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Geostationary Operational Environmental Satellite (GOES-N Report)
Volume 1. Technical

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GEOSTATIONARY OPERATIONAL ENVIRONMENTAL SATELLITE

GOES-N

REPORT

VOLUME 1: TECHNICAL

STUDY PROJECT MANAGER*: DR. HARRY E. MONTGOMERY
STUDY PROJECT SCIENTIST**: DR. ROBERT ADLER

PREPARED BY

ADVANCED MISSIONS ANALYSIS OFFICE

GODDARD SPACE FLIGHT CENTER

DECEMBER 1991

* MANAGERS : THOMAS KARRAS AND RICHARD WIRTH
** PREVIOUS STUDY PROJECT SCIENTIST . WILLIAM SHENK

SUMMARY OF CONTENTS OF THE GOES-N STUDY REPORT

The GOES-N study consisted of five distinct tasks including:

- Determining replication costs of GOES I-M and GOES-7 in the GOES-N time frame,
- Defining and evaluating modifications to GOES I-M to improve efficiency or reduce costs,
- Defining evolutionary changes to the GOES I-M design to satisfy National Weather Service (NWS) 1983 and NOAA 1989 requirements.

The GOES-N Study Report refers to the results of the GOES I-M replication cost study. A report of this task was completed and transmitted to NOAA in September 1989. This report is currently being updated to reflect the latest developments in the GOES I-M program. The GOES-7 replication cost study report is being prepared as a separate document.

The categorization and disposition of NOAA requirements is reported in Volume 1 Section 4. Results of the GOES I-M efficiency/cost improvement modifications study are described in Section 7.1. The system concept Options I, II, and III that generally represent the results of the Task 2, 3A, and 3B studies are summarized in Section 7.2. Another result of the GOES-N study - the determination of which NWS 1983 and NOAA 1989 requirements can be met with the three options is contained in Volume 1 Section 7.

Conclusions and Recommendations are covered in Volume 1 Section 8. Imager, sounder, control system, Space Environment Monitor, Search and Rescue, Weather Facsimile, Data Collection System, and Products/Process/Communications recommendations have been extracted from Sections 9, 10, and 11. Section 8 also contains conclusions pertaining to programmatic operational satellite issues (prerequisite development strategies, the direct procurement of instruments by the government, protoflight missions, etc.).

Sections 9, 10, and 11 address instrument, control system, Image/Navigation/Registration, and other system design considerations and surveys. These sections are supported by the appendices in Volume 2.

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CONTENTS

ACRONYMS and ABBREVIATIONS

ACC	Attitude Control Computer
ACE	Attitude Control Electronics
ACS	Attitude Control System
A/D	Analog-to-Digital
AIRS	Atmospheric Infrared Sounder
AMAO	Advanced Missions Analysis Office
AOCE	Attitude and Orbit Control Electronics
AP	Aerosol Properties
APAR	Absorbed Photosynthetically Active Radiation
APL	Applied Physics Laboratory
ATDRSS	Advanced Tracking and Data Relay Satellite Systems
ATS	Applications Technology Satellite
AWIPS	Advanced Weather Information Processing System
BOL	Beginning of Life
BPSK	Binary Phase Shift Key
CCD	Charged-Coupled-Device
CCIR	Consultative Committee International Radio
CCITT	Consultative Committee on International Telegraph and Telephone
CDA	Command and Data Acquisition
CDR	Critical Design Review
CIMSS	Cooperative Institute for Meteorological Satellite Studies
CM	Conventional Matching
C/N	Carrier to noise ratio
COSPAS	MORFLOT Search and Rescue Space System (USSR)
CP	Cloud Products
CRAF	Comet Rendezvous and Flyby
CSC	Computer Science Corporation
DAPS	DCS Automatic Processing System
DCP	Data Collection Platform
DCPI	DCP Interrogation
DCPR	DCP Response
DCS	Data Collection Systems
DOMSAT	Domestic Communications Satellite
DRIRU	Dual Redundant & Inertial Reference Unit
DSN	Deep Space Network
DUS	Data Utilization Station
E^b/N^o	energy per bit to noise density ratio
EIRP	Effective Isotropic Radiated Power
ELV	Expendable Launch Vehicle
ELT	Emergency Locator Transmitter
EOL	End of Life
EOS	Earth Observing System
EPIRB	Emergency Position Indicating Radio Beacon

EPS	Energetic Particle Sensor
ERL	Environmental Resources Laboratory
ES	Earth sensor
EUV	Extreme Ultraviolet
FORS	Fiberoptic Rotation Sensors
FOV	Field of View
FTS	Fourier Transform Spectrometer
G/T	gain-to-temperature ratio
GE	General Electric
GEM	Geosynchronous Environmental Mission
GEO	Geosynchronous Earth Orbit
GFE	Government Furnished Equipment
GFRP	Graphite Fiber Reinforced Plastic
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning Satellite
GSFC	Goddard Space Flight Center
GST	GOES-N Study Team
GTO	Geosynchronous Transfer Orbit
GVAR	GOES Variable data format
GVHRR	Geosynchronous Very High Resolution Radiometer
$H\alpha$	Hydrogen-alpha
$H\alpha I$	Hydrogen - Alpha Imager
HAC	Hughes Aircraft Company
HEPAD	High Energy Proton and Alpha Detector
HIS	High-resolution Interferometer Sounder
HgCdTe	Mercury Cadmium Tellurium
HRG	Hemispheric Resonator Gyroscope
HSRS	High Spectral Resolution Sounder
HST	Hubble Space Telescope
I&T	Integration and Test
ICD	Interface Control Document
IFOV	Instantaneous Field of View
IGFOV	Instantaneous Geometric Field of View
IMC	Image Motion Compensation
InGaAs	Indium Gallium Arsenide
INR	Image Navigation and Registration
INSAT	Indian Satellite
InSb	Indium antimonide
I/O	Input/Output
IP	Imagery Products
IR	Infrared
IRU	inertial reference unit
ITT	International Telephone & Telegraph Company
IUE	International Ultraviolet Explorer
JPL	Jet Propulsion Laboratory
LAS	Loral AeroSYS

LEO	Low Earth Orbiting
LMS	Lightning Mapper Sensor
LNA	Low Noise Amplifier
LP	Lightning Products
LPARL	Lockheed Palo Alto Research Laboratory
LPS	Low energy Plasma Sensor
LTR	Loop Transfer Recovery
LWIR	Long Wave Infrared
MCC	Mission Control Center
MDI	Michelson Doppler Imager
MDL	Multiuse Data Link
MDSSC	McDonnelly Douglas Space System Company
MEPED	Medium Energy Proton/Electron Detector
METSAT	Meteorological Satellite
MLI	Multi-layer Insulation
MMC	Mirror Motion Compensation
MORFLOT	Soviet Ministry of Merchant Marine
MP	Moisture Products
MSFC	Marshall Space Flight Center
MSI&T	Mission System Integration & Test
MTF	Modulation Transfer Function
N/A	Not applicable
NASA	National Aeronautics Space Administration
NASCAP	NASA Charging Analyzer Program
NASTRAN	NASA Structural Analysis Program
NEΔN or NEDN	Noise Equivalent Delta Radiance
NEΔT or NEDT	Noise Equivalent Delta Temperature
NEA	Noise Equivalent Angle
NESDIS	National Environmental Satellite & Data Information Service
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
O/A	Orbit/Attitude
OATS	Orbit and Attitude Tracking System
OBC	On Board Computer
OGE	Operations Ground Equipment
OSIP	Operational Satellite Improvement Programs
OSSA	Office of Space Science and Applications
PA	Power Amplifiers
PDR	Processed Data Relay
PID	proportional-plus-integral-plus-derivation
POP	Program Operation Plan
PP	Precipitation Products
PSK	Phase Shift Key
PtSi	Platinum Silicon
QPSK	Quadraphase Shift Key
RAO	Resources Analysis Office

RF	Radio Frequency
RFP	Request For Proposal
RH	Relative Humidity
RM	Radar Matching
ROM	Rough Order of Magnitude
RSS	Root Sum Square
S&R	Search and Rescue
SAMEX	Solar Activity Measurement Experiments
SARSAT	S&R Satellite
SBRC	Santa Barbara Research Center
SDL	Sounder Data Link
SEDS	Small Explorer Data Systems
SEL	Space Environmental Laboratory
SEM	Space Environment Monitor
SINDA	System Improved Numerical Differencing Analyzer
SK	Station Keeping
SM	Satellite Matching
SMC	Spacecraft Motion Compensation
SMM	Solar Maximum Mission
S/N	Signal to niose ratio
SOCC	Satellite Operations Control Center
SOHO	Solar Heliospheric Observatory
SOW	Statement of Work
SP	Snow and ice Products
SS	Summer Solstice
SSAA	Short Span Attitude Adjustment
SSAI	Science Systems and Applications Incorporated
SSPA	Solid State Power Amplifier
SVM	Solar Vector Magnetograph
SWF	Spatial Weighting Function
SXI	Solar X-Ray Imager
SXT	Solar X-Ray Telescope
TBD	To be determined
T&C	Telemetry and Command
TDI	Time-delay Integration
TDRSS	Tracking and Data Relay Satellite Systems
TEC	Total Electron Content
TED	Total Electron Detector
TIROS	Television Infrared Operational Satellite
TLM	Telemetry
TM	Thematic Mapper
TP	Temperature Products
TWTA	Traveling Wave Tube Amplifier
UAQPSK	Unbalanced Asynchronous QPSK
UHF	Ultra High Frequency
UIT	Ultraviolet Imaging Telescope

USAF	United States Air Force
USMCC	United States Mission Control Center
VAS	VISSR Atmospheric Sounder
VHF	Very High Frequency
VHRR	Very High Resolution Radiometer
VISSR	Visible Infrared Spin Scan Radiometer
VP	Vegetation Products
WEC	Westinghouse Electric Company
WD	Whole Disk
WEFAX	Weather Facsimile
WFOV	Wide Field of View
WP	Wind Products
WSR	Weather Service Radar
WSR-88D	WSR limited production phase, D for doppler
XRS	X-Ray Sensor

UNITS

μm	micrometer
μrad	microradian
A	amperes
arcmin	arcminute (minutes of arc)
arcsec	arcseconds (seconds of arc)
bps	bits per second
°C	degree centigrade
ft	feet
Hz	hertz
in	inch
K	degrees kelvin
kbps	kilobit per second
keV	thousand electron volts
km	kilometer
lb	pound
m	meter
mbar	millibar
Mbps	million bits per second
MeV	million electron volts
MeV/n	million electron volts per nucleon
MHz	megahertz
min	minute
mrad	milliradian
ms	millisecond
mW	milliwatt
nm	nanometer
nT	nanotesla
oz	ounce
rad	radian
s	second
sr	steradian
V	volt
W	watt

SYMBOLS

λ	wavelength
σ	standard deviation
υ	wave number
dB	decibel
f#	f-number
RC1, RC2, ...	NOAA Core Requirements
RE1, RE2, ...	NOAA Enhanced Requirements
RO1, RO2, ...	NOAA Option Requirements
R_s	radius of the sun
Z	atomic number
Δ	delta

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FOREWORD

The Advanced Missions Analysis Office (AMAO) of the Goddard Space Flight Center (GSFC) has completed a study to evaluate the feasibility, risks, schedules, and associated costs of advanced space and ground system concepts to meet National Oceanic and Atmospheric Administration (NOAA) requirements for the next generation of Geostationary Operational Environmental Satellites (GOES) following the GOES I through M series currently under development but not yet launched. The study is the first step in a multi-phased procurement effort that is expected to result in launch ready hardware in the early 2000s time frame.

The study was initiated in response to a request for a Phase-A feasibility study, in November 1988 from Mr. Thomas Pyke, Assistant Administrator for Satellite and Information Services, NOAA, addressed to the NASA Associate Administrator for the Office of Space Science and Applications (OSSA), Dr. Lennard Fisk.

Preliminary planning for the study at both GSFC and NOAA began in early 1989 with a NOAA sponsored GOES-N Requirements Working Group meeting. A formal GOES-N requirements document was issued by NOAA in May 1989. Funding to proceed with the study was received at GSFC in October 1989.

This report represents the latest activity of GSFC in translating meteorological requirements of NOAA into viable space systems in geosynchronous earth orbits (GEO). GOES-N represents application of the latest spacecraft, sensor, and instrument technologies to enhance NOAA meteorological capabilities via remote and *in-situ* sensing from GEO.

The GOES-N series shows promise of becoming another significant step in NOAA weather forecasting space systems, meeting increasingly complex emerging national needs for that agency's services.

ACKNOWLEDGEMENTS

This study is the collective product of a dedicated GOES-N team of GSFC and NOAA civil service and contractor personnel.

The total dedication to this study of the following key technical personnel is gratefully acknowledged: Frank Bauer, Cynthia Fryer, Maryanne Gallagher, Larry Goldberg, Thomas Karras, Harry Montgomery, Stephen Paddack, George Roach, William Shenk, and Les Thompson all of GSFC; Teresa Cooper, Enrico Mercanti of McDonnell Douglas Space System Company (MDSSC), Richard Wirth of EER; Sanford Ashton, Winfield Farthing, and Marvin Maxwell of Swales and Associates; Daniel Arnaud of Computer Science Corporation (CSC); and Robert Martel of Westinghouse Electric Company (WEC).

We acknowledge the significant contributions of the individuals listed below toward completing this endeavor which will benefit mankind in its ability to better monitor and predict weather conditions over the next decade: NASA Headquarters - James Greaves; GSFC - Norman Ackerman, William Barnes, Edward Bielecki, Howard Branch, William Bryant, David Butcher, Robert Callens, Harry Culver, Bernard Dixon, Marlon Enciso, John Flaherty, James Gatlin, David Hepler, Patricia Huber, Ronald Muller, Richard Pinamonti, Charles Thienel, Robert Wallace, and Arnold Wenger; NOAA - Edward Bisone, Deborah Garr, Ronald Gird, Paul Menzel, William Mazur, Anthony Mostek, Ralph Peterson, Stanley Schneider, Arthur Schwalb, James Sparkman, and Fred Zbar; CSC - Dominic Barbiere, Don Novak, and Dale Headrick; MDSSC - Dawn Hayner; Swales and Associates - Smiley Hsu and Jim Carr; WEC - Andrew Bidas; ATR - Peter Hui and Alan Reth. The following is a partial listing of organizations that provided associated support during the conduct of the study; Santa Barbara Research Center (SBRC), Hughes Aircraft Company (HAC), Loral AeroSYS (LAS), International Telephone and Telegraph (ITT). There were others, too, not listed herein, who provided assistance.

Special thanks are due to John Townsend, former Director, GSFC; John Klineberg, Director, GSFC; Peter Burr, Deputy Director, GSFC; and Paul Mowatt, Deputy Director, Flight Projects Directorate, who carefully reviewed the products of the study and provided advice throughout its development. The individual members of the GSFC management council also provided valuable advice and needed support through all phases of the study.

A number of persons generously contributed their time and expertise in addressing the requirements for the Space Environment Monitor (SEM) for GOES-N, including Dick Grubb, Dick Donnelly, Ron Zwickle, Pat Bornmann, Herb Sauer, and Ernie Hildner, all of NOAA's Space Environment Laboratory (SEL) in Boulder, Colorado. Also very helpful were Bill Wagner, then of SEL, and Pat Mulligan of the National Environmental Satellite and Data Information Service (NESDIS) who have, through their advocacy, been largely responsible for shepherding the Solar X-ray Imager (SXI) through its inter-agency approval process. In the area of energetic particles measurements, Bach Sellers of Panametrics, Incorporated and David Winningham of the Southwest Research Institute, have been particularly helpful. For the Solar Vector Magnetograph/Hydrogen - Alpha Imager (SVM/HαI), we have had helpful discussions with

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1.0 INTRODUCTION

This GOES-N study was conducted by the GSFC AMAO in close cooperation with personnel of various GSFC organizations and directorates: the Resources Analysis Office (RAO); the Office of Flight Assurance; the Meteorological Satellite (METSAT) Project; and the Mission Operations and Data Systems, Space Science, Earth Science, and Engineering directorates. The study was performed in close cooperation with NESDIS and NWS personnel.

NOAA and NESDIS established a GOES-N Requirements Working Group (GNRWG) in October 1988 that subsequently resulted in a set of formally documented NOAA requirements and guidelines in May 1989. This document contained the 1983 National Weather Service (NWS) requirements that have been applied, in part to, the GOES I-M series plus new requirements generated by the working group focusing on expanded imager, sounder, SEM, Data Collection System (DCS), and Weather Facsimile (WEFAX) capabilities. The requirements were categorized as core, optional, and enhanced depending on their importance and stages of advancement.

Correspondence between NOAA and NASA leading to funded authorization of the GOES-N study began in August 1988. Preliminary planning for the study commenced within AMAO in late 1988. AMAO received funds to proceed with the effort in October 1989. A final report, presented to NOAA on October 31 - November 1, 1990 followed a successful preliminary briefing to the GSFC Management Council on October 22, 1990.

The objective of the study was, and remains, to identify and evaluate preliminary concepts of advanced instruments, space infrastructures, and associated ground systems that meet NOAA "evolutionary" requirements to satisfy that agency's operational needs in the post GOES I-M time frame (2000 - 2010). The concepts were assessed for feasibility, cost, risk, and schedules. The purpose of the study was to provide NOAA with the technical information needed to secure approval for a "new start" and to permit initiation of definition Phase-B studies.

With these guidelines as a basis, AMAO was initially requested to perform four specific tasks (Section 2): (1) determine the cost of replicating the GOES I-M series in the GOES-N time frame and (2) define and evaluate modifications to GOES I-M that would improve efficiency or reduce costs. The third and fourth tasks were to define and evaluate design changes to the GOES I-M system to satisfy (3A) the NWS requirements stipulated in 1983 and (3B) the May 1989 NOAA requirements. During the course of the effort, another study was requested by NOAA in mid-1990: to determine the cost of replicating GOES-7 in the GOES-N time frame; funding for this task was received in December 1990.

The analyses performed during the studies resulted in the conclusion that the spacecraft/instrument combinations referred to as options could satisfy most but not all the 1989 NOAA GOES-N requirements. The ones that could not be satisfied by any evolutionary concept are referred to as "unmet" requirements. Option I essentially supported the "core" requirements, basically utilizing a modified GOES-I-M spacecraft with improved imager and sounder plus an improved and expanded capability SEM. Option II is a more advanced system which satisfies many of the NOAA "core and optional" requirements utilizing a bus different from the GOES I-M spacecraft, with an improved imager, an advanced sounder, and increased capability WEFAX, DCS, and

SEM sensors. Option III addresses the more difficult to achieve enhancements to NOAA requirements. These have been determined to require a different bus, a new and, perhaps, an auxiliary imager, and advanced sounder. Option III also includes a new SVM/Hα, and a new total electron counter (TEC) as integral parts of the SEM. Details of the three options are contained in Sections 7.2.1, 7.2.2, and 7.2.3. The results of the study are configured to provide NOAA with sufficient information to select for further study one of these or some hybrid option depending on feasibility, risk, schedule, and cost criteria. In addition, sufficient cost information on the three options is provided in Volume 3 to NOAA to initiate the "new start" process for the new system.

