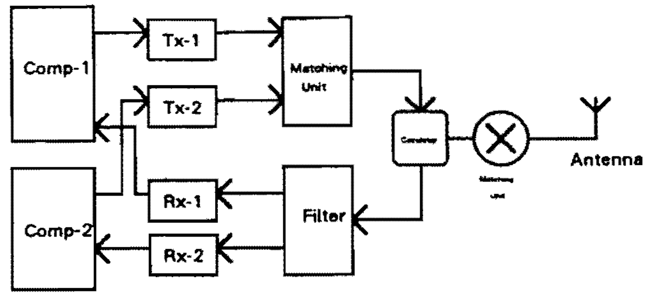


Figure 7: Ground Station Communication Architecture

On average, the satellite will be making four passes over Iowa per day with an average contact time of about 8 minutes per pass. It is expected that the data rate of 10 Kbps will be sufficient to handle the above-mentioned data on a time shared basis.

Various multiple access techniques were considered for Comm-2 and it was found that a 'packet data transfer' scheme is most appropriate. In this scheme, all the ground transponders have identical transmitters and receivers that share a common frequency band. Each ground transponder will be assigned a unique identification code and a digital logic circuit onboard the satellite will separate the data received from various ground transponders. In order to coordinate the data transfer from various transponders and avoid data clash, the satellite needs to exchange control signals with the transponders. This can be handled by either the existing downlink transmitters (Tx-1 or Tx-2) on a time shared basis or else another transmitter (Tx-3) will need to be employed.

Frequency Allocation

Keeping in view the recent radio frequency allocation by the World Administrative Radio Conference (WARC) for small satellites, two frequency bands were selected for Comm-1 and Comm-2. These are:

100–200 MHz VHF Band
400–500 MHz UHF Band

The VHF band will be used for the uplink while the downlink will operate in the UHF band. It is expected that the two bands will provide sufficient frequency isolation between the transmitters and the receivers to permit a full duplex operation.

The ultimate selection of frequency; however, is based on the allocation by the Federal Communication Commission (FCC). The process of frequency allocation by the FCC is presently in its final stage.

Antenna Design

Satellite Antenna The satellite antenna will consist of four to eight quarter-wave dipole elements attached in a symmetrical manner, perpendicular to the satellite's longitudinal axis. This will result in two symmetrical beams of about 150 degrees, one facing the Earth, while the other away from Earth.

Ground Station Antenna A Crossed Yagi directional antenna will be utilized at the ground station for transmission and reception of signals to and from the satellite. The antenna will have a beam width of about 60 degrees and will have a tracking capability of 360 degrees in the horizontal plane and 150 degrees in the vertical plane.

Ground Transponder Antenna In order to keep ground-transponder complexity to a minimum, a fixed, Crossed Yagi-array antenna is considered suitable. The antenna will have one set of reflectors, about three sets of director elements, and is expected to provide a beam width of about 100 degrees.

Command and Control

The Command and Control system will handle all telemetry to and from the ground station, schedule all the on-board experiments, collect data from various sensors and perform various other housekeeping functions. It will essentially consist of a flight computer, storage memory and the interface hardware.

Flight Computer Specifications

- DOS compatible software.
- Operating system shall be ROM based, with an automatic reload capability in the event of program crash.
- Capability of software update after launch.
- Low power CMOS technology.
- 286 or 386 motherboard with multi-tasking capability.
- On-board RAM of 4-8 megabytes.
- Multi-channel (analog and digital) data acquisition card.

Processing Requirements

Bus Functions

- Monitoring/analysis of bus status sensors and control of satellite bus subsystems.
- Interpretation of command data , command execution and generation of reply message.
- Periodic sanity checks.

Payload Functions

- Monitoring of payload status sensors.
- Acquisition of payload data.
- Processing of payload data.
- Storage of processed data.
- Storage of ground sensors data.
- Downlinking of payload data.

I/O Capability

- Serial input of 10K bps data from Rx-1 (Comm-1)
- Serial input of 10k bps data from Rx-2 (Comm-2)
- Serial output of 10k bps data to Tx-1 (Comm-1)
- Serial output of 10k bps data to Tx-2 (Comm-2)
- 8 bit parallel two way data transfer with storage memory.
- 2-byte (16bits) parallel two way data transfer with data acquisition card.