Replication cost estimates for both GOES I-M and GOES-7 in the GOES-N time frame are contained in separate reports. The study also indicates a need for additional specific studies to be completed before Phase-B (definition) and Phase-C/D (fabrication, test, and launch) begin; these are summarized in Section 8.

The sections which follow explain or describe in detail the analysis of requirements, the characteristics and expected performance of the three options studied in terms of NOAA requirements satisfied, "unmet" requirements, high risk technology elements, cost estimates, and recommendations.

1.1 Role of GOES-N in NOAA Planning

The GOES-N mission will be designed to provide unique measurements to satisfy advanced NOAA requirements in the year 2000 time period and beyond. While GOES-N will continue to supply unique data sets (e.g., winds from cloud motions) to the global numerical models and to assist synoptic scale prediction, most of the new and/or enhanced requirements emanate from observational needs for mesoscale/severe storm events or global change studies. Specific requirements are presented in Section 4.0.

In addition to enhanced meteorological requirements, there are new needs for monitoring the space environment and the sun There is also a need for improved communications for meteorological data and for data measured *in-situ* from remote platforms. Finally, there is a requirement for locating distress signal sources as early as possible which would require a position location capability in geosynchronous orbit. Further details of these requirements are contained in Section 11.

The GOES-N mission will be a continuation of the successful GOES program which started in May 1974 with the launch of SMS-1. It would be the 15th member of the series. The GOES-N mission will also be able to take advantage of new technological developments that have occurred since the planning phase of GOES I-M (1980-1984). The GOES-N meteorological data would complement measurements from the low orbiting NOAA satellite series and the information from the rest of the NOAA system (e.g., WSR-88D radars, profilers, surface stations, radiosondes, etc.). Prior to the launch of GOES-N, the proposed NOAA/NWS modernization program should be completely implemented.

GOES-N data are expected to have a greatly expanded operational use due to the Advanced Weather Information Processing System (AWIPS) installation expected to be installed at over 100 forecast offices. AWIPS will facilitate the combination of GOES-N measurements with data from other sources. GOES-N information is also expected to receive widespread use by the research community, which should lead to further operational improvements that can not be determined at this time.

2.0 SCOPE OF STUDY

The scope of the study was based on NOAA requirements stipulated in its Statement of Guidelines and Requirements: GOES-N Phase-A Study, dated May [illegible], 1989. The scope of the study was initially defined as the accomplishment of four tasks:

1. Estimate the cost of replicating the GOES I-M series in the GOES-N time frame. (Volume III)
2. Define modifications to the GOES I-M design that will result in either cost reductions or improve efficiency. Evaluate each proposed modification on the basis of feasibility, risk, schedule impacts, and costs.

3A. Define changes to the GOES I-M design that will result in the system satisfying the NWS 1983 requirements. Evaluate each proposed design change on the basis of feasibility, risk, schedule impacts, and costs.

3B. Define changes to the GOES I-M design that will result in the system satisfying the NOAA 1989 requirements. Evaluate each proposed design change on the basis of feasibility, risk, schedule impacts, and costs.

Funding was received in December 1990 to conduct a study to determine the cost of replicating GOES-7 in the GOES-N time frame. (This study now complete is being reported in a separate document.)

To accomplish these four assigned tasks, the scope of the study included analyzing NOAA requirements, categorizing them "core", "optional", or "enhanced" depending on their importance in satisfying national weather forecasting needs.

The analyses of both NOAA requirements and the GOES I-M system, currently under development, resulted in scoping the effort to identify and include approximately eighty specifically recommended studies, each related to one or more requirements (or an efficiency improvement or cost saving). These studies were described in sufficient detail to permit manpower requirement estimates. A weighted system of study assessment criteria that included cost, risks, schedules, "value", "payoff", "tall poles", and study and science benefits was developed and applied to each study. The studies were arranged in priority order and agreed to by NOAA officials.

However, the total resources required to accomplish these studies exceeded what was available, and it was agreed by NOAA that the scope of the study would have to be reduced. In addition, the imagers, sounders, and control system were to be subjected to limited analyses with the other instruments - SEM, WEFAX, Search and Rescue (S&R), and DCS subjected to comprehensive "surveys". As a consequence of this change in scope over what was originally intended, and by direction of the GSFC Director, the entire effort was labeled the GOES-N Study. The revised scope of the study, as performed, included:

- Instruments to meet NESDIS requirements
- Spacecraft characteristics to meet operational and instrument accommodation requirements,

- Ground command and data handling characteristics to meet NESDIS and spacecraft requirements, and
- Spacecraft and instrument interfaces with the ground data handling system.

2.1 Meteorological Requirements Analysis

NOAA GOES-N requirements were compared with current GOES I-M requirements. Next, GOES-N capability increases were identified and translated into corresponding instrument/sensor requirements. The translation was further extended to include data product needs, recognizing the many diverse elements of the GOES user community.

The links between derived instrument/sensor requirements, current instrument sensing capabilities, and projected (into the GOES-N time domain) instrument advances that may be available were analyzed. Determination of the feasibility, risks, and costs of meeting NOAA requirements using anticipated state of the art in instrument technology were made. Significant incompatibilities were identified and quantified. The ability to extend the performance of the existing GOES I-M sensors is included in this assessment.

The feasible instrument payload options selected individually and collectively entail certain interface requirements on the host spacecraft and on the total ground data handling system. The study includes the identification and assessment of these interface requirements.

2.2 Spacecraft System Analysis

Basically, in accordance with NESDIS guidelines, a generic 3-axis stabilized bus evolving from the GOES I-M series was the initial focus of consideration for accommodating instruments and providing appropriate interfaces with the total ground system. (Note: later in the study NESDIS did request a study to determine replication costs of the GOES-7 spin stabilized system.) The scope of the study included:

- Payload accommodations
- Ground systems requirements
- On-board data processing
- Attitude control system requirements
- Thermal control system
- Other subsystem analyses as required

From this, several basic concepts utilizing evolutionary or commercially available spacecraft were developed with feasibility, schedule, cost, and risk assessments stipulated. Overall design concepts, including instruments, were generated suitable for expendable launch vehicle (ELV) interface analyses. In addition, designs showing the proposed configuration deployed in orbit were developed.

2.3 Launch Vehicle Considerations

With the space system concept developed, Rough Order of Magnitude (ROM) mass, center of gravity, configuration, and volume estimates were used to determine specific candidate ELV's currently available or under development that can meet launch requirements for the GOES-N series circa 2000.

2.4 Ground Segment Requirements Analysis

In addition to impacts on instrument designs and the GOES-N spacecraft, GOES-N user requirements are expected to result in increased capabilities of various elements of the ground segment of the NESDIS GOES system. Included in this requirements analysis area are considerations of:

- Ground system elements and communication networks within and external to NOAA
- Data flows

The results of this segment of the GOES-N study are contained in Section 11.

2.5 Phase-B Preparations

A major output of this study is information suitable for preparing a Phase-B study Statement of Work (SOW).

2.6 Study Exclusions

This study addressed feasibility, cost estimates, and risk assessments to serve as a basis for a comprehensive Phase-B procurement. Certain items, normally subjected to a preliminary system design or advanced mission analysis, were excluded or deferred. Generally excluded were preliminary systems designs of the instruments and spacecraft subsystems. Also excluded were "advanced missions" type analyses of the GOES ground segment (command, control, data collection and dissemination). Within the framework of these major categories of study exclusions, specific items excluded were:

- Certain recommended studies delineated in Section 8
- Integration and test (I&T) considerations
- Pre and post launch operational scenarios
- Safety considerations
- Performance assurance provisions
- Non-"evolutionary" concepts
- Sensor analyses other than imagers and sounders (the remaining instruments were subjected to "surveys").

3.0 BACKGROUND

Even as the GOES I-M series of meteorological satellites was in the process of development, NOAA had already begun its internal deliberations for a post GOES I-M geosynchronous earth orbiting follow-on called GOES-N. Reportedly, NOAA considerations for this advanced mission included the GOES I-M program status, expected advances in instrument and sensor capabilities, newly emerging NOAA science requirements, the projected NWS modernization program currently underway, and new spacecraft developments including the NASA geoplatform system. As a result of these and other related factors, initial correspondence between NOAA and NASA was exchanged beginning in 1988.

In a letter dated August 23, 1988 to Dr. Lennard Fisk, Associate Administrator for OSSA, NASA Headquarters, Mr. Thomas Pyke, Assistant Administrator for Satellite and Information Services, NOAA, stated that it was time "for NOAA to begin exploring options for continuing geostationary meteorological services past GOES I-M." He also said that his Advanced Systems Planning Division would begin working with the NWS to produce a requirements document for geostationary services past the GOES-M mission.

In his letter of response dated October 13, 1988, Dr. Fisk agreed that it was "time to start planning for the follow-on to GOES-M" to avoid a potential coverage deficit due to an unforseen event such as the launch failure that resulted in the loss of GOES-G.

In his second letter to Dr. Fisk, dated November 10, 1988, Mr. Pyke formally requested that the AMAO at GSFC "complete a Phase-A feasibility study with cost assessments" for a satellite system to follow GOES-M.

In a letter dated December 6, 1988, Dr. John Townsend, Director, GSFC, was requested by Dr. Fisk to identify a study team within GSFC to conduct the desired study. He stated that he believed "the AMAO would be an appropriate organization to complete such a study".

Later, in a letter dated December 23, 1988, Dr. Townsend responded to Dr. Fisk that GSFC would support the request and would conduct the required study within the AMAO with Richard Wirth as the Study Manager.

In his letter to Mr. Pyke dated January 23, 1989, Dr. Fisk responded that GSFC would conduct the requested GOES-N study via the AMAO. Dr. Fisk also stated that NASA was "happy to see that provisions for Phase-A/B definition studies are being factored in at the beginning. This should go a long way toward avoiding the kind of cost growth problems we've had with the GOES I-M program."

The foregoing record of correspondence constituted the formal authorization for AMAO to plan and conduct a GOES-N feasibility study with risk and cost assessments for a satellite system to provide post GOES-M services.

Letters dated October 14, 1988 to the user community from Mr. Stanley Schneider, Chief of Special Projects Divisions, NESDIS announced the establishment of a GOES-N Requirements Working group and invited participants to attend a meeting on January 10 and 11, 1989, to start the process of developing requirements. The meeting served as a basis for an initial partial list of user requirements that were selectively distributed for review on April 6, 1989, at the GOES I-M Conference.

The NOAA Guidelines and Requirements for the GOES-N Phase-A Study was completed on May 22, 1989. The document was prepared by the NOAA/NESDIS Office of Systems Development Advanced Systems Planning Division.

During the period December 1988 to mid-1989, planning for a Phase-A study was initiated within AMAO including study objectives, technical approach, schedules, and resource requirements.

At a joint GSFC/NASA HQ/NESDIS meeting held on April 14, 1989, Mr. Wirth of GSFC presented the Center's baseline scope of a full Phase-A study together with estimated costs, civil service and on-site contractor manpower, and instrument/related off-site contract estimates. Total GOES-N Study Project cost estimates ranged from $3.0M to $4.3M. (GSFC RAO estimates ranged from $4.0M to $6.0M.) In response to this estimate, NESDIS stipulated a spending limit of approximately $1.56M for this study.

NESDIS expressed a need for a feasibility study that would include cost estimate and risk assessments for various mission options. The main driver for this request was to enable NESDIS to provide upper levels of NOAA management with sufficient information to initiate the new start process. NESDIS emphasized that "design" was not a required end product of the proposed study but only to be performed as needed to determine costs, feasibility, and risks. Referred to was an "evolutionary spacecraft" and instruments that already have (or will have) a "flight heritage." NESDIS mentioned that another purpose of this study was to help determine Phase-B scope, requirements, etc

As a result of this and a later (June 5, 1989) meeting, a revised GOES-N Phase-A Study Plan was prepared, responsive to the NESDIS request, with an attached cost estimate of $1.56M, consistent with NESDIS funding availability This plan was transmitted to NESDIS via a letter dated June 19, 1989 from GSFC (R. Wirth, Study Manager) to NESDIS (S. Schneider, Chief, Advanced Systems Planning Division).

Internal to GSFC, there was concern that the limited resources would not permit the accomplishment of a complete Phase-A study. When this was reported to the GSFC Management Council in July 1989, at a Director's Study Review, the Director ordered the study renamed the "GOES-N Study." Notice of this change was subsequently transmitted to NESDIS officials verbally and at the study team's weekly staff meetings.

In mid-1990, NESDIS requested that the study be modified to include replication costs of a GOES-7 in the GOES-N time frame. Funding in the amount of $105K was provided by NESDIS for this task (December 1990).

4.0 DEFINITION OF REQUIREMENTS

4.1 Overview

During the past decade, since the observation requirements for the GOES I-M series were established in the early 1980's, there has been:

1) Increased understanding of mesoscale/severe storm processes.
2) Improvements in numerical modeling from the mesoscale up through the global scale.
3) A strong international focus on the importance of monitoring global change.
4) The approval of a major improvement in the ground based measurement of numerous meteorological parameters and the interactive facilities to use these new data (the NWS modernization). In the future, these measurements will be combined with satellite data.
5) A greater need for *in-situ* measurements from remote locations as part of the overall data base.
6) Recognition of the need for more sophisticated space environment measurements.
7) Higher speed transmission of meteorological data.
8) The need for the rapid location of a satellite received distress signal.

The list above indicates a need to develop new observational requirements for satellite sensors that would be available in the 2000 time period. In some instances, what the capability might be beyond 2000 (e.g., numerical modeling requirements) must be anticipated so that observational requirements will be properly established. The GOES-N requirements were developed from these considerations along with the expected role that GOES-N is expected to have in the overall observing system that would be in place after 2000 (e.g., the NWS modernization, polar orbiting satellites, etc.).

Most of the GOES-N requirements were developed from the January 1989 GOES-N Requirements workshop. The workshop was attended by representatives from government (e.g., NOAA, NASA), industry, and the academic community. GOES-N requirements were generated for the different satellite sensors and/or functions that comprise the entire satellite system. In general, meteorological and space environment requirements were translated into satellite related performance units (e.g., spatial and temporal resolution, radiometric levels and sensitivities, etc.). Similarly, the communication and search and rescue functions were specified in terms of required performance (e.g., data rates, location accuracies etc.).

Following the workshop, there were smaller group meetings to refine the requirements and provide NOAA/NESDIS with the comprehensive input needed to initiate the GOES-N study. By June 1989, the requirements were given to the AMAO.

A set of global change study requirements has been extracted from NASA documents (e.g., Earth Observing System (EOS) working group reports) associated with the planning of the EOS mission. More details on these requirements will be presented at the end of this section. Because global change is a relatively new program area, the global change requirements will probably be subject to relatively rapid evolution as the program matures. The GOES-N mission could make a substantial contribution to satisfying global change measurement requirements.

4.2 Imaging and Sounding Requirements

The NWS is a prime contributor to the requirements. The majority of its requirements concern meteorological measurements which are made by instruments that take images of the earth in various spectral bands and that obtain spectral data primarily in the visible and infrared which can be used to generate winds and profiles (mostly temperature and moisture).

Following the January 1989 workshop, the NWS reviewed its imaging and sounding requirements and sent NESDIS a memorandum containing its needs. This memorandum was the basis of the imaging and sounding requirements used in the GOES-N study.

The NWS imaging and sounding requirements were subdivided into three groups. core, options, and enhancements. The core requirements are the most essential. Many are a revalidation of those specified in the 1983 GOES I-M requirements and contain some which have been difficult to meet as the GOES I-M series has evolved. The optional requirements were those that the NWS wanted to explore seriously including areas which were desired on GOES I-M but were considered to be not feasible in that time frame. Other optional requirements have been added as the need for more sophisticated products grows as the 2000 time period is approached (e.g., the combination of satellite data with the measurements from the modernization of NWS during the 1990s). The enhanced requirements are highly desirable; however, it is recognized that many of these could be expensive and/or have high technological risks. Therefore, they were given lower priority than the core and optional requirements by the GOES-N Study Team (GST). There were additional prioritizations provided within the optional and enhanced requirements categories.

When the GST received the imager and sounder requirements from NOAA (the NWS memorandum) it summarized them into a compact tabular form. Tabl[illegible] requirements summary for the imager that subdivides the requirements into the thre[illegible] types of requirements. The requirements near the top of Table 4.2.1-a[illegible]ment rela[illegible] the ones near the bottom are affected by the performance of the complete system (i.e., in[illegible] and spacecraft). This latter group is mostly connected with registration and navigation. Tables 4.2.1-a through e relate to the imager requirements of the May 1990 NOAA requirements document by number. These numbers were used to identify each requirement to studies that were identified during the study period. The NWS memorandum contains details of why NWS wants each capability; the highlights are:

1) The core imager channels are the same as those on the GOES I-M imager. The four additional optional channels would primarily improve cloud height measurement (13.3 μm), be used to track areas of moisture in cloud free areas (7.3 μm), detect clouds

TABLE 4.2.1 GOES-N IMAGER REQUIREMENTS SUMMARY

AREA	CORE REQUIREMENTS	OPTIONS	ENHANCEMENTS
CHANNELS	• 0.55 - 0.75 μm • 3.8 - 4.0 μm • 6.5 - 7.0 μm • 10.2 - 11.2 μm • [illegible] - 12.5 μm	ADD: • 0.86 μm • 1.6 μm • 7.3 μm • 13.3 μm (All at 4 Km resolution)	• Calibrate Visible Channel • Add Low Light Capability at Night
SPATIAL RESOLUTION	• 0.55 - 0.75 μm - 1 km • 3.8 - 4.0 μm - 4 km • 10.2 - 11.2 μm - 4 km • 11.5 - 12.5 μm - 4 km • 6.5 - 7.0 μm - 8 km	[illegible]8 - 4.0 μm - 2 km [illegible]5 - 7 μm - 4 km	• 0.55 - 0.75 μm - 0.5 km
TEMPORAL RESOLUTION AND COVERAGE	• Full Disk - ≤ 30 min • 3000 x 3000 km - ≤ 5 min • 1000 x 1000 km - ≤ 2 min		
SENSITIVITY AND DYNAMIC RANGE	• 3.8-4.0μm - NEΔT of 1.4K @300K • 6.5-7.0μm - NEΔT of 1K @230K • 10.2-11.2μm - NEΔT of 0.35K @300K • 11.5-12.5μm - NEΔT of 0.35K @300K	[illegible]3.8-4.0μm - NEΔT of 0.1K [illegible]300K [illegible]5-7.0μm - NEΔT of 0.3K [illegible]0K [illegible].2-11.2μm - NEΔT of 0.1K [illegible]0K [illegible].5-12.5μm - NEΔT of 0.1K @300K *	Increased dynamic range for window IR channels to 350K
ENCIRCLED ENERGY		Add Specification	
CLOUD SMEARING	Imager output to be within 0.02 of its final true value within 1 IGFOV		
CHANNEL TO CHANNEL SIMULTANEITY	Coincident data covering 8 x 8km area within 5 sec.		