Reliability/Redundancy

Since the Command and Control system acts as a brain of the satellite, it has to be very reliable. The following measures are considered to achieve a high degree of reliability:

- ROM based main operating system
- Auto backup in case of failure
- Periodic diagnostic/self test(sanity check)
- Use of multiple parity bits and extensive parity checks
- Using two mother boards in a master-slave arrangement, with the slave having the ability to operate standalone in case of master's failure.
- Extensive shielding of components from radio frequency interference

Thermal

The thermal analysis being done now is currently in the preliminary stages. All thermal analysis is being done by mechanical engineering students at the University of Iowa. During the Spring 1993 semester, the students created a FORTRAN finite-element analysis program to model the thermal environment and find any problem areas. Like all finite-element codes this program divides the satellite into a number of nodes which are representative of different parts of the satellite and pieces of hardware. The thermal control system can be represented by different thermal resistances between each node. By inputting orbit information, space environment factors, and the thermal properties of the nodes, the program calculates the temperatures at each node during the orbit. At the present time only passive elements such as thermal blankets and coatings are expected to be used.

Ground System

The control center will be located in Boone, IA, a small town located about 15 miles west of Ames. The control center will be responsible for the following activities:

- Receive and archive payload data
- Receive and process bus data
- Schedule and verify all payload activities
- Verify all bus commands
- Resolve payload and bus anomalies
- Make payload data available to users
- Manage and train personnel

Figure 8 shows the layout of the ground station.

Cost and Schedule

Table 5: Project Cost Summary

Payload Hardware	\$196,286
Launch	(est.) \$500,000
Flight Hardware	\$243,540
Personnel	\$811,200
Ground Equipment	\$143,663
Miscellaneous	\$374,665
Total	**\$2,269,354**

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References

Larson, W.J., and Wertz, J.R.,(ed), *Space Mission Analysis and Design*, 2nd ed., Microcosm, Inc., Torrance, California, and Kluwer Academic Publishers, Dordrecht, The Netherlands, 1992.

Wertz, J.R.(ed), *Spacecraft Attitude Determination and Control*, D. Reidel Publishing Company, Dordecht, Holland, 1978.

Hughes, P.C., *Spacecraft Attitude Dynamics*, John Wiley and Sons, New York, 1986.

Stickler, A.C. and Alfriend, K.T., "An Elementary Magnetic Attitude Control System," *AIAA Mechanics and Control of Flight Conference*, 1974, AIAA Paper No. 74-923.

Roberson, R. E., "Gravitational Torques on a Satellite Vehicle", *J. Franklin Inst.* 265, 1958, p. 12-33.

Chobotov, V. A., *Spacecraft Attitude Dynamics and Control*, Krieger Publishing Company, Malabar, Florida, 1991.

Kaplan, M. H., *Modern Spacecraft Dynamics and Control*, John Wiley and Sons, Inc., New York, New York, 1976.

Hunt, J.W., and Ray, J.C., "Flexible Booms, Momentum Wheels, and Subtle Gravity-Gradient Instabilities," 1992, AIAA Paper No. 92-1673.

Peterson, M.R., and Grant, D.G., "The Polar BEAR Spacecraft," *Johns Hopkins APL Tech. Dig*, Vol. 8, no. 3, 1987, p. 295-302.

Hoskin, B. C., and Baker, A. A.(ed)., *Composite Materials for Aircraft Structures*,, American Institute of Aeronautics and Astronautics, Inc., New York, New York, 1986.