* Signal to Noise and NEΔT performance requirements are needed and should be provided by NOAA in later studies.

TABLE 4.2.1 GOES-N IMAGER REQUIREMENTS SUMMARY
(continued)

AREA	CORE REQUIREMENTS	OPTIONS	ENHANCEMENTS
EARTH LOCATION ACCURACY (System Requirement) • Day (± 8 hours from noon) • Night (± 4 hours from midnight)	 4km (3 σ) - Nadir 6km (3 σ) - Nadir	 2km (3 σ) - 45° Latitude 2km (3 σ) - 45° Latitude	
IMAGE STABILITY (System Requirement)	• ±21 μr N-S and E-W - (3 σ) ≤ 0.1° Inclination • ±24 μr N-S and E-W - (3 σ) ≤ 0.5° Inclination	• ± 10 μr N-S and E-W (3 σ) ≤ 0.1° Inclination • ± 12 μr N-S and E-W (3 σ) 0.5° Inclination • 1 μr (3 σ) - E-W Adjacent pixels • 3 μr (3 σ) - N-S Adjacent pixels	
REGISTRATIONS (System Requirement) • Channel to Channel • Image to Image • Day • Night	 14 μr (3 σ) • 42 μr (3 σ)-15 min • 84 μr (3 σ)-90 min • 70 μr (3 σ)-15 min • 105 μr (3 σ)-90 min	 14 μr (3 σ) 90 min 14 μr (3 σ) 90 min	
TIMELINESS	Maximum delay of 30 sec between data acquisition and transmission		
CONFLICTS AND IMPROVED PERFORMANCE		• Reduce recovery time after spacecraft maneuvers to 1 hour • Midnight performance should approach daytime performance • Minimum of single window IR channel during eclipse • Add lightning mapping	• Additional imager to resolve schedule conflicts (resolution - 2km vis.; 6km IR). Also serves as a backup instrument to the primary imager.

TABLE 4.2.1-a

GOES-N+ IMAGER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENTS
SPECTRAL BAND & SPATIAL RESOLUTION	RC1 (met) 0.55 - 0.75 μm - 1km 3.8 - 4.0 μm - 4km 6.5 - 7.0 μm - 8km 10.1 - 11.2 μm - 4km 11.5 - 12.5 μm - 4km	RO1 INCREASE RESOLUTION 3.8 - 4.0 μm - 2km 6.5 - 7 μm - 4km ADD SPECTRAL BANDS 0.86 μm - 4km 1.6 μm - 4km 7.3 μm - 4km 13.3 μm - 4km	RE1 0.55 - 0.75 μm - [illegible]km
EARTH LOCATION ACCURACY DAY (NOON ± 8 HOURS) NIGHT (MIDNIGHT ±4 HOURS)	RC2 (met) 4km (3σ) - NADIR 6km (3σ) - NADIR	RO2 2km (3σ) - 45° LATITUDE 2km (3σ) - 45° LATITUDE	

TABLE 4.2.1-b

GOES-N+ IMAGER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENTS
REGISTRATIONS:			
PIXEL-TO-PIXEL	RC3 -42 μr (3σ) - INCLINATION $\leq 0.1^{\circ}$ -48 μr (3σ) - INCLINATION $\leq 0.5^{\circ}$	RO3 -14 μr BETWEEN ANY TWO PIXEL	
CHANNEL-TO-CHANNEL	RC4 0.5 km (3σ) AT NADIR (14μr)		
IMAGE-TO-IMAGE DAY	RC5 (met) 42 μr (3σ)-15 min 84 μr (3σ)-90 min	RO5 14 μr (3σ)-90 min	
NIGHT	70 μr (3σ)-15 min 105 μr (3σ)-90 min	14 μr (3σ)-90 min	
TEMPORAL RESOLUTION AND COVERAGE	RC6 (met) FULL DISK - $\leq$30 min 3000 X 3000 km - $\leq$5 min 1000 X 1000 km - $\leq$2 min		

TABLE 4.2.1-c

GOES-N+ IMAGER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENTS
SENSITIVITY & DYNAMIC RANGE	RC7 (met) -3.8-4.0 μm-NEDT OF 1.4K @ 300K -6.5-7.0 μm-NEDT OF 1K @ 230K -10.2-11.2 μm-NEDT OF 0.35K @ 300K (ALSO 1.4K @ 200K) -11.5-12.5 μm-NEDT OF 0.35K @ 300K	RO7 -3.8-4.0 μm-NEDT OF 0.1K @ 300K -6.5-7.0 μm-NEDT OF 0.3K @ 240K -10.2-11.2 μm-NEDT OF 1.0K @ 300K -11.5-12.5 μm-NEDT OF 0.1K @ 300K	RE7 INCREASED DYNAMIC RANGE FOR IR WINDOW CHANNELS TO 350K
CLOUD SMEARING	RC8 IMAGER OUTPUT TO BE WITHIN 0.02 OF ITS FINAL TRUE VALUE WITHIN 1 IGFOV		
CHANNEL-TO-CHANNEL SIMULTANEITY	RC9 (met) COINCIDENT DATA COVERING 8X8km AREA WITHIN 5 SEC		
TIMELINESS	RC10 (met) MAX. DELAY OF 30 SEC BETWEEN DATA ACQUISITION AND TRANSMISSION		

TABLE 4.2.1-d

GOES-N+ IMAGER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENTS
IMPROVED PERFORMANCE		RO11A -REDUCE RECOVERY TIME AFTER SPACECRAFT MANEUVERS TO 1 HOUR -MIDNIGHT PERFORMANCE SHOULD APPROACH DAYTIME PERFORMANCE RO11B -MINIMUM OF SINGLE WINDOW IR CHANNEL DURING ECLIPSE	
ENCIRCLED ENERGY (BLURRING)		RO12 ADD SPECIFICATION	
VISIBLE CALIBRATION			RE13 CALIBRATE VISIBLE CHANNEL
NIGHT VISIBLE			RE14 ADD LOW LIGHT CAPABILITY AT NIGHT
CONFLICTS			RE15 ADDITIONAL IMAGER FOR BACKUP AND TO RESOLVE SCHEDULE CONFLICTS (RESOLUTION-2km VIS.;6km IR)
LIGHTNING MAPPER		RO16 ADD LIGHTNING MAPPER	

TABLE 4.2.1-e

CORE/REMEDIAL REQUIREMENTS FOR IMAGER					
CHANNEL NUMBER	SPECTRAL RANGE (μm)	SPATIAL RES. (km)	BRIGHTNESS/THERMAL SENSITIVITY (S/N or NEDT)	DYNAMIC RANGE	PRINCIPAL APPLICATIONS
1	0.55 - 0.75	1	3:1 AT 0.5% ALBEDO	0-100% ALBEDO	WEATHER MONITORING; SEVERE STORM DETECTION; CLOUD MAPPING, TYPING, AND MOTION; SNOW COVER; INSOLATION; (CLOUD FILTER)
2	3.80 - 4.00	4	1.4K AT 300K	4-320K	NIGHT TIME CLOUD DETECTION AND H_2O VAPOR ESTIMATES
3	6.50 - 7.00	8	1.0K AT 230K	4-320K	JET STREAM LOCATION AND UPPER ATMOSPHERIC CIRCULATIONS (WATER VAPOR)
4	10.20 - 11.20	4	1.4K AT 200K 0.35K AT 300K	4-320K	DAY/NIGHT SURVEILLANCE OF CONVECTION STORMS, LOW LEVEL MOISTURE, SURFACE TEMPERATURES, WINDS, SOIL MOISTURE (THERMAL INERTIA)
5	11.50 - 12.50	4	0.35K AT 300K	4-320K	LOW LEVEL WATER VAPOR & SURFACE TEMPERATURES

against a snow background (1.6μm), and measure the areal extent of vegetation (0.9 μm). The enhancements would permit a more quantitative use of the visible channel and use the visible channel at night (e.g., fog detection).

2) The spatial resolutions of the core channels are the same as the GOES I-M imager. The options and enhancement improvements to three of the five existing GOES I-M channels would yield major benefits for cloud motion measurement for winds, other cloud property measurements (e.g., type, amount, and height), and for the general interpretation of imagery, especially small scale cloud features (e.g., thunderstorm outflow boundaries).

3) The temporal resolution requirements are well within those of the GOES I-M imager.

4) The core sensitivity and dynamic range needs are the same as GOES I-M. The optional radiometric sensitivities will primarily allow considerably more accurate determination of surface temperature (either terrestrial or clouds) and lower tropospheric water vapor. The enhancement option of a wider dynamic range will permit the sensing of surface temperature in summertime desert areas and hot spots produced by fires.

5) The next three areas are concerned with image quality (cloud smearing) and/or utilization of the data for multispectral techniques (e.g., surface temperature measurement). The encircled energy requirement will require a detailed specification in later phases of the program.

6) The core system requirements associated with earth location accuracy, image stability (called pixel to pixel registration in the NWS memorandum), and registrations are the same as the GOES I-M program. The spatial improvements are mostly connected with data matching with the NWS modernization measurements, the accuracy of cloud motion-wind determinations, and the potential for very accurate cloud height determination using stereographic techniques with simultaneously acquired images in the overlapping regions of two spacecraft.

7) The 30 second timeliness requirement emanates from the high perishability of rapid scan imagery in severe storm situations.

8) The operational conflicts and improved performance requirements category contains needs for extending the number of hours of operational data, improving the quality around midnight (when the stress on instruments and spacecraft is maximum), and adding the capability to detect lightning. The enhancement requirement in this category recognizes the potential conflict when continuous operational rapid scan imagery over limited areas is required at the same time that there is a need for continuous full disk imaging to support international users and to obtain winds from cloud motion over the full disk for global models. It is also recognized that a second imager could serve as a backup to the primary imager in the case of a malfunction of the primary imager.

Table 4.2.2 is a summary of sounder requirements presented in a format similar to the requirements in Table 4.2.1. Tables 4.2.2-a through c relate to the sounder requirements of the May 1990 NOAA requirements document by number and were used in the same manner as the imager numbers (Table 4.2.1a-e). The highlights are (again, the details are in the NWS memorandum):

TABLE 4.2.2 GOES-N SOUNDER REQUIREMENTS SUMMARY

AREA	CORE REQUIREMENTS	OPTIONS	ENHANCEMENTS
CHANNELS	Same as GOES I-M sounder	High spectral resolution spectrometer or interferometer (4-15μm)	
SPATIAL RESOLUTION	$\leq$ 8km		$\leq$ 4km
TEMPORAL RESOLUTION AND COVERAGE	• 3000 x 3000 km in $\leq$ 40 min • 1000 x 1000 km in $\leq$ 10 min	• 3000 x 3000 km in $\leq$ 30 min • Sounding image products - 2500 x 2500km in $\leq$ 20 min	Increase in effective dwell times by factors of 2 and 4
MEASUREMENT ACCURACY • Temperature	1000-700mb - $\pm$ 2K 700-300mb - $\pm$ 1.5K 300-100mb - $\pm$ 2.5K	All levels - $\pm$ 1K	
• Humidity	1000-600mb - $\pm$ 20% RH 600-200mb - $\pm$ 15% RH	All levels $\pm$ 1.5-3K dewpoint	
SENSITIVITY	A sounding for each 60 x 60km area using 9 clear pixels	Single pixel sounding	
CLOUD DETECTION	Visible channel at $\leq$ 8km resolution	• Day--visible channel with 1km resolution • Night--window IR with 2km resolution	
ENCIRCLED ENERGY	• 70% of energy within IGFOV • 83% of energy within 10km (1.25 IGFOV with 8km IGFOV)		

TABLE 4.2.2 GOES-N SOUNDER REQUIREMENTS SUMMARY
(continued)

AREA	CORE REQUIREMENTS	OPTIONS	ENHANCEMENTS
SPECTRAL RESPONSE	• 72% of area under spectral response curve should lie between ($v + \Delta v/2$) and ($v - \Delta v/2$) • 96% of area should lie between ($v + \Delta v$) and ($v - \Delta v$) • Total area will be all non-zero responses of 1% or greater of maximum peak		
CROSSTALK	Pixel to pixel memory of $\leq$ 0.25 NEΔT		
QUANTIZING	Least Significant Bit=0.5 NEΔT		
EARTH LOCATION ACCURACY (System Requirement)	$\leq$ 4km (3σ) absolute		
IMAGE STABILITY (System Requirement)	Relative position accuracy - 0.1 IGFOV between adjacent IGFOV		
CHANNEL TO CHANNEL REGISTRATION (System Requirement)	• Radiometric centroids matched within 2% of total IGFOV width (1σ) • Half-power IGFOV channel widths within 1% (1σ)	• Co-register cloud detection visible and IR data to within 14 μr (3σ) • All IGFOV's matched to within 2% (1σ)	
IMAGE TO IMAGE REGISTRATION (System Requirement)	Within 1 IGFOV (3σ)		

TABLE 4.2.2-a

GOES N+ SOUNDER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENT
CHANNELS	RC17 (met) SAME AS GOES I-M SOUNDER @ 8KM	RO17 HIGH SPECTRAL RESOLUTION SPECTROMETER OR INTER-FERROMETER (4-15 μm) WITH 8km RESOLUTION	
CLOUD DETECTION	RC18 (met) VISIBLE @ 8KM	RO18 -DAY--VISIBLE CHANNEL WITHIN 1km RESOLUTION -NIGHT--IR WINDOW WITH 2km RESOLUTION	
MEASUREMENT ACCURACY	SEE TABLE RC17-1		
TEMPERATURE	RC19 (met) 1000-700mb-±2K 700-300mb-±1.5K 300-100mb-±2.5K	RO19 ALL LEVELS-±1K	
HUMIDITY	RC19 (met) 1000-600mb-±20% RH 600-200mb±15% RH	RO19 ALL LEVELS ±1.5-3K DEW POINT	
SENSITIVITY	RC20 (met) A SOUNDING FOR EACH 60X60km AREA USING 9 CLEAR PIXELS	RO20 SINGLE PIXEL SOUNDING	

TABLE 4.2.2-b

GOES-N+ SOUNDER REQUIREMENTS SUMMARY			
AREA	**CORE**	**OPTIONAL**	**ENHANCEMENTS**
SPATIAL RESOLUTION	RC21 (met) ≤ 8KM		RE21 ≤ 4KM
TEMPORAL RESOLUTION & COVERAGE	RC22 (met) -3000 X 3000 km IN ≤ 30 min -1000 X 1000 km IN ≤ 10 min	RO22 -3000X3000 km IN ≤ 40 min (SEE RC22) -SOUNDING IMAGE PRODUCTS-2500X2500km IN≤ 20 min TEMP. ACCURACY DEG RADED BY 50%	RE22 (met) INCREASE IN EFFECTIVE DWELL TIMES BY FACTORS OF 2 AND 4
EARTH LOCATION ACCURACY	RC23 ≤4KM (3σ) ABSOLUTE		
REGISTRATION			
PIXEL-TO-PIXEL	RC24 0.1 IGFOV BETWEEN ADJACENT IGFOV'S		
CHANNEL-TO-CHANNEL	RC25 -RADIOMETRIC RESPONSE CENTROIDS MATCHED WITHIN 2% OF TOTAL IGFOV WIDTH (1σ) HALF-POWER IGFOV CHANNEL WIDTHS WITHIN 1% (1σ)	RO25 -CO-REGISTER CLOUD DETECTION VISIBLE & IR DATA WITHIN 14 μr (3σ) -ALL IGFOV'S MATCHED TO WITHIN 2% (1σ)	
IMAGE-TO-IMAGE	RC26 WITHIN 1 IGFOV (3σ)		

TABLE 4.2.2-c

GOES-N+ SOUNDER REQUIREMENTS SUMMARY			
AREA	CORE	OPTIONAL	ENHANCEMENTS
SPECTRAL RESPONSE	RC27 (met) - 72% OF AREA UNDER SPECTRAL RESPONSE CURVE SHOULD LIE WITHIN THE SPECTRAL BANDPASS -96% OF AREA SHOULD LIE WITHIN TWICE SPECTRAL BANDPASS -TOTAL AREA WILL BE ALL NON-ZERO RESPONSES OF 1% OR GREATER OF MAX PEAK		
ENCIRCLED ENERGY	RC28 -70% OF ENERGY WITHIN IGFOV -83% OF ENERGY WITHIN 10km (1.25 IGFOV WITH 8km IGFOV)		
CROSSTALK	RC29 PIXEL-TO-PIXEL MEMORY OF ≤0.25 NEDT		
QUANTIZING	RC30 (met) LEAST SIGNIFICANT BIT= 0.5 NEDT		

1) The core channels are the same as the GOES I–M sounder. The optional channels will have to be of much higher spectral resolution in order to achieve the required accuracy shown in the options column for accuracy To achieve the higher spectral resolution will require an interferometer or spectrometer covering the spectral range from 4–15μm with a spectral resolving power of $\lambda/\Delta\lambda$ of $\geq$ 1200:1.

2) In general, the core and optional spatial and temporal resolutions are close to those of the GOES I–M sounder. The enhanced spatial resolution ($\leq$4km) is to further reduce cloud effects, and the enhanced increase in dwell time is to improve radiometric performance. Special products from sounding data are anticipated (e.g., cloud top heights) where some compromise can be made in radiometric performance with a commensurate increase in coverage per unit time. The result is the optional requirement for sounding image products.

3) The core accuracy requirement is the same as what is expected to be achieved with the GOES I–M sounder. By 2000, the combination of better model performance, expected better forecast accuracy, and the accuracy increases expected from other observing systems leads to the strong optional requirement for a higher level of performance which should be achievable with the remote sensing performance outlined under sounder item 1 above.

4) A sounding is required for each 60 x 60km area using a maximum of nine clear pixels within that area (the same as the GOES I–M requirement). The optional requirement for single pixel sounding recognizes:
   a) that the possibility of a single clear area within a 60 x 60km area is significantly greater than 9 clear pixels.
   b) the positive value of having 10km sounding resolution in clear areas to define strong thermal gradients in dynamic meteorological situations, and
   c) the reduction of noise created by different averaging situations either/or in time and space.

5) The core requirement of a visible spectral band at the same resolution as the sounding spectral bands is the same as the GOES I–M sounder. The higher spatial resolution visible and infrared optional requirements are to improve day and nighttime cloud detection respectively, which is one of the most serious negative influences on accurate sounding.

6) The core requirements for encircled energy, spectral response, crosstalk, and quantizing are either the same as GOES I–M or have been added to improve the radiometric quality of the data.

7) The core systems requirements for earth location, image stability, channel to channel registration, and image to image registration are close to those for the GOES I–M sounder. They are needed for matching sounding data with measurements from other sources (e.g., profilers, surface and radiosonde stations), for calculating the motions of features seen in the sounder data, and for contributing to the strong requirement for obtaining radiometric data for sounding from the same atmospheric column and underlying surface, with consistent cloud effects or the lack of cloud effects on each measurement. The optional requirements for co–registration of the higher resolution visible and infrared data to the sounding channels is also needed for precise cloud effect estimation. The instantaneous field of view (FOV) matching to within $\pm$2% is needed to ensure that the radiances required for sounding are coming from the same atmospheric column and underlying surface.

All imaging and sounding requirements ultimately are connected to geophysical parameters that will be needed beyond 2000. Table 4.2.3 is a sample list of parameters which, in some cases, are divided into subcategories. The parameters expected to be derived from measurements from the imager are correlated with imager channels in Table 4.2.4, which shows all the proposed optional spectral bands as well as the five core spectral bands. It is obvious that most of the parameters will be derived from combinations of spectral bands rather than from just a single channel. Thus, the requirements for spectral band to spectral band registration affect the quality of the derivations for virtually all the parameters. The same is true for most of the other requirements, because they influence total imaging performance (e.g., encircled energy, image stability, etc.).

The primary products from the sounder are temperature and moisture profiles, and the spectral bands are selected to best obtain the profiles. As with the imager, the other requirements (signal to noise, additional high resolution imaging arrays, etc) have been chosen to provide improved derivation of the profiles. There are, however, a number of other products that can be produced from sounder data such as surface temperature and cloud top heights. Past experience has also shown (e.g., VISSR Atmospheric Sounder (VAS)) that, with such a wide range of spectral information available from the sounder, many new products will be developed which cannot be specified now.

As previously mentioned, many of the requirements are either new or improvements over what is expected on GOES I-M. In these instances, an attempt has been made to assess the value of each of these requirements. The "optional" sounder requirements were not converted by NWS or NOAA into instrument parameters; i.e., spectral channels, sensitivity, etc., (See Section 9.3.2). This will not only help appreciate the expected value of each requirement but also assist in making system trade-off decisions where the value has to consider technological complexity, risk, and cost. Details of this assessment in the area of image navigation and registration are presented separately in Appendix A1.

Another consideration is where the parameters will be used in meteorological analyses. Table 4.2.5 shows the expected use of each major parameter category as a function of major meteorological events and/or uses. There is a strong emphasis on mesoscale/regional scale events and contributions to numerical models. Tropical and extratropical cyclones are shown as separate events. Table 4.2.5 shows that each of the parameters will contribute to the analysis of most of the events with some (e.g., winds and the profiles) contributing to all of them.

4.3 Space Environment Monitoring Requirements

4.3.1 Summary of Requirements

Requirements for the GOES-N SEM contained in the "Statement of Guidelines and Requirements, GOES-N Phase-A Study" are summarized in Table 4.3.1, reproduced from that document. The first four instruments listed Table 4.3.1-a and 4.3 1-b; i.e., the Energetic Particle Sensor (EPS), magnetometer, full-disk X-Ray Sensor (XRS), and the SXI are identified as the "Baseline" payload for GOES I-M and will be carried over into GOES-N, although with some enhancement of the range of particle energies covered by the EPS. It should also be noted that the SXI will not be flown until late in the GOES I-M series. The remainder of the requirements in Table

TABLE 4.2.3 SAMPLE OF ANTICIPATED GOES-N PRODUCTS *

PRODUCT	SUB CATEGORIES	
	SYMBOL	DESCRIPTION
CLOUD PRODUCTS (CP)	CP-H CP-A CP-T	CLOUD HEIGHT CLOUD AMOUNT CLOUD TYPE
TEMPERATURE PRODUCTS (TP)	TP-P TP-S	TEMPERATURE PROFILES SURFACE TEMPERATURE
MOISTURE PRODUCTS (MP)	MP	MOISTURE PROFILES (SOUNDER) TROPOSPHERIC MOISTURE ESTIMATES (IMAGER)
WIND PRODUCTS (WP)	WP-C WP-M	WINDS FROM CLOUD MOTIONS WINDS FROM MOISTURE MOTIONS
AEROSOL PROPERTIES	AP-V AP-D	VISIBILITY RELATED (e.g., HAZE) DUST STORMS
GENERAL IMAGERY INTERPRETATION (IP) LIGHTNING PRODUCTS (LP) VEGETATION PRODUCTS (VP) SNOW AND ICE PRODUCTS (SP) PRECIPITATION PRODUCTS (PP)		

* THESE PRODUCTS MAY BE PRODUCED IN CONJUNCTION WITH RADAR MEASUREMENTS (RM), CONVENTIONAL MEASUREMENTS (CM), (e.g., SURFACE REPORTS, RADIOSONDES), AND OTHER SATELLITE MEASUREMENTS (SM).

TABLE 4.2.4
PROPOSED GOES-N IMAGING SPECTRAL BANDS
VERSUS THEIR USE IN DERIVING EXPECTED PRODUCTS

	SPECTRAL BAND CENTRAL WAVELENGTH (μm)								
PARAMETER	**0.65**	**0.9**	**1.6**	**3.9**	**6.7**	**7.3**	**10.7**	**12.0**	**13.3**
1. Surface Temperature and Lower Tropospheric Moisture									
a. Day	S				S	S	P	P	
b. Night				P	S	S	P	P	
2. Convection Intensity	P•			S	S		P		P
3. Winds									
a. Cloud Motions◊									
(1) Mesoscale									
(a) Day	P•		S		S	S	P		P
(b) Night				P°	S	S	P		P
(2) Global	P•		S	P	S	S	P		P
b. Moisture Motions	S				P	P	S		
4. Cloud Properties									
a. Type	P		P	P	P	S	P	S	
b. Height	P•		S	P■	P		P		P
c. Amount	P			P°			P		
5. Mid Tropospheric Water Vapor	S				S	P			
6. Upper Tropospheric Water Vapor	S				P	S			
7. Circulation Features and Imagery Interpretation (e.g., Jet Streams)	P			P°	P	P	P		S
8. Vegetation	P	P							
9. Snow and Ice	P				S	S			
10. Soil Moisture	S				S	S	P	S	
11. Fires	S			P°			P		
12. Precipitation	P			P°	S		P		P
13. Radiation Balance	P	S	S	S	S	S	P	P	S
14. Aerosols (including dust)	P*	S		P°	S		P		

P = Primary Use S = Secondary Use

• Stereo
■ Stereo at night with 2km resolution
° 2km resolution at night
◊ Best cloud motion results will also use cloud parameter products
* Low light level data at night

TABLE 4.2.5
SIGNIFICANT ANTICIPATED GOES-N PRODUCTS ASSOCIATED WITH EACH MAJOR EVENT/USE

(PRODUCTS CODE IS THE SAME AS TABLE 4.2.3)

	ANTICIPATED PRODUCTS										
EVENTS/USES	**[illegible]**	**TP**	**MP**	**WP**	**AP**	**IP**	**LP**	**VP**	**SP**	**PP**	**M**
SEVERE LOCAL STORMS	X	X	X	X	X	X	X	X		X	X
TROPICAL CYCLONES	X	X	X	X		X	X			X	X
EXTRATROPICAL CYCLONES	X	X	X	X		X	X		X	X	X
NUMERICAL MODELS • GLOBAL	X	X	[illegible]	X				X	X		X
• MESOSCALE/REGIONAL SCALE	X	X	X	X				X	X		X
REGIONAL SURVEYS	X	X	X	X	X	X	X	X	X	X	X
CLIMATE/GLOBAL CHANGE	X	X	X	X	X		X	X	X	X	X

TABLE 4.3.1

GOES-N-, SEM REQUIREMENTS' SUMMARY			
AREA	CORE	OPTIONAL*	ENHANCEMENTS
ENERGETIC PARTICLES	RC31 PROTONS AND ALPHAS 30keV>700MeV per NUCLEON ELECTRONS $\leq$ 30keV - 4MeV HEAVY IONS FLUENCE ($Z \geq 3$)	RO31 ELECTRONS AND POSITIVE IONS 10eV - 30keV	
MAGNETIC FIELDS	RC32 (met) 3 COMPONENTS OF THE VECTOR FIELD TO $\leq$ 1nT ACCURACY		
TOTAL ELECTRON CONTENT		RC32 IONOSPHERIC RADIO BEACON MEASURES POLARIZATION ROTATION AT VHF	

* NESDIS SHOULD PROVIDE MORE COMPLETE REQUIRED ACCURACIES ALONG WITH TEMPORAL, SPATIAL AND SPECTRAL RESOLUTIONS.

TABLE 4.3.1

GOES-N+ SEM REQUIREMENTS SUMMARY (CONTINUED)			
AREA	**CORE**	**OPTIONAL**	**ENHANCEMENTS**
SOLAR OBSERVATIONS	RC33 (met) FULL-DISK X-RAY SENSOR FLUX IN 0.5 - 4 AND 1 -8 ANGSTROM BANDS	RO33 SOLAR EUV SPECTROMETER TIME INTEGRATED FLUX IN SEVERAL SPECTRAL LINES	
	RC34 (met)* SOLAR X-RAY IMAGER CORONA IMAGES IN SEVERAL BANDS	RO34 SOLAR MAGNETOGRAPH PHOTOSPHERIC VECTOR FIELD IN EACH ACTIVE REGION WITH 2.5nT SENSITIVITY	
		RO35 SOLAR HYDROGEN ALPHA LINE IMAGER HIGH FRAME RATE (1 MINUTE) SOLAR IMAGES IN HYDROGEN ALPHA LINE & CONTINUUM	

* CONTRACTUAL ARRANGEMENT WITH LORAL AEROSYS (LAS) IS IN PROGRESS

TABLE 4.3.1-A
GOES-N CANDIDATE INSTRUMENTS - SEM

INSTRUMENT	MEASURES	FOV	SPECTRAL RESOLUTION	SPATIAL RESOLUTION
Energetic Particle Sensor	0.03 to 700MeV/n for p and α 30keV to 4MeV for e $Z \geq 3$ particle fluence	---	3 channels/ decade	---
Magnetometer	Ambient vector field	---	---	---
Full-Disk X-Ray	0.5-4Å, 1-8Å solar brightness	WD*	0.5-4Å band	WD
Solar X-Ray	X-ray images	$\geq 1.5R_s$	TBD	5 x 5 $arcsec^2$
Local Plasma	Charged particle flux		-15 channels	TBD
EUV Spectrometer	Average EUV brightness	WD	TBD	WD
Solar Magnetograph	Solar vector magnetic field	WD+	TBD	2 x 2 $arcsec^2$
Hα Imager	Hα Images	WD+	0.5Å	1 x 1 $arcsec^2$
Radio Beacon	N/A	N/A	N/A	N/A

* WD = Whole Disk
* FOV might be smaller than whole disk

TABLE 4.3.1-B
GOES-N CANDIDATE INSTRUMENTS - SEM

INSTRUMENT	CADENCE	DYNAMIC RANGE	T/M BPS	COMMENTS
Energetic Particle Sensor	$\leq$ 30sec 0.03 to 4MeV	TBD	20	Crude directionality required above 1 MeV
Magnetometer	0.5sec	-400 to +400nT	100	Specifications assume Spacecraft field is accounted for.
Full-Disk X-Ray	$\leq$ 3sec	as for GOES I-M	10	Fewer range changes than in present instrument are desirable
Solar X-Ray Imager	60sec	as for GOES I-M	2×10^5 (3×10^4)	Must have EUV filter to acquire routine EUV images.
Local Plasma	$\leq$ 3sec in each channel		50	Crude directionality
EUV Spectrometer	0.5 to 1.0 hr	TBD	10	Must be well calibrated for several lines in 1-2000λ range.
Solar Magnetograph	10 minute.	-.03 to 0.3T	2×10^4	Multiple wavelength (heights) desirable. Accuracy set by technological limits.
Hα Imager	$\leq$ 60sec	TBD	1×10^6	Line-center and continuum.
Radio Beacon	N/A	N/A	1	Continuously broadcasts two frequencies in 100-400 MHz range; total power 1 W.

4.3.1, i.e., the EUV Spectrometer, the SVM/Hα and the Radio Beacon TEC, were classified as potential improvements to the SEM, with final selection and determination of funding to be deferred until after completion of the study. Following the format established in the "Guidelines" for the imager and the sounder as to core requirements, options, and enhancements, the Study Team identified the first four instruments as "core", and the remainder as "options". The performance characteristics are presented in Tables 4.3.1-a and 4.3.1-b.

4.3.2 Discussion

4.3.1.1 Requirements Met by GOES-I

The requirements listed above for the magnetometer and the full disk XRS are unchanged from the specified performance for GOES-I. Because the existing instruments are expected to meet those requirements, no effort has been devoted to alternate instrumentation approaches. It has, of course, been necessary to consider system level impacts of these requirements, such as the level of magnetic interference imposed by the spacecraft for the magnetometer, and provision of appropriate FOV and pointing for the XRS. The magnetometer monitors the progress of geomagnetic activity from the vantage point of geosynchronous orbit for correlation with ground magnetic activity and for input to operational field models which include the effects of magnetospheric current systems as well as the solid earth. It also provides the local magnetic coordinate frame-of-reference for energetic particle activity. The XRS provides the primary means of monitoring and classifying solar x-ray activity, and provides significant data to NOAA's long range solar-terrestrial forecasting capability, because it often provides the first detection of solar flare onset, even when ground based observatories are clouded over or at night. Flare intensity and duration are related to coronal mass ejections, and, thus, the real-time monitoring by GOES is important to the prediction of possible solar particle and magnetic storm activity at earth.

4.3.1.2 Enhanced Requirements for Earth Environment Observations

The EPS, Low energy Plasma Sensor (LPS) and Radio Beacon TEC jointly monitor several parameters of the particle environment as ordered by the earth magnetic field. The EPS requirements are similar to those for the GOES I-M program, but the range of observations has been considerably expanded. The lower end of the energy range for proton and alpha particle observations has been moved from 0.8MeV/nucleon to 30keV/nucleon. Similarly, the lower energy cutoff for electron observations has been moved from 0.5MeV to 30keV. The heavy ion ($Z \geq 3$) channels are not monitored on GOES I-M. The EPS provides continuous data to monitor solar and geomagnetically trapped radiation important to ionospheric effects as well as radiation hazards to operating spacecraft, astronauts, and high altitude aircraft. The extension of the range of electron energies will be particularly useful in understanding and monitoring the causes of "deep dielectric charging" and surface charging of spacecraft systems.

The LPS is intended to monitor the low energy range of particles responsible for many of the instances of spacecraft electrostatic charging which have plagued geosynchronous and near-geosynchronous orbiting satellites with operational anomalies and, in some instances, damage or outright failures. Its availability on multiple geosynchronous satellites will provide data important not only to the host spacecraft but to any geosynchronous spacecraft at nearby longitude stations.

Ultimately, NOAA hopes to use these data together with other operational data to be able to extrapolate knowledge of the particle radiation environment and magnetospheric properties at any geosynchronous satellite location.

The requirement for the Radio Beacon is also new with GOES-N, although it has for years been high on the list of priorities for enhancement of SEM observations on GOES because of its potential contribution to monitoring the state of the ionosphere and its effects on radio communication. The United States Air Force (USAF) has, however, implemented the capability to monitor this parameter with the Global Positional Satellite (GPS) system, largely supplying the data NOAA needs for ionospheric monitoring. As a result, the priority for this addition to the GOES-N capability is reduced.

4.3.1.3 Enhanced Requirements for Solar Observations.

Addition of the SXI, the EUV, the SVM/Hαl capabilities to GOES-N would result in a dramatic increase in the solar observation capabilities of GOES-N relative to current spacecraft. The SXI, SVM/Hαl, through their ability not only to monitor more parameters of solar activity but to map the location on the sun as well, will improve significantly the accuracy with which NOAA forecasts the terrestrial effects of solar activity. The EUV spectrometer would provide an otherwise unavailable monitor of the electromagnetic radiation responsible for upper atmosphere heating important to prediction of the effects of atmospheric drag on spacecraft orbits and lifetime. These data are also important for monitoring atmospheric and ionospheric activity affecting radio propagation. Archival of the data from an expanded set of GOES observations would also provide a valuable coherent data base for study of long term solar variability.

The SXI has been identified by NOAA as an operational (core) requirement, and will in fact be developed and flown on a later spacecraft in the GOES I-M series. The other instruments are identified as potential enhancements, pending identification of sponsoring agencies and funding availability.

4.4 Data Collection Systems (DCS) Requirements (Table 4.4.1)

The study requirements were to define options for locating sources of interfering signals in the DCS channel bandwidth and for increasing Data Collection Platform (DCP) data rates and channel capacities.

4.5 WEFAX Requirements (Table 4.4.1)

The study requirements were to determine the impacts on the spacecraft, the ground system and WEFAX receive stations of adding three channels in the WEFAX band to the existing analog channel. The new channels are a second analog WEFAX channel, a digital WEFAX channel operating at 19.2kbps, and a 50kbps data channel (termed the NOAA port). An additional requirement was to determine the impacts to the spacecraft of operation during eclipse periods.

TABLE 4.4.1

GOES-N+ DCS/WEFAX REQUIREMENTS			
AREA	**CORE**	**OPTIONAL**	**ENHANCEMENTS**
DATA COLLECTION SYSTEM (DCS)	RC36 INTERROGATES PLATFORMS & RECEIVES DATA FROM THESE & OTHER NON-INTERROGATABLE PLATFORMS (met) CHANNEL CAPACITY = 266 266 CHANNELS AT 100 OR 300 BAUD 40 CHANNELS AT 1200 BAUD DCS SHALL HAVE THE CAPABILITY TO EARTH LOCATE A TRANSMISSION		
WEFAX	RC37 CHANNEL 1 LOW RESOLUTION WEFAX A, ANALOG (met) CHANNEL 2 LOW RESOLUTION WEFAX B, ANALOG CHANNEL 3 HIGH RESOLUTION WEFAX, ANALOG AND DIGITAL CHANNEL 4 NOAA PORT PRODUCTS SYSTEM TO OPERATE AT UNREDUCED POWER LEVEL DURING PERIOD OF SPACECRAFT ECLIPSE		

4.6 Search & Rescue (S&R) Requirements (Table 4.5.1)

The study requirements were twofold. One was to determine the feasibility of earth locating 406MHz Emergency Locator Transmitter/Emergency Position Indicating Radio Beacon (ELT/EPIRB) distress signals from geosynchronous orbit to an accuracy of 20 kilometers or determine what accuracies are feasible. The second was to define the ground system requirements to receive and process distress beacons relayed through the spacecraft and to interface with U.S Mission Control Center (MCC).

4.7 Products, Process and Communications Requirements

The requirements were to:

- Study ground system operations including staffing and skill levels
- Determine impacts on telemetry and command processing of the orbit and attitude control system
- Determine the impact of new instruments and improved image navigation/registration on instrument downlink data rates and processing
- Assess the impact of new products and their timeliness on the GOES Variable data format (GVAR), processing requirements, and required user ground equipment
- Determine the impact of new instruments receiving and processing equipment at the Satellite Operations Control Center (SOCC)
- Estimate the impact of new instruments and additional WEFAX channels on Command and Data Acquisition (CDA) transmit and receive equipment and the telemetry and command system

4.8 Global Change Measurement Requirements

Meeting future global change requirements (cf., Section 4) is likely to become an increasingly important need for all future satellite systems. No specific global change requirements were formally proposed in the GOES-N study. However, worldwide future geosynchronous satellite information could have a major role in satisfying global change requirements. In general, most diurnal measurements are best made by geosynchronous satellites, and the many positive characteristics of viewing the earth from this orbit could lead to the extremely accurate and timely derivation of many geophysical parameters.