Table 6: Project Schedule

Year	1992		1993			1994			1995	
Semester	Fall	Spring	Summer	Fall	Spring	Summer	Fall	Spring	Summer	Fall
Preliminary Design	■									
Detailed Design		■	■							
Construction			■	■						
Proof of Concept	■	■	■							
Systems Tests				■	■					
Integrated Tests					■	■				
End-to-End Tests							■	■	■	
Training					■	■	■	■	■	
Shipment										■
Pre-launch Tests										■
Launch										■
Initial Operations										■
Sustained Operations										■

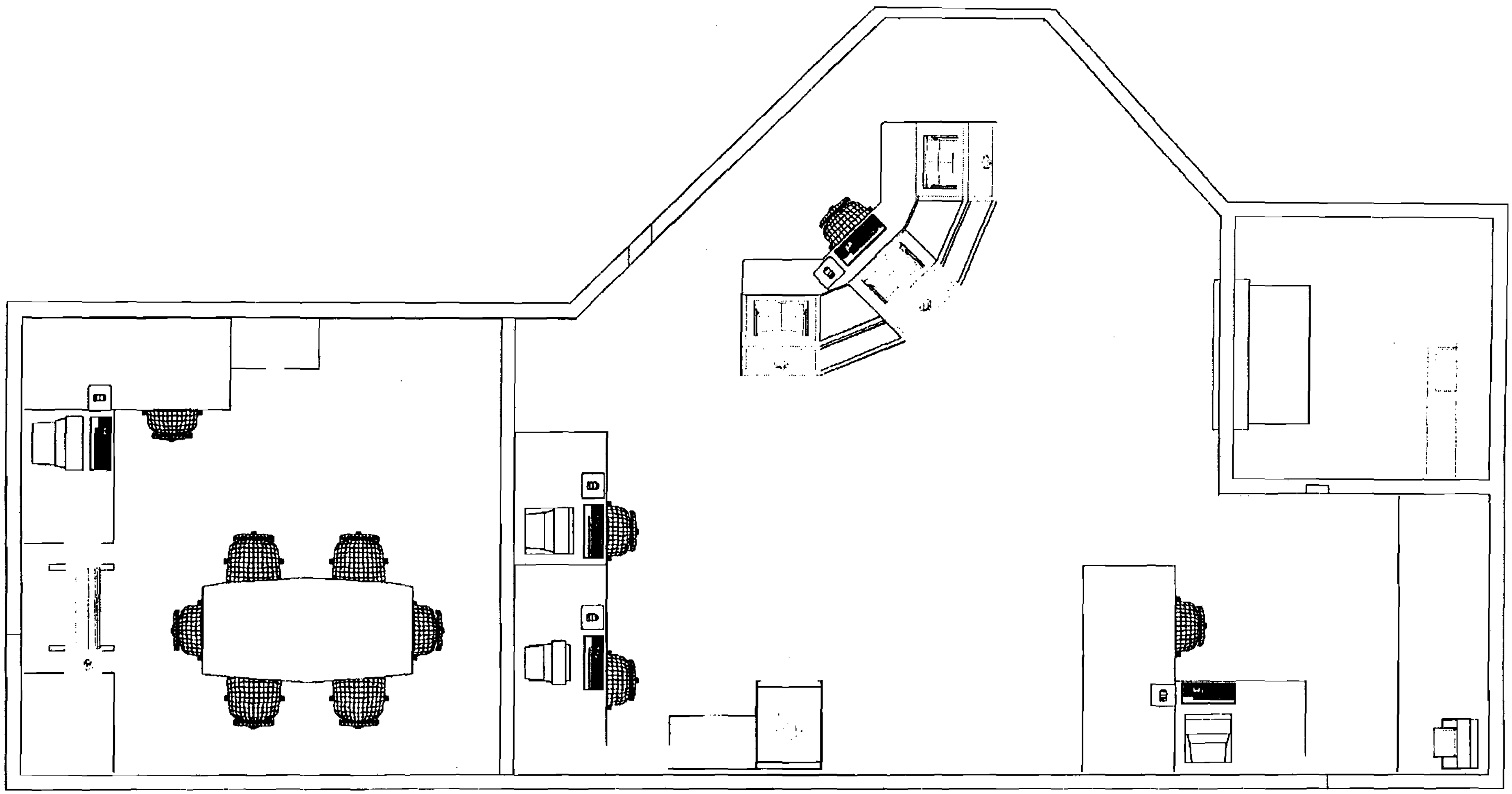

Fig. 8