Previous quantitative global change requirements have been presented in NASA documents (e.g., *Proposed NASA Contribution to the Climate Program*). A substantial effort to update the requirements has been part of the EOS program. Table 2 in the *EOS Observing System Science and Mission Requirements Working Group Report*, Volume I, 1984 provided a detailed list of global change observational needs. The list was presented by parameter accuracy, spatial resolution, and observation frequency requirements. Often, requirement ranges were given, especially for accuracy which was divided into "desired" and "required" categories.

TABLE 4.5.1

GOES-N+ SEARCH AND RESCUE REQUIREMENTS			
AREA	**CORE**	**OPTIONAL**	**ENHANCEMENTS**
SPACE SEGMENT	RC35 RECEIVE 406MHz UPLINK SIGNALS FROM ELT/EPIRB FOR DISTRESS ALERTS (met) RELAY DISTRESS SIGNALS TO EARTH STATIONS AT 1544.5MHz (met) PROVIDE LOCATION DETERMINATION OF DISTRESS SIGNALS SOURCE TO ≤20km		
GROUND SEGMENT	RC35 HARDWARE NECESSARY TO RECEIVE & PROCESS SIGNALS RECEIVED FROM SPACECRAFT SOFTWARE NECESSARY TO PROCESS SIGNALS RECEIVED FROM SPACECRAFT & TO RECOVER TRANSMITTER LOCATION SYSTEM DESIGN TO INTERFACE WITH U.S. MISSION CONTROL		

Table 4.6.1 is a subset of Table 2 in the EOS report for those parameters that can be measured from geosynchronous orbit. It contains more than half of the parameters listed in Table 2. Table 4.6.1 shows the accuracy, spatial resolution and observation frequency requirements. In a few cases (e.g., vegetation identification) the accuracy requirements have been changed into units that are more familiar.

The GOES-N program could meet all of these observational frequency requirements. It could make strong contributions to the measurements of wind, surface temperature, clouds, snow, radiation, temperature, and moisture profiles and lightning

TABLE 4.6.1 Global Change Observational Needs For Those Parameters That Future Geosynchronous Satellites Could Measure

PARAMETER	ACCURACY		SPATIAL RES.	OBSERVATION FREQUENCY
	DESIRED	REQUIRED		
Soil Features • Moisture-Surface	5%	10%	1-10 km	2 days
• Texture-Color	10%	10%	30 m	annual
Surface Temperature • Land	0.5K	1K	1km ± 0.5 km	12 hours
• Inland waters	0.1K	0.5K	30 m	12 hours
• Ocean	0.1K	0.5K	4 km (open ocean) 1 km (coastal ocean)	12 hours
• Ice	0.5K	1K	1 km	1 day
Vegetation • Identification	90%'	85%'	1 km	7 days
• Areal extent	95%'	90%'	30 m	30 days
•Condition (stress morphology phytomass)	10%	15%	30 m	3 days
• APAR*	10%	20%	30-500 m	3 days
• Leaf area index canopy structure and density	10%	20%	30 m	3 days
Clouds • Cover	2%	5%	1 x 1 km	6 hours
• Top height	0.25 km	0.5 km	1 km	6 hours
• Emission temperature	0.5K	1K	1 x 1 km	6 hours
• Albedo	0.01	0.02	50 x 50 km	6 hours

* APAR = Absorbed Photosynthetically Active Radiation
' = Probability of Correct Class

TABLE 4.6.1 Global Change Observational Needs For Those Parameters That Future Geosynchronous Satellites Could Measure (cont'd)

PARAMETER	ACCURACY		SPATIAL RES.	OBSERVATION FREQUENCY
	DESIRED	REQUIRED		
Water vapor	10% RH	20% RH	100 x 100 km x 100 mbar (vertical)	12 hours
Snow-Areal extent	5%	10%	1 km	7 days
Radiation • Shortwave	2%	5%	1 x 1 km	1 day
• Longwave	2%	5%	1 x 1 km	1 day
• Short & long wave	2%	5%	100 x 100 km	6 hours
Precipitation	5%	10%	1 km	daily
Evapotranspiration	5%	10%	1 km	daily
Runoff	10%	10%	30 - 500 km	daily
Phytoplankton • Chlorophyll Open ocean/coastal Ocean/inland waters	10%	20%	0.03 - 4 km	2 days
• Pigment groups Open ocean/coastal Ocean/inland waters	10%	20%	0.03 - 4 km	2 days
Turbidity-Inland water/coastal ocean	10%	20%	0.03 - 1 km	2 days
Wetlands areal extent	10%	20%	30 m	3 days
Inland ice-Temperature	1.0K	1.0K	100 x 100 km	annual mean
Sea Ice-Areal extent	10 km	100 km	5 - 20 km	weekly

TABLE 4.6.1 Global Change Observational Needs For Those Parameters That Future Geosynchronous Satellites Could Measure (cont'd)

PARAMETER	ACCURACY		SPATIAL RES.	OBSERVATION FREQUENCY
	DESIRED	REQUIRED		
Atmospheric constituents *				
Tropospheric chem.	5%	20%	10 x 10 x 1 km	1 day
Middle atmosphere	5%	10%	500 x 500 x 3.5 km	1 day
Upper atmosphere	10%	25%	500 x 500 x 3.5 km	1 day
Aerosols				
Tropospheric chem.	5%	20%	10 x 10 x 1 km	1 day
Temperature				
Troposphere	0.5K	1K	100 x 100 x 5 km	1 day
Middle atmosphere	1K	2K	500 x 500 x 3.5 km	1 day
Upper atmosphere	5K	10K	500 x 500 x 3.5 km	1 day
Winds				
Troposphere		2 m/s	100 x 100 x 3.5 km	12 hours
Middle atmosphere		3 m/s	500 x 500 x 3.5 km	1 day
Upper atmosphere		10 m/s	500 x 500 x 3.5 km	1 day
Lightning (number of flashes, cloud to cloud, cloud to ground)	95% of actual strokes	90% of actual strokes	1 - 10 km	continuously

* Ozone and Compounds of Carbon, Nitrogen, Hydrogen, Chlorine, Sulfur, etc.

5.0 DEFINITION OF TASKS 1, 2, 3A, AND 3B AND THE GOES-7 REPLICATION TASK

Task 1 was assigned to determine the cost of replicating GOES I-M in the GOES-N time frame (circa 2000). This task is intended to cover the NOAA option of essentially extending the GOES I-M series should circumstances or budgetary constraints warrant such a decision. The current GOES I-M system was thoroughly analyzed with assessments made relative to needed expenditure increases or decreases based on a large variety of cost-influencing parameters. A description of the analyses, assumptions, and the logic used to construct the recurring and non-recurring cost estimates is contained in Volume III of this report.

Task 2 was defined as a feasibility study of candidate modifications to the GOES I-M system that would result in efficiency improvements or cost reductions. The modifications were to be conceived, described, evaluated, and ranked in priority order based on a complex formula that included science and other benefits accruable from implementation of the proposed items. The associated studies conducted resulted in quantified assessments of the risk and cost of implementing the modifications together with schedule impacts, if any, and value of the changes relative to NOAA science requirements. The results of Task 2 are summarized in Sections 7.1 and 8.0. Costs associated with Task 2 are contained in Volume III under the Option I heading.

Task 3A comprises determining, describing, evaluating, and ranking a number of changes to the GOES I-M design that will result in satisfying the 1983 NWS requirements not included in GOES I-M design specifications. The "changes" were deemed applicable to instruments, spacecraft subsystems, and system elements including the ground system. Each candidate change was evaluated with regard to risk, feasibility, cost, and schedule impacts in addition to benefits to NOAA mission objectives for GOES-N. Effects of each change on each NWS 1983 requirement were carefully determined after detailed analyses were completed. The cost of each proposed design change is included in the cost matrices contained in Volume III of this report.

Task 3B is exactly the same as Task 3A with the exception that the requirements criteria used were those stipulated in the 1989 NOAA requirements document, previously referenced. The procedures used for the analyses and assessments are the same as those used for Task 3A. Cost results due to these design changes are reflected in Volume III under the Options II and III headings.

A study to estimate the costs of replicating GOES-7 in the GOES-N time frame, funded in December 1990, has been completed. Results of the study are contained in a separate document from the GOES-N Report.

6.0 STUDY APPROACH

6.1 Task 1 Approach

Task 1, the estimated cost of replicating GOES I-M in the GOES-N time frame, was a direct financial analysis performed by the AMAO and the RAO. Task 1 is a completely stand alone study, not related via options, to Tasks 2, 3A, or 3B. Task 1 was reported separately in a memorandum dated October 18, 1989 from RAO/C. L. Fryer to Code 402/T. Karras, subject: GOES-N Task 1 Cost of GOES-I, J, K, L, M in the GOES-N time frame. This memorandum references and contains two prior memoranda, dated September 18 and 22, 1989, from RAO/C. L. Fryer to Code 402/T. Karras, same subject, and an update.

6.1.1 Resources Analysis Office (RAO) Capabilities and Role in Task 1

The goal of the RAO is to provide independent assessments for proposed new starts based on mission parameters and management plans. RAO provides resource estimating services to flight projects throughout the center. Parametric cost analysis is the method by which estimates are derived. RAO develops tools for its cost modeling capability and in addition, develops and maintains data bases of technical performance, cost, and manpower utilization for all flight projects. This information is used in conjunction with estimating techniques to develop various models for use in resources estimating.

6.1.2 Goal of Task 1

The goal of Task 1, to estimate the cost of GOES I-M in the GOES-N time frame, was accomplished in two major steps. First, a modeled estimate for GOES I-M was developed in 1989 dollars. Second, replication costs of GOES I-M were determined. GOES-N cost estimates were developed in both 1989 and projected real year dollars.

6.1.3 Task 1 Costing Approach

6.1.3.1 Major Ground Rules

Major ground rules set by the project established the RAO approach for costing. Four of the ground rules that were major cost determinants are.

- The GOES I-M contractor will build GOES-N
- GOES-N is an exact replica of GOES I-M
- GOES-I spacecraft and instrument weights were used to cost GOES I-M and GOES-N
- GOES-N (first spacecraft) build time frame is January 1995 - December 1998 (four years); launch ready January 1999

6.1.3.2 Developed Hypothesis for Modeling Costs

In developing a modeled estimate for GOES I-M, RAO tested two hypotheses, Metsat Project and RAO, to determine the correct build scenario for GOES I-M. The two resulting estimates from the hypotheses were compared to estimated total cost derived from actual expenditures. The hypothesis which generated costs closest to the estimated total cost for GOES I-M was considered to be the correct build scenario and was used to model GOES I-M and subsequently GOES-N. The two build scenarios that RAO tested are in Table 6.1:

TABLE 6.1 GOES I-M

SPACECRAFT SEQUENCE	RAO'S HYPOTHESIS	PROJECT'S HYPOTHESIS
FIRST	NEW DESIGN	NEW DESIGN
SECOND	MINOR MODIFICATION	RECURRING UNIT
THIRD	MINOR MODIFICATION	RECURRING UNIT
FOURTH	MINOR MODIFICATION	RECURRING UNIT
FIFTH	MINOR MODIFICATION	RECURRING UNIT
IMAGER & SOUNDER	**RAO'S HYPOTHESIS**	**PROJECT'S HYPOTHESIS**
FIRST	NEW DESIGN	NEW DESIGN
SECOND	RECURRING UNIT	RECURRING UNIT
THIRD	MINOR MODIFICATION	RECURRING UNIT
FOURTH	MINOR MODIFICATION	RECURRING UNIT
FIFTH	MINOR MODIFICATION	RECURRING UNIT

Major differences between the two hypotheses occurred in the second through fifth builds for both spacecraft and imager and sounder. RAO's hypothesis was derived from the time differential over which the spacecraft and the instruments are being built. Technological advances over the build time frame and possible problems with unavailable parts will result in minor modifications to the first spacecraft design, as opposed to being exact replicas or recurring units. Similarly, for the imager and sounder, it is RAO's belief that only the second set of instruments will incur recurring costs or be an exact replica of the first, while the remaining instrument sets will experience minor modifications due to technological advances and unavailable parts.

On the other hand, the Projects hypothesis assumes that the second through fifth spacecraft and imager and sounder will be exact replicas of the first.

With the correct build scenario for GOES I-M, RAO was able to determine replication costs for GOES I-M and consequently a modeled estimate for GOES-N.

6.1.3.3 Developed Estimated Total Cost for GOES I-M

Estimates generated by the two hypotheses were compared to the estimated total cost derived from project actual expenditures in order to determine the correct build scenario. The estimated total cost was derived from three sources: LAS, the METSAT Project and RAO. LAS actual expenditures plus its estimates to complete was lower than the Metsat Project's POP (Program Operation Plan) total estimate to complete, so the difference between the two was added to LAS estimate to calculate the project estimated cost. Because these amounts represent costs prior to the July 1989 stop work order on GOES-K, L, M as a result of design problems with the instruments, RAO added an additional allowance to account for these problems. This estimated total cost was compared to the hypotheses in order to determine the correct build scenario for GOES I-M.

6.1.3.4 Modeled Costs for GOES I-M and GOES-N

With the correct build scenario, RAO was able to model costs for GOES I-M; replication costs for GOES I-M; and subsequently costs for GOES-N. Contingency for medium risk was added to the estimate to account for unknown problems and model fit. A build schedule was developed for GOES-N and costs were spread in real year dollars.

6.1.3.5 Past GOES Cost and Weight History

To verify cost validity, RAO reviewed the cost and weight history of past GOES programs and developed a dollar per pound cost comparison.

6.1.4 Task 1 Results

6.1.4.1 Selected Most Realistic Hypothesis

A comparison of modeled costs based on the two hypotheses, Project and RAO, to the estimated total cost based on actual expenditures for GOES I-M indicates that the RAO-hypothesized build scenario is the more realistic. Modeled costs based on the Project hypothesis underestimate actual expenditure by approximately twenty percent, whereas modeled costs based on the RAO hypothesis overestimate actuals by approximately five percent.

6.1.4.2 Estimated replication costs

Having modeled costs for GOES I-M, replication costs for GOES I-M in the late 1990s were easily determined. Stated ground rules which resulted in a cost savings for GOES-N were:

- The same contractor builds GOES-N as is currently building GOES I-M
- GOES-N is an exact replica of GOES I-M
- GOES-I spacecraft and instrument weights are used to model costs for GOES-N

Modeled costs for GOES-N with five (5) spacecraft predict a cost savings when compared to GOES I-M. This savings is due to the fact that there are no new design costs for the first spacecraft and set of instruments. There are no new design costs because of the stated ground rule that GOES-N is to be an exact replica of GOES I-M. However, RAO did factor in substantial design modification costs for the first spacecraft instruments due to the fact that GOES-N will be a new contract and is scheduled to start ten (10) years after GOES-I started. It is highly unlikely that GOES-N will not benefit from the technology advances that will have occurred over the 10 year interval. Had GOES-N been part of the same contract as GOES i-M and had it been built concurrently, then the savings would probably have been greater.

6.1.4.3 Comparison of Past GOES Projects to GOES I-M and GOES-N

A comparison of the dollar per pound ratios of GOES-I through M and GOES-N with the same ratios for GOES-2 and 3, GOES-4, 5, and 6 as well as GOES-G and 7 (GOES-G never achieved orbit due to a launch vehicle failure and did not receive a numerical designation) shows close correlation, an indicator of the validity of the GOES-N modeled cost estimates.

6.2 Translation of Tasks 2, 3A, and 3B to Options I, II, and III

NOAA requirements for GOES-N were analyzed, as described in Section 4.0 above, with each requirement categorized as "Core", "Optional", or "Enhanced." (Figure 6.1)

6.2.1 Recommended Studies

For each requirement, one or more specific studies were recommended as being necessary. These are listed in alphabetical order in Table 6.1 and defined in detail in Appendix 6A. Some of the studies were applicable, or responsive to, more than one requirement. The resources required to do each study were translated into civil service (or contractor)staff months. Table 6.2 shows the staff months required for each of the studies described in Appendix 6A.

6.2.2 Studies ranked in priority order, based on "values"

After each study was conceived, labeled, and described, it was subjected to an analysis procedure that involved: (Figure 6.2)

1. Designating each study as an "improvement modification" (Task 2) or a "design change" applicable to Task 3A or Task 3B (Figure 6.1)
2. Determining for each study the risk associated with implementing the proposed modification or design change, and a qualitative estimate of the schedule required to effect the modification or change. Each of these parameters was given a value ranging from 10 to 1 or 1 to 10 as applicable for comparison purposes. In addition, at the same time, the "value" (1-10) of each item relative to the affected NOAA requirements was stipulated.
3. Next a "tall pole" assessment was made based on risks, estimated costs, and schedule impacts.
4. A "payoff" value of each study was calculated as a function of the "value" of each change to satisfying a NOAA requirement and its associated "tall pole".
5. A "study benefit" was then calculated by comparing the "payoff value" with the assessed effect of the change on each NOAA requirement.

6. A parallel "scientific benefit" was also derived by comparing "tall poles" with the assessed value of each NOAA requirement.
7. The "study" and "scientific" benefit values were combined to establish a priority ranking for each of the approximately 50 studies.

The priority rankings compared with total resources constraints were used as a basis for selecting the studies which would be accomplished (Table 6.3) within the scope of the GOES-N Study. The list was presented to NOAA officials and adjusted to satisfy NOAA requests. Resource limitations forced a corresponding shift of studies to or from the "done" category (Table 6.2). The unfunded studies are listed in Table 6.4. (The funded and unfunded studies are also shown in priority order in Tables 6.3 and 6.4.)

After the list of recommended studies was finalized and agreed to by NOAA the accomplishment of the studies was indicated via analysis (for spacecraft, imagers, and sounders) and surveys (for DCS, WEFAX, S&R, and ground systems). It soon became apparent that the bulk of Tasks 2, 3A, and 3B could be satisfied by three space system configurations defined in Section 7 and that the proposed modifications and/or design changes could be simultaneously linked with basic NOAA requirements and one of the three specific combinations (options) of spacecraft, instruments, and launch vehicles. The three spacecraft systems were labeled Option I, Option II, and Option III, respectively. Figure 6.3 shows the relationship of the NOAA-assigned Tasks 2, 3A, and 3B with the GOES-N study generated Options I, II, and III.

Table 6.5 is a matrix showing the spacecraft, sensors, and launch vehicles as functions of the three options. The "baseline" system refers to the GOES I-M bus and payload with minor additions or improvement modifications included. All options satisfy more requirements than expected from GOES I-M.

The study was subsequently conducted and completed on the basis of Options I, II, and III. The configuration selected for Phase-B is expected to be a NOAA selected hybrid of these options.

Each of the three options was subjected to a formal cost estimate analysis with the results shown in Volume III. The cost estimating procedure used for each option closely paralleled that used for the accomplishment of Task I (Section 6.1). The approach for the study included separate efforts to:

- Derive recommendations for future studies (Section 8).
- Determine additional studies deemed needed as the study progressed from its inception.
- Prepare for supporting follow-on phases of the GOES-N program (e.g., Phase-B).
- Prepare recommendations for research where study results show they are needed.

Figure 6.1

NOAA REQUIREMENTS/STUDIES RELATIONSHIP

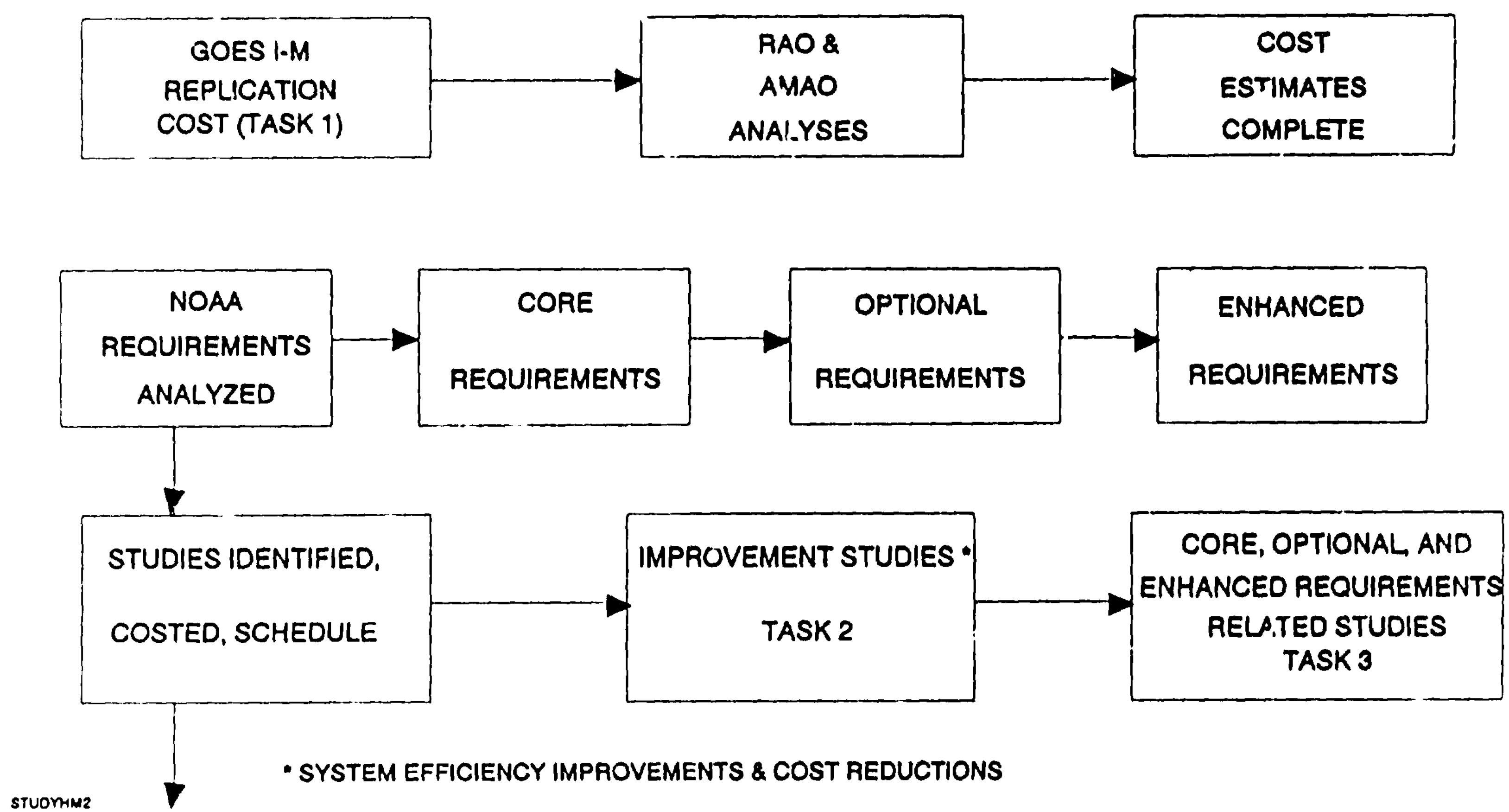


TABLE 6.2 LIST OF GOES-N STUDIES*

#	#	STUDY	DESCRIPTION	($M)	FUNDING STATUS
60	1	SC1	MAGNETOMETER	3.0	U**
15	2	SC2	IMPROVE EARTH SEN	4.0	F**
49	3	SC3	SIM STA/HSE KEEP	3.6	U
42	4	SC4	7 YR LF.INC FOR NO N-S STA KP	3.0	F
71	5	SC5	ELIM 3 DEAD SCANS	3.0	U
40	6	SC5	CHANGE MOM WHLS (DRP LMD)	1.0	F
50	7	SC7	GRND TRANSMITTERS	4.0	U
65	8	SC8	STORE SPINNING	4.0	U
68	9	SC9	ADD COMPUTER	4.0	U
2	10	SC10	USE INERTIAL REF UNIT	4.0	F
48	11	SC11	S/C FLIP 180 deg	3.6	U
9	12	SC12	MOM WHEEL (MW) TACHOMETER	4.0	F
69	13	SD1	SOFT WHL MOUNTS	4.0	U
41	14	SD2	MOM WHEEL (MW) DYN BALANCE	1.0	F
17	15	SS1	INCHWORM CO-REGIS	2.0	F
10	16	SS2.1	CENTER IR DET	2.0	F
45	17	SS2.2	I-K SNDR CH-CH REGIS	1.0	U
35	18	SS3.1	DAY/NITE NAV	0.3	F
11	19	SS3.2	OPS ECLIPSE	0.1	F
5	20	SS4.1	SENSOR POINTING	2.0	F
59	21	SS4.2	VARIABLE E-W SAMPLE	1.0	U
8	22	SS4.3	COLLOCATE MOTOR/ENCODER	2.0	F
18	23	SS4.4	IMC/MMC BASED ON IRU	3.0	F
17	24	SS4.5	SERVO/2km at nadir	2.0	F
67	25	SS5.1	STIFFEN STRUCTURE	1.5	U
79	26	SS5.2	STRUCTURAL APPROACHES	4.0	U
78	27	SS5.3	SYS ENGINEER REGISTRATION	2.0	U
16	28	SS6	ADD VIS ARRAY TO SNDR	1.8	F
64	29	SS7.1	IMAGE PLANE IMC	2.0	U
31	30	SS7.2	DIGITAL PROCESSOR	2.0	F
25	31	SS7.3	SNDR NAVIGATION/SERVO	2.0	F
66	32	SS8	RAM SELF TEST	1.0	U
47	33	SS9	AUTO-COLLIMATION ALIGN	2.0	U
7	34	SS10	LOW EXPANSION MAT	2.0	F
20	35	SS11.1	FLEX PIVOTS	1.0	F
57	36	SS11.2	SERVO CURES	2.0	U
6	37	SS11.3	SERVO/2km at 45 DEGREE	3.0	F
62	38	SS12	OFF-AXIS OPTICS DESIGN	3.0	U
4	39	SS13	ENCIRCLED ENERGY	2.0	F
51	40	SS14	FASTER IMAGER	4.0	U
54	41	SS15	SPINNING IMAGER	4.0	U
24	42	SS16	ADD'L IMAGER	1.8	F
21	43	SS17.1	NEW SOUNDER	4.0	F
44	44	SS17.2	SENSITIVITY NEW SNDR	4.0	F

** U: unfunded study
** F: funded study
* See Appendix 6A

TABLE 6.2 LIST OF GOES-N STUDIES (continued)

#	#	STUDY	DESCRIPTION	($M)	FUNDING STATUS
76	45	SS18	19 TO 14 SND CHANNELS	0.5	U
75	46	SS19	IM STAB 42μr	1.5	U
27	47	SS20	CH-CH REG 14μr	1.0	F
74	48	SS21	IM-IM REG 42μr	3.0	U
73	49	SS22	IM SENSTVTY 1K NEDT	2.0	U
72	50	SS23	I-K SNDR SENSITIVITY	4.0	U
23	51	SS24	IM SENSITIV .1K NEDT	3.0	F
70	52	SS25	IM SENSITIV 350K MAX	0.8	U
26	53	SS26	CLOUD SMEAR (.02°FINAL)	2.3	F
14	54	SS27	LARGER SUNSHADE (MIDNITE)	1.5	F
36	55	SS28	VIS CALIBRATION	1.3	F
30	56	SS29	NITE VISIBLE	0.5	F
38	57	SS30	LIGHTNING MAPPER	0.3	F
56	58	SS31	LARGER COOLER (SOUNDER)	1.8	U
29	59	SS33	SNDR CONTEMP IR FOR NITE	1.0	F
34	60	SS34	SINGLE PIXEL SOUNDING	1.0	F
63	61	SS35	4KM SOUNDING	3.0	U
52	62	SS36	HIGH SPEED SOUNDING	1.0	U
12	63	SS37	SNDR CROSSTLK <.25*NEDT	0.5	F
39	64	SS38	IM-IM REG 14μr	4.0	F
53	65	SS39	AMBIENT IR TESTING	1.0	U
61	66	SS40	HIGH RESOLUTION IMAGING	2.0	U
19	67	SS41	LARGER COOLER IMAGER	2.5	F
58	68	SS42	IMPROVED INST REDUN	1.0	U
77	69	SS43	PIX/PIX REGIS (1μr/3μr)	0.0	U
55	70	SS44	WIDE FIELD TST COLLIMATOR	3.0	U
33	71	SS45	SNDR VIS/IR REGISTRATION	4.0	F
32	72	SN1	IMGR GRND NAV/REG RESMPLR	4.0	F
46	73	ST1	IMGR/ERTH SEN SM BSPLT	1.0	U
37	74	SDCPS	DATA COLLECTION PLAT SYS	4.0	F
28	75	SWEFAX	WEATHER FACSIM BROADCAST	2.0	F
3	76	SSEM	SOLAR ENVIRON MONITORING	4.0	F
43	77	SPP&C	PRODUCTS PROCESS AND COMM	4.0	F
1	78	S/C-OP	STUDY S/C OPTIONS	12.0	F
22	79	SSAR	SEARCH AND RESCUE	2.0	F
80	80	SG1	GOES N IMPACTS (WORK STATION)	5.0	U
81	81	SG2	GOES N IMPACTS ON PREDICTION	10.0	U

U: unfunded study
F: funded study

TABLE 6.3 FUNDED STUDIES IN PRIORITY ORDER

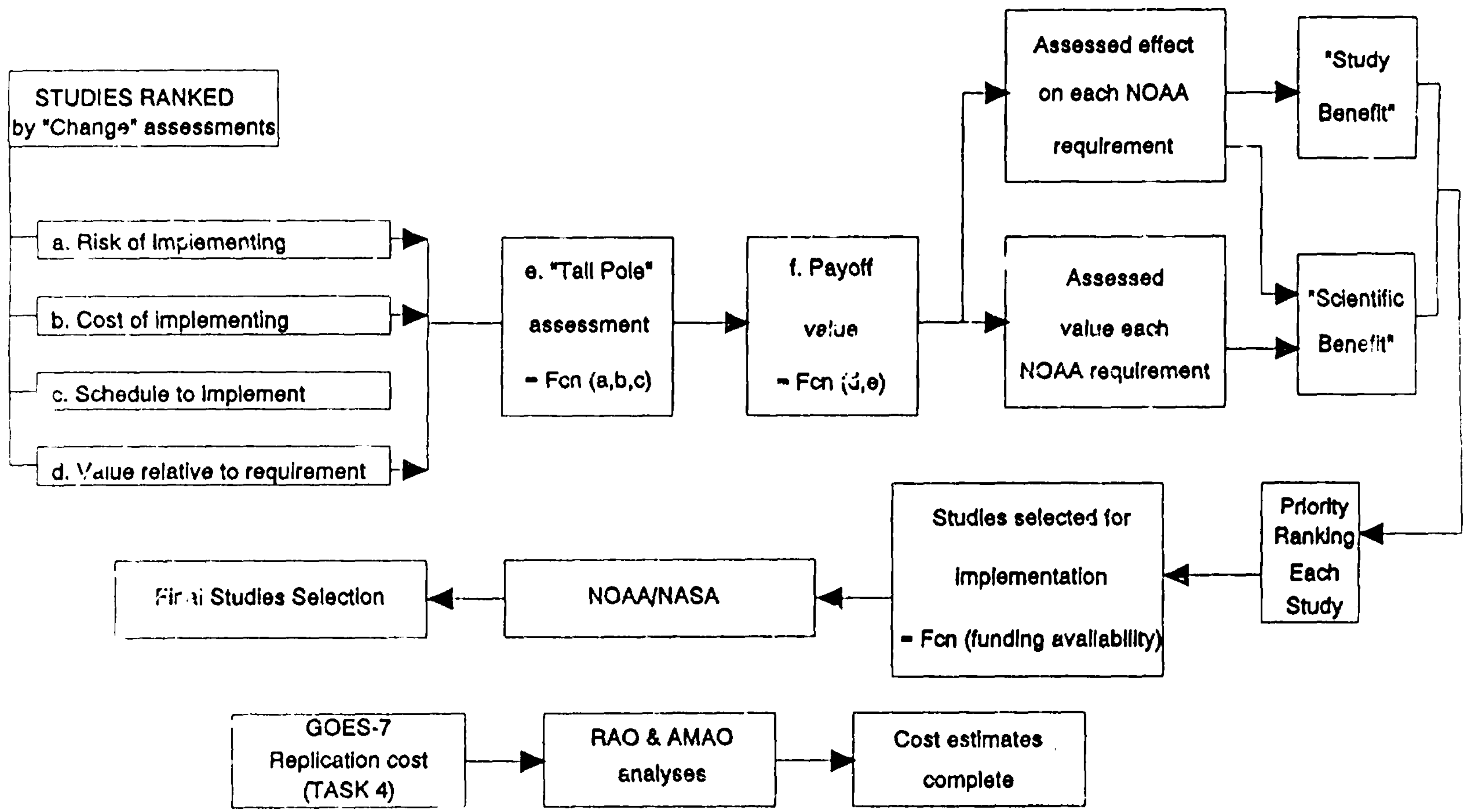
#	#	STUDY	DESCRIPTION	($M)
1	78	S/C-OP	STUDY S/C OPTIONS	12.0
2	10	SC10	USE INERTIAL REF UNIT	4.0
3	76	SSEM	SOLAR ENVIRON MONITORING	4.0
4	39	SS13	ENCIRCLED ENERGY	2.0
5	20	SS4.1	SENSOR POINTING	2.0
6	37	SS11.3	SERVO/2km at 45 DEGREE	3.0
7	34	SS10	LOW EXPANSION MAT	2.0
8	22	SS4.3	COLLOCATE MOTOR/ENCODER	2.0
9	12	SC12	MOM WHEEL (MW) TACHOMETER	4.0
10	16	SS2.1	CENTER IR DET	2.0
11	19	SS3.2	OPS ECLIPSE	0.1
12	63	SS37	SNDR CROSSTLK <.25°NEDT	0.5
13	24	SS4.5	SERVO/2km at nadir	2.0
14	54	SS27	LARGER SUNSHADE (MIDNITE)	1.5
15	2	SC2	IMPROVE EARTH SEN	4.0
16	28	SS6	ADD VIS ARRAY TO SNDR	1.8
17	15	SS1	INCHWORM CO-REGIS	2.0
18	23	SS4.4	IMC/MMC BASED ON IRU	3.0
19	67	SS41	LARGER COOLER IMAGER	2.5
20	35	SS11.1	FLEX PIVOTS	1.0
21	43	SS17.1	NEW SOUNDER	4.0
22	79	SSAR	SEARCH AND RESCUE	2.0
23	51	SS24	IM SENSITIV .1K NEDT	3.0
24	42	SS16	ADD'L IMAGER	1.8
25	31	SS7.3	SNDR NAVIGATION/SERVO	2.0
26	53	SS26	CLOUD SMEAR (.02°FINAL)	2.3
27	47	SS20	CH-CH REG 14μr	1.0
28	75	SWEFAX	WEATHER FACSIM BROADCAST	2.0
29	59	SS33	SNDR CONTEMP IR FOR NITE	1.0
30	56	SS29	NITE VISIBLE	0.5
31	30	SS7.2	DIGITAL PROCESSOR	2.0
32	72	SN1	IMGR GRND NAV/REG RESMPLR	4.0
33	71	SS45	SNDR VIS/IR REGISTRATION	4.0
34	60	SS34	SINGLE PIXEL SOUNDING	1.0
35	18	SS3.1	DAY/NITE NAV	0.3
36	55	SS28	VIS CALIBRATION	1.3
37	74	SDCPS	DATA COLLECTION PLAT SYS	4.0
38	57	SS30	LIGHTNING MAPPER	0.3
39	64	SS38	IM-IM REG 14μr	4.0
40	6	SC6	CHANGE MOM WHLS (DRP LMD)	1.0
41	14	SD2	MOM WHEEL (MW) DYN BALANCE	1.0
42	4	SC4	7 YR LF,INC FOR NO N-S STA KP	3.0
43	77	SPP&C	PRODUCTS PROCESS AND COMM	4.0
44	44	SS17.2	SENSITIVITY NEW SNDR	4.0

TABLE 6.4 UNFUNDED STUDIES IN PRIORITY ORDER

#	#	STUDY	DESCRIPTION	($M)
45	17	SS2.2	I-K SNDR CH-CH REGIS	1.0
46	73	ST1	IMGR/ERTH SEN SM BSPLT	1.0
47	33	SS9	AUTO-COLLIMATION ALIGN	2.0
48	11	SC1[illegible]	S/C FLIP 180 deg	3.6
49	3	SC3	SIM STA/HSE KEEP	3.6
50	7	SC7	GRND TRANSMITTERS	4.0
51	40	SS1[illegible]	FASTER IMAGER	4.0
52	62	SS36	HIGH SPEED SOUNDING	1.0
53	65	SS39	AMBIENT IR TESTING	1.0
54	41	SS15	SPINNING IMAGER	4.0
55	70	SS44	WIDE FIELD TST COLLIMATOR	3.0
56	58	SS31	LARGER COOLER (SOUNDER)	1.8
57	36	SS11.2	SERVO CURES	2.0
58	68	SS42	IMPROVED INST REDUN	1.0
59	21	SS4.2	VARIABLE E-W SAMPLE	1.0
60	1	SC1	MAGNETOMETER	3.0
61	66	SS40	HIGH RESOLUTION IMAGING	2.0
62	38	SS12	OFF-AXIS OPTICS DESIGN	3.0
63	61	SS35	4KM SOUNDING	3.0
64	29	SS7.1	IMAGE PLANE IMC	2.0
65	8	SC8	STORE SPINNING	4.0
66	32	SS8	RAM SELF TEST	1.0
67	25	SS5.1	STIFFEN STRUCTURE	1.5
68	9	SC9	ADD COMPUTER	4.0
69	13	SD1	SOFT WHL MOUNTS	4.0
70	52	SS25	IM SENSITIV 350K MAX	0.8
71	5	SC5	ELIM 3 DEAD SCANS	3.0
72	50	SS23	I-K SNDR SENSITIVITY	4.0
73	49	SS22	IM SENSTVTY 1K NEDT	2.0
74	48	SS21	IM-IM REG 42μr	3.0
75	46	SS19	IM STAB 42μr	1.5
76	45	SS18	19 TO 14 SND CHANNELS	0.5
77	69	SS43	PIX/PIX REGIS (1μr/3μr)	0.0
78	27	SS5.3	SYS ENGINEER REGISTRATION	2.0
79	26	SS5.2	STRUCTURAL APPROACHES	4.0
80	80	SG1	GOES N IMPACTS (WORK STATION)	5.0
81	81	SG2	GOES N IMPACTS ON PREDICTION	10.0

Figure 6.2

STUDY SELECTION CRITERIA



STUDYHM

Figure 6.3

OPTION/TASK RELATIONSHIP

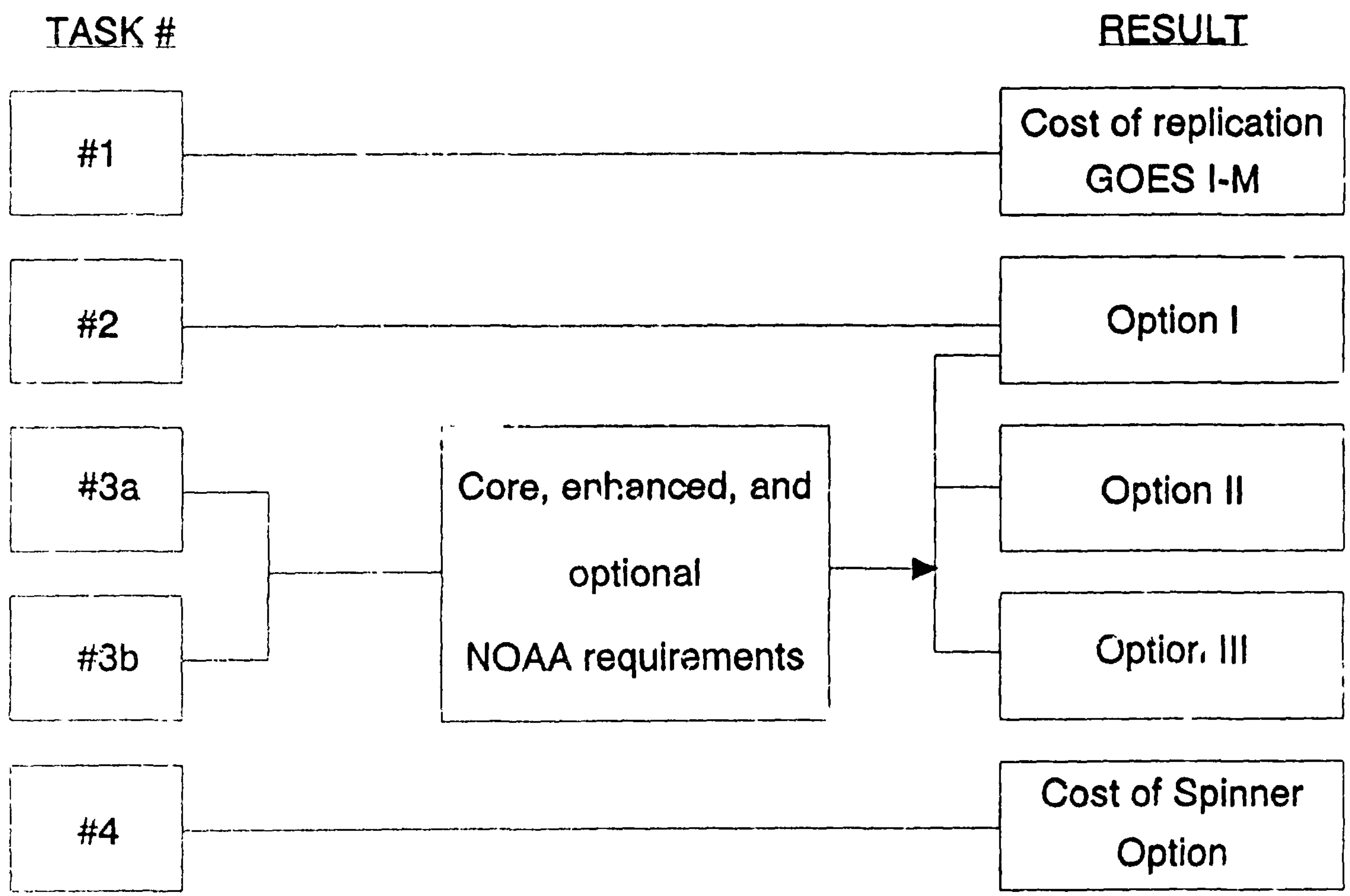


TABLE 8.5 GOES-N PAYLOAD/SPACECRAFT/LAUNCH VEHICLE MATRIX

DESCRIPTION	BASELINE ATLAS II	OPTION I ATLAS II	OPTION II ATLAS IIA	OPTION III ATLAS IIAS
Spacecraft (I-M bus)	X	X	---	---
Spacecraft (other)	---	---	X	X
Imager	X	---	---	---
Imager (improved)	---	X	---	---
Imager (7 bands)	---	---	X	---
Imager (new)	---	---	---	X
Imager (additional)	---	---	---	X
Lightning mapper	---	---	X	X
Sounder	X	---	---	---
Sounder (improved)	---	X	---	---
Sounder (high spectral res., passive cooler)	---	---	X	---
Sounder (high spectral res., active cooler)	---	---	---	X
WEFAX	X	X	---	---
WEFAX (new)	---	---	X	X
Data Collection System	X	X	---	---
Data Collection System (new)	---	---	X	X
S&R	X	X	X	X
S&R (new)*	---	---	---	---
SEM:				
Energetic Particle Sensor (EPS)	X	---	---	---
EPS (improved)	---	X	X	X
Magnetometer	X	X	X	X
X-Ray Sensor	X	X	X	X
Solar X-Ray Imager (new)	X	X	X	X
Low Energy Plasma Sensor	--	X	X	X
Solar Magnetograph/H-Alpha	---	---	---	X
Total Electron Content	---		---	X

* S&R (new) HAS POSITION LOCATION CAPABILITY

7.0 SUMMARY OF OPTIONS I, II, AND III AND STUDY RESULTS

This Section contains results of candidate improvement studies to satisfy Task 2 requirements; descriptions of Options I, II and III; and a listing of "Unmet" NOAA requirements. (NOTE: Option I was derived from Task 2 as shown in Figure 6.3.) Each option is further discussed in terms of payload concept summary, spacecraft configuration and heritage, ground system and spacecraft communications, risk identification, schedule assessments, and launch vehicle. Cost estimates for these options are contained in Volume 3 of this report. Results of the Task 1 study, to determine replication costs of GOES I-M in the GOES-N time frame, have already been reported to NOAA and are not repeated in Volume 3 of this report. Results of the 1990-1991 study to determine replication costs of GOES-7 in the GOES-N time frame will be issued under separate cover.

7.1 Task 2 Improvement Studies

The specific Task 2 related recommendations, based on studies conducted, are:

- Speed up sounder alignment (7.1.1)
- Remote alignment adjust mechanisms (7.1.2)
- Flex pivot for imager east-west scanner (7.1.3)
- Relocation of the east-west shaft encoder (7.1.4)
- Positive temperature control of the aft optics (7.1.5)
- Imager improvements (7.1.6)
- Noise Equivalent Delta Temperature (NEΔT) improvements (7.1.7)
- Optics and focal plane arrays (7.1.8)
- Sounder improvements (7.1.9)

When the study team defined the three options presented in this report as strawman spacecraft systems, the concept underlying the Option I spacecraft was that of a minimal cost program based almost exclusively on the GOES I-M heritage. This implies that GOES-N would be virtually identical to GOES-M in all respects, with changes only where cost and efficiency improvements could be made. The assumption is, therefore, that GOES-M instruments will meet the core requirements, which in most cases are those currently specified for GOES-I. There have been, however, some problems with the GOES-I development, the *de facto* heritage for this study, which led to broadening the Option I concept to allow instrument changes where the fundamental design approach is not changed and where the changes do not alter the spacecraft interface, i.e., power, weight, volume, footprint, telemetry, etc.. The changes to be incorporated were subjects of many of the study tasks, and so could not be specified until the completion of those studies. However, as reported in this and other sections of this report, they included such things as relocation of the east-west shaft encoder to the motor side of the shaft, a two-point mirror mount, the use of optical encoders in lieu of inductosyns, the use of different structural materials, and changes which could offer improvement of the signal-to-noise ratio of the instruments. Option I system and payload study recommendations are further defined in Section 8.

7.1.1 Speed-up Sounder Alignment (Option I)

One modification to the GOES-N Option I system to reduce cost would be to reduce the time to manufacture a filter wheel sounder. A significant amount of time is spent in aligning and adjusting the optical configuration of the infrared system in the sounder. Figure 7.1.1-1 shows the sounder optical system layout. The present alignment approach for the Infrared (IR), after the field stop plate, relay optics, and detectors are mounted on the cooler patch, requires adjusting the physical positions of the twelve IR detectors so that a signal can be detected. A collimated IR image of a slit, or knife edge, is scanned through the FOV and the relative locations of the twelve field stops determined by observing the detector outputs as the field stop images are relayed onto the detectors. Adjustment of the fold mirrors and beamsplitter angles and locations, and moving the three focusing lenses, are used to bring the four sounding "beams" in each of three spectral regions into co-registration. Finally, the signals from the detectors are maximized by positioning the detectors so as to intercept the maximum amount of the vignetted beam, completing the IR alignment procedure. This is a slow process often requiring many iterations if the specified co-registration of the bands is to be achieved. A preliminary concept has been developed as part of the GOES-N Task 2 studies that may significantly reduce some of this alignment effort.

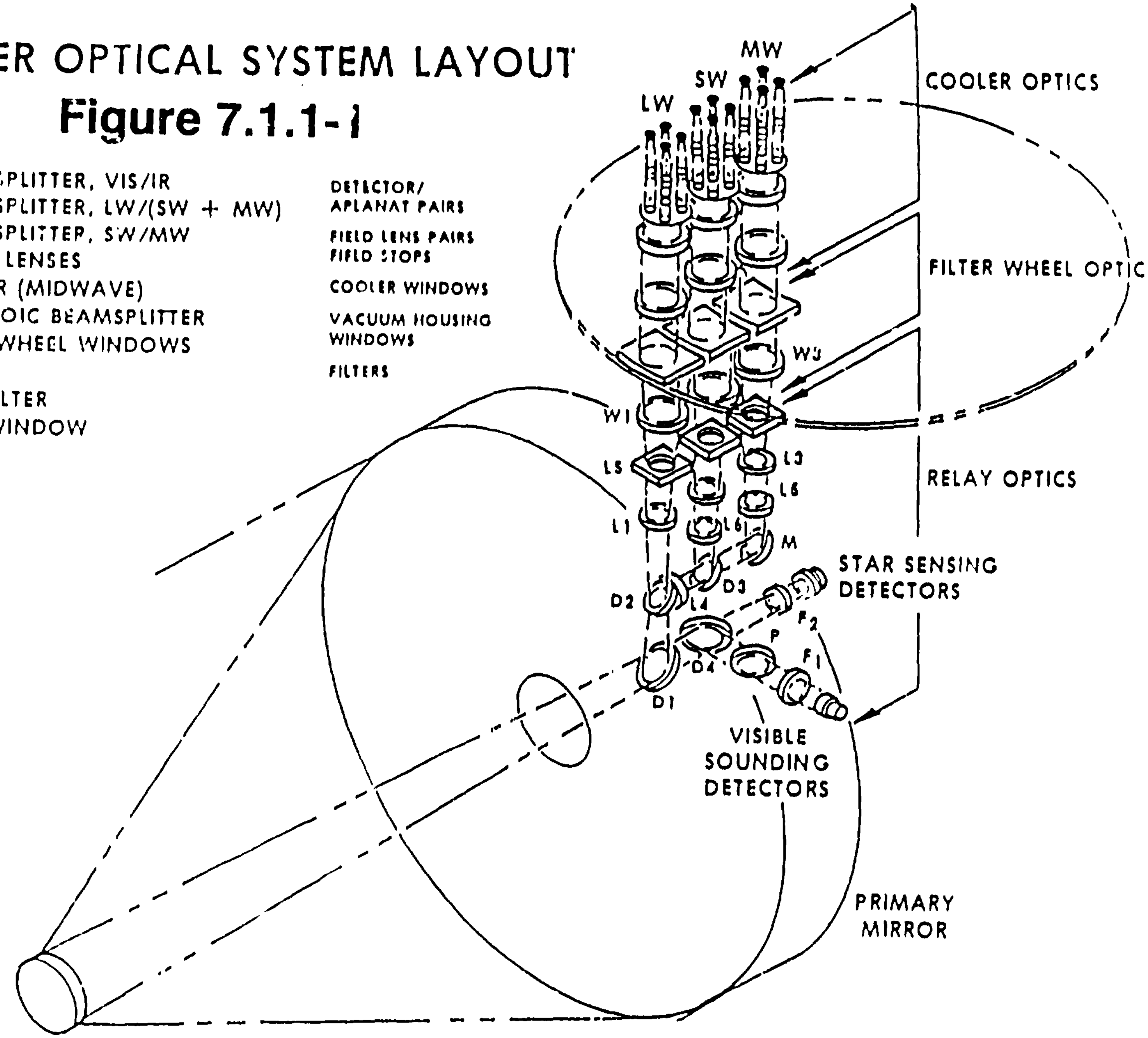
The concept is to align the optics in the sounder to set the magnification, focus and co-register the four sounding beams in each of the three IR bands, before "peaking" of the IR detectors, by using the collimator and an imaging IR detection system to "look" at the field stop plates. Since the field stop plate of the sounder, (Figure 7.1.1-1) is almost in focus for objects at infinity, photons emitted or reflected from the field stop plate will exit from the sounder in nearly parallel rays. The collimator will bring these rays to a focus and generate an image of the field stop plate (Figure 7.1.1-2). One of the field stop plates can be observed and its size and location measured by viewing this image with an infrared detection system through a narrow spectral filter, corresponding to one of the filters in one of the three spectral regions. By changing the spectral filters the other two field stop plates can be observed. Thus, the information needed to adjust and validate the focus, magnification, and co-registration of the bands can be acquired. During this process the filter wheel should be stopped with one of the larger spectral bandwidth filters in the path.

The field stop plate is too cold to allow easy observation using emitted photons. The system would be configured using an illuminator and beam splitting system in the back of the collimator to provide the reflected photons that will be observed (2A on Figure 7.1.1-2). It may be desirable to have a spectral defining filter in series with the illuminator before the beamsplitter to minimize the observation of the other bands. One approach would use a field stop plate with a surface that has a highly directional reflectivity, but not a mirror, so as to maximize the return of photons back towards the source at angles that will go backwards through the sounder optical system. A material with a different reflectivity could provide a center marker and the apertures will look "dark" because the photons going through them will tend to be absorbed in the detectors, or not reflected back to the collimator. An alternative would be to put a small set of flyable reflecting tags on the present field stop plate that would allow determination of the alignment and perhaps provide a larger return signal. The infrared imaging system at the back of the collimator could be an image plane scanner or could be a small set of detectors that will "scan" by moving the

SOUNDER OPTICAL SYSTEM LAYOUT

Figure 7.1.1-1

D1 = DICHROIC BEAMSPLITTER, VIS/IR
D2 = DICHROIC BEAMSPLITTER, LW/(SW + MW)
D3 = DICHROIC BEAMSPLITTER, SW/MW
L1-L6 = INTERMEDIATE LENSES
M = FOLDING MIRROR (MIDWAVE)
D4 = STAR/VIS TRICHROIC BEAMSPLITTER
W1, W2, W3 = FILTER WHEEL WINDOWS
F_1 = VISIBLE FILTER
F_2 = STAR SENSING FILTER
P = DEPOLARIZING WINDOW
LS = LYOT STOP



AEROSPACE/OPTICAL DIVISION ITT

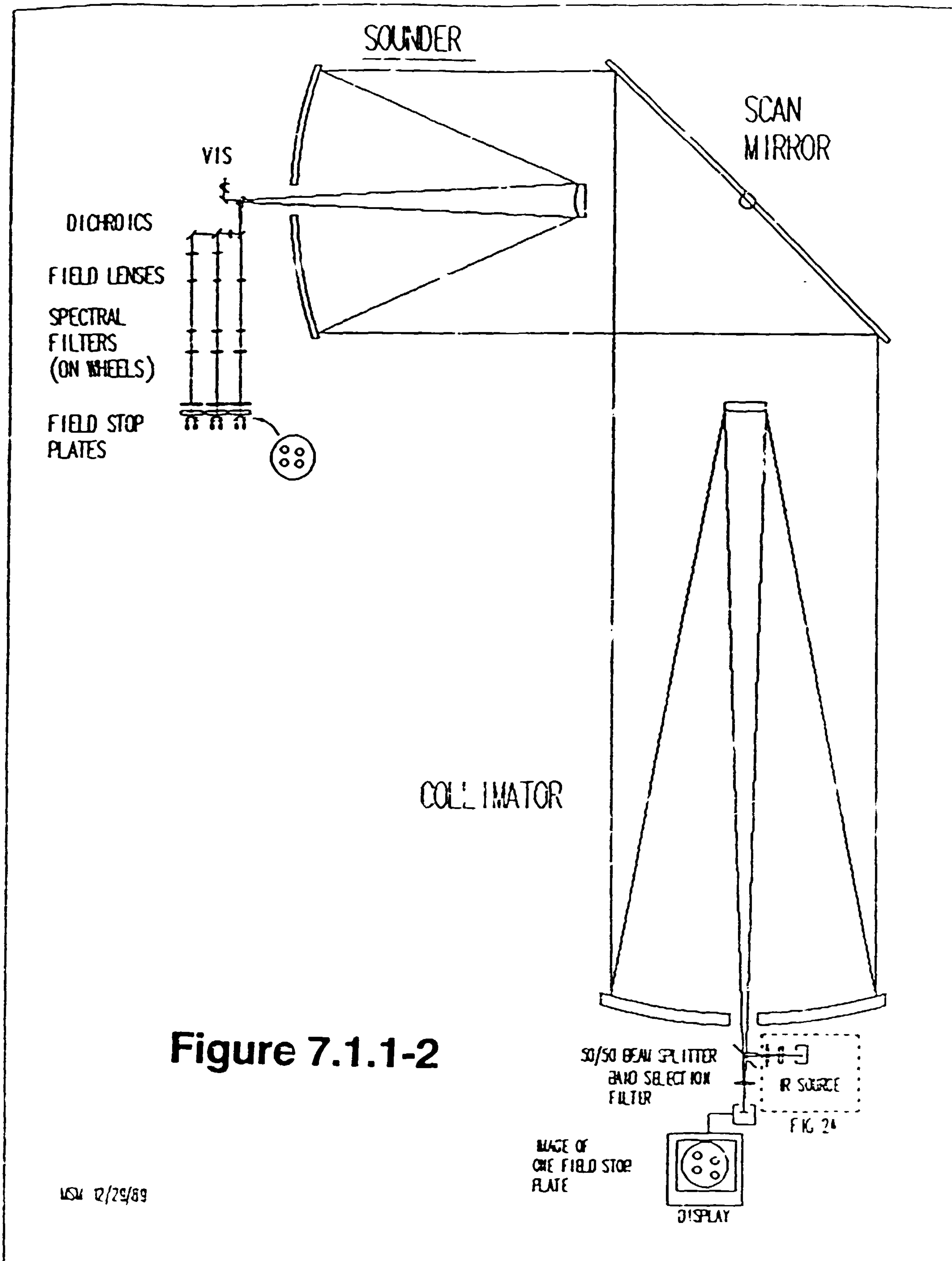

SOUNDER
SCAN MIRROR
VIS
DICHROICS
FIELD LENSES
SPECTRAL FILTERS (ON WHEELS)
FIELD STOP PLATES
COLLIMATOR
50/50 BEAM SPLITTER
BAND SELECTION FILTER
IR SOURCE
IMAGE OF ONE FIELD STOP PLATE
DISPLAY
12/29/89

Figure 7.1.1-2

sounder's pointing mirror using it's Image Motion Compensation (IMC) inputs. This alignment scheme will experience a large throughput loss because of the two way beam path; i.e., from the source through the optics to the aperture plate then back through the optics to the detector. This should not pose a problem since a high intensity source can easily be provided for this type of test.

A detailed optical analysis is required to establish the desired optical properties of the field stop plate for this operation and the effect of this change, if any, on the performance of the sounder. An analysis of the required source intensities and the sensitivity required in the IR imaging system to be located in the back of the collimator is needed to determine the time required to generate an image of the field stop plate, and thus the actual feasibility of this concept.

7.1.2 Remote Alignment Adjust Mechanisms (Options II and III)

Setting the alignment of the several focal planes of the GOES-I imager and sounder to the required co-registration accuracy has proven to be a difficult task, principally because the use of the bench cooler for the IR alignment produces stress on the vacuum housing which appears to cause significant displacement of the visible channels with respect to the IR, and even to some extent among the IR channels themselves. As of this writing, the final accuracy of the alignment procedures has still not been demonstrated. Final alignment at instrument thermal vacuum level is desirable so that, because the entire instrument is at vacuum, the minimum mechanical stress is applied to the vacuum housing. Remote adjustment mechanisms (and alignment detection) are required. Such mechanisms have been recommended for the advanced imager and high resolution sounder to provide in-flight adjustment capability to better meet the stringent co-registration requirements imposed on those instruments. The mechanisms and the need for in-flight adjustment are discussed in more detail in Section 9.5.2.

7.1.3 Flex Pivot for Imager East-West Scanner (Options II and III)

Of all moving mechanisms involved in the GOES-N instruments, the bearing assembly for the Imager east-west scanner has by far the most cumulative travel over the mission lifetime of five years. Because of the two axis scan implementation, this bearing assembly must endure approximately 2 x 10^3 times the total travel of the north-south bearing assembly on the GOES-7 VAS, and is still subject to the problems associated with small scan excursion, wherein the balls never completely turn over and the ball tracks do not overlap in the races. In view of the difficulties experienced with the Visible Infrared Spin Scan Radiometer VISSR/VAS instruments, qualification and life test of the GOES-I bearings have been of great concern throughout the instrument development cycle. Regrettably, mission suitability has not been demonstrated, even at this late date, and such demonstration is difficult in any case because of the necessity to properly account for flight loads on the bearings and to accurately accelerate the life test.

This type of small angle, extended life cycle motion has in the past been accomplished with great success by flex pivots, essentially small flat springs supporting the moving structure. For suitably small angle motion, these devices have essentially unlimited life. The pivots are sometimes excited near their natural frequency to induce harmonic motion, with amplitude and phase control of the motion, but also may be used as "bearings" in a position control servo loop similar to the

GOES scan mirror drive. We have found no prior application which required the accuracy and linearity with which the scan angle must be controlled and measured for GOES-N, though similar ultimate scan accuracy was achieved through ground resampling of the Thematic Mapper (TM) data. The flex pivot with motor encoder drive has been studied, and appears promising although further analysis and a proof-of-concept test model would be required to demonstrate compatibility with the very high accuracy shaft encoder needed. The study results are reported in further detail in Section 10.

7.1.4 Relocation of the East-West Shaft encoder (Option III)

Studies of the effects of relocation of the east-west shaft encoder and incorporation of a two point mirror mount were carried out with (surprisingly) negative results; i.e., the changes considered did not improve the pointing performance of the instrument scanner. The optical encoder trade study (10.4.2.2.1.2) produced more positive results, but based on significant non-recurring costs, this modification was deferred to the Option II instrument. The redesign of the structure using low temperature coefficient materials (10.4.1.3.1) offers significant improvements in pointing performance, but violates the guideline that the Option I instrument is to be essentially the same design concept as GOES-I. This modification is deferred to the Option III imager. The studies have identified the focal plane temperature as the principal driver of signal-to-noise performance.

7.1.5 Positive Temperature Control of the Aft Optics (Option I)

One modification which is recommended and not incorporated currently in the GOES I-M program is positive temperature control of the aft optics. This change could be incorporated with likely negligible impact to the spacecraft interface, and may ultimately be required to approach the specified performance requirements for channel-to-channel co-registration.

7.1.6 Imager I - Improvements (Option I)

Figure 9.1.1-1 shows the general instrument arrangement of and important spacecraft interface information for the Option I imager. Although the concept had been to maintain the spacecraft interface unchanged, the weight allocation allows modest growth over the GOES-I instrument to accommodate the changes recommended. The remainder of the information in Figure 9.1.1-1 reflects the status of the GOES-I imager.

7.1.7 Noise Equivalent Delta Temperature (NEΔT or NEDT) Improvements (Options I, II, and III)

Improvement of the NEΔT for the imager through lower focal plane temperature should be achievable in Option I by changing the surface finish of the Astromast boom to a specular, low emissivity reflector. The analysis by ITT and verified indenpendently for this study shows that this change alone results in an operating temperature advantage of nearly 10K to a control temperature of about 92K for either the imager or the sounder. Performance modeling for the imager in this report has been done only at the 85K control temperature we expect for Options II and III, but for the detector noise limited performance expected, the 92K control temperature would result in improved NEΔT at all wavelengths, potentially by a factor of three relative to GOES-I.

7.1.8 Optics and Focal Plane Arrays (Option I)

The optics and focal plane arrays for the Option I imager are identical to the GOES-I imager. Collected light is spectrally separated through dichroic beam splitters and individual filters to one visible and four IR focal planes, with detector arrays in each focal plane acting as field stops. All individual focal plane arrays are required to be co-registered in object space, placing stringent requirements on the stability of the complex aft optics. Figure 9.1.1-2 shows the required superposition of focal plane arrays in object space for the Option I imager. The redundant IR detectors are realized by utilizing linear detector arrays of four elements (two elements in the case of the 8km Instantaneous Field of View (IFOV) channel 3) and only utilizing half of them at any time. The eight visible channels, as in GOES-I, are not redundant in the Option I imager.

7.1.9 Other Considerations

Overall image quality and calibration accuracy can be improved by dc restoring on every available space look, rather than at two minute intervals as currently done on GOES-I. This will significantly reduce the effect of 1/f noise, and is recommended for the Option I imager. The Attitude and Orbit Control Electronics (AOCE) software must be modified to eliminate discontinuities in the IMC signal durin , scan turn-around. It is assumed that this modification will be incorporated at some point in the GOES I-M program. It is also assumed that at some point in the GOES I-M program a stable, full time Coherent Error Integrator will be developed. This may be necessary to achieve within frame registration requirements at end-of-life.

7.1.10 Sounder Improvements (Option I)

In keeping with the concept of the Option I spacecraft system as a minimal cost approach to GOES-N, changes to the spacecraft and instruments from the GOES-I configuration are limited to those for cost and/or efficiency improvements and those instrument modifications offering significant performance benefits without significant impact to spacecraft interfaces. The Option I sounder design concept is therefore identical to GOES-M. It is a filter wheel radiometer with eighteen infrared spectral channels arranged in three spectral bands on the filter wheel. Each spectral band has an array of four detector channels, each with a nominal 8.66km diameter IFOV, which receive radiation through common spectral filters sequenced in that particular band of the wheel. One visible spectral channel with four detector channels of 8.66km diameter IGFOV is provided on one separate uncooled focal plane, and eight 1km square IGFOV star sensor detector channels are provided on another.

The detectors FOV are scanned over the scene in object space by a two-axis gimballed mirror. In order to accomplish the required sounding rate for GOES-I, each sounding must be completed in 100 milliseconds. The scan drive related studies described in Section 9.1.1 which were carried out with negative results for the imager are equally applicable to the sounder, i.e. no "easy fixes" for the difficulties experienced with the GOES-I scanners have been found.

Significant improvement in the sounder to improve the Noise Equivalent Delta Radiance (NEΔN or NEDN) is limited by the focal plane temperature, which can be significantly lowered within the concept of a low cost, minimal impact system by changing the external finish of the Astromast solar sail boom as described in Sections 9.1.1 and 9.5.3.1. The same magnitude of performance gain as for the imager can be realized through this means, and a focal plane temperature of 92K should be realizable. Performance has been modeled only at the 85K temperature expected with Option II and the 65K expected with Option III.

Co-registration of the sounder channels to the stringent requirements of RO25 remains a major problem for GOES-N, as discussed in Section 9.4.1.3. It is recommended that improved means of alignment and co-registration of the sounder channels be developed for all spacecraft options, as discussed there. It is also recommended, as with the Option I imager, that the aft optics be temperature stabilized to avoid the possibility of diurnal drift between channel centroids in the various spectral bands.

Major instrument interface requirements for the Option I sounder are presented in Table 9.3.1-1. As in the imager, approximately 7kg of weight growth in the sounder sensor module relative to GOES I-M has been allocated to accommodate the thermal control and alignment modifications recommended. In all other cases, the specifications are taken from GOES I-M allocations current at the beginning of this study.

7.2 Options I, II, and III Summaries

Tables 6.5 and 7.2-1 summarize sensor complements, spacecraft candidates, and launch vehicle classes. Figure 7.2-1 provides some general conclusions with regard to Options I, II, and III that were derived from NOAA Tasks 2, 3A, and 3B

7.2.1 Option I (Tables 7.2-2 and 7.2-3)

7.2.1.1 Payload Concept Summary

The concept of the Option I spacecraft system is one of minimal cost and is based on the GOES I-M system. Changes to the spacecraft and instruments from the GOES I-M configuration are limited to those for cost and/or efficiency improvements and only those instrument modifications offering significant performance benefits without significant impact to existing spacecraft interfaces.

The payload content for Option I is depicted in the matrix of Table 6.5. It was configured nearly identical to the GOES I-M payload with relatively minor improvements and additions to represent the minimum risk/cost system considered in this study. Many of the improvements referred to in the Option I configuration include items that NOAA, the NASA GOES Project, and GOES I-M contractor personnel would include if they "had a chance to do GOES I-M over again". Some of the items considered may yet be incorporated into the GOES I-M program. Because this concept is minimally different from GOES I-M, the GOES I-M spacecraft was the only candidate considered for the Option I payload and therefore, must meet the weight, space, and power needs of the improved payload. This fact should be kept in mind because it is a major driver in the limited nature of improvements made to various GOES I-M hardware components in subsystems utilized for the Option I payload. The spacecraft and its minor modifications are addressed in Section 7.2.1.2.

Using the Option I column of Table 6.5 as a guide, the first payload item to be considered that is different from GOES I–M is the improved imager. For many reasons (discussed in Section 9.1.1) the only imager improvements recommended for this option are:

Launch Vehicle Performance

Launch Vehicle	Sponsor/ Contractor	Initial Launch Capability	Launch Costs	Fairing Diameter	Maximum Payload (Kgs) LEO (100nml) i=minimum	i=90	Synch Alt Transfer	Earth Escape (Parabolic)
United States:								
Thor (w/upper stage)	USAF/McDonnell Douglas	9 in storage	• •	1.65m	•	286	•	•
Delta II (7920)	McDonnell Douglas	1990	$51-71M	2.90m	5,039	3,819	1,270	•
Delta II (7925)	Mc Donnell Douglas	1990	$51-71M	2.90m	•	•	1,819	1,270
Atlas E	USAF/General Dynamics	(Thru 12/93)	$29-36M	2.13m	1,089	794	•	•
w/upper stage	USAF/General Dynamics	(Thru 12/93)	$34-46M	2.13m	•	1,724	454	295
Atlas I	General Dynamics	1989	$71-80M	3.30-4.19m	5,900	•	2,340	1,520
w/upper stage	General Dynamics	1989	$76-90M	3.30-4.19m	•	•	•	• •
Atlas II	General Dynamics	1991	$83-92M	3.30-4.19m	6,780	•	2,680	1,940
w/upper stage	General Dynamics	1991	$88-102M	3.30-4.19m	•	•	•	• •
Atlas IIA	General Dynamics	1992	$89-99M	3.30-4.19m	7,120	•	2,810	2,100
w/upper stage	General Dynamics	1992	$94-109M	3.30-4.19m	•	•	•	• •
Atlas IIAS	General Dynamics	1992/93	$108-121M	3.30-4.19m	8,610	•	3,490	2,670
w/upper stage	General Dynamics	1992/93	$113-131M	3.30-4.19m	•	•	•	• •
Titan II	USAF/Martin Marietta	1988	$42-78M	3.05m	2,200	1,905	• •	• •
w/upper stage	USAF/Martin Marietta	1988	$47-88M	3.05m	3,350	2,850	• •	• •
Titan II (min refurb)	USAF/Martin Marietta	1990	$19-28.5M	2.44-3.05m	2,200	1,905	• •	• •
Titan II/MSX	USAF/Martin Marietta	1992	$39M+	3.05m	• •	3,400	• •	• •
Titan III	Martin Marietta	1989	$165-185M	3.05-3.65m	14,742	12,519	•	•
w/OIS (III-T)	Martin Marietta	1990	• •	3.05-3.65m	•	•	4,990	3,630
Titan III (SRMU)	Martin Marietta	1991	$165-185M	3.05-3.65m	17,237	• •	• •	• •
Titan IV	USAF/Martin Marietta	1989	$230-276M	5.08m	17,690	14,515	• •	• •
w/Centaur	USAF/Martin Marietta	1990	$280-326M	5.08m	• •	• •	• •	4,627
Titan IV (SRMU)	USAF/Martin Marietta	1991	$230-276M	5.08m	21,319	17,509	• •	• •
w/Centaur	USAF/Martin Marietta	1991	$280-326M	5.08m	• •	• •	• •	6,124
Shuttle	NASA/Rockwell Int'l	1988	$300-345M	4.57m	24,721	•	• •	• •
Shuttle C	NASA/Rockwell Int'l	Under Study	• •	4.57-7.62m	45K-77K	•	• •	• •

• • Data Not Currently Available

Table 7.2-1

FIGURE 7.2.1

GENERAL CONCLUSIONS

- **OVERALL PROGRAM COSTS**
  - LOWER IF R&D PRECEDES PHASE-C/D
  - HIGHER IF R&D INCORPORATED IN PHASE-C/D
- **USING OPTION I* FOR GOES-N ALLOWS TIME FOR ORDERLY R&D FOR NEXT GENERATION**

* IMPROVED GOES I-M DESIGN

FIGURE 7.2.1 (continued)

SPACECRAFT OPTION I

(ESSEN ıLLY SUPPORTS CORE REQUIREMENTS)

SPACECRAFT

MODIFIED GOES I-M BUS: IMPROVED CONTROL SYSTEM/EARTH SENSOR

PAYLOADS

IMAGER:	IMPROVED NAV. & REG., SERVO, OPTICAL ENCODER
SOUNDER:	IMPROVED CO-REGISTRATION
WEFAX:	LIKE GOES I-M
DCS:	LIKE GOES I-M
S&R:	LIKE GOES I-M
SEM:	
EPS:	IMPROVED
MAGNETOMETER:	LIKE GOES I-M
XRS:	LIKE GOES I-M
SXI:	PROPOSED FOR GOES M
LOW ENERGY PLASMA:	NEW

1. Incorporate positive temperature control of the aft optics to improve channel–to–channel registration
2. DC–restore on every available space look to improve calibration accuracy
3. Lower the focal plane temperature to improve NEΔT by reducing the emissivity of the Astromast boom

The general suggestions previously discussed in Section 7.1.3 are also to be considered for the Option I improved imager as appropriate. Details of the Option I imager are contained in Section 9.1.1.

Three minor improvements are suggested for the Option I sounder, two of which are the same as suggested for the imager. The improvements recommended (addressed in Section 9.3.1) are:

1. Lower the focal plane temperature to improve the NEΔN by changing the external finish of the Astromast solar sail boom
2. Control the temperature of the aft optics to minimize diurnal drift between channel centroids in the various spectral bands
3. Develop and implement an improved means of alignment and co–registration of the sounder channels

This last recommendation (discussed in Section 9.4.1.3.1) involves slowing down the filter wheel speed and increasing settling time between scan mirror steps. Again, as for the Option I imager, the general suggestions offered in Section 7.3.1 are also to be considered for the Option I sounder as appropriate. Details of the Option I sounder are contained in Section 9.3.1.

The final payload items that are different from GOES I–M on the Table 7.2.1 list are in the SEM configuration. Option I has an EPS which is improved over the GOES I–M version and carries a local plasma sensor which is not presently part of the GOES I–M contingent of payload instruments. The baseline GOES I–M EPS is modified for Option I by the addition of new data channels to extend the range of measurements of protons, alphas and electrons, into lower energy regions and to add the capability to measure heavy ions fluence. These measurements were identified by NOAA as core requirements for GOES–N. The local plasma sensor, a new instrument to the GOES system, can measure electrons and protons in much lower energy regions than the EPS (i.e., 10eV to 30KeV). Two alternative designs are available for this instrument. One concept would utilize the NOAA K, L, M satellite series Total Electron Detector (TED) with appropriate modifications to provide adequate look angles. The other concept utilizes a LPS of the type flown by Southwest Research Institute and others on several missions. Information about the improved EPS and local plasma sensor are found in Section 11.6.3 which references appendices containing greater detail.

7.2.1.2 Option I - Spacecraft Configuration and Heritage

The spacecraft design considered for Option I is basically the same as the current GOES I–M which is shown in Figure 7.2.2. Lengthy discussions with LAS, the designers and manufacturers of the GOES I–M spacecraft, resulted in identification of relatively minor mechanical modifications that can be made to the basic GOES I–M structure that would allow an increase in payload and additional fuel potential of up to 64kg for the Option I improvements. The modifications consist, basically, of adding extra skin thickness or stiffeners, to the central thrust tube and instrument mounting areas and beefing up many of the truss joints. It was not considered necessary to build an entirely new structure. The risk to the basic structure design of incorporating these modifications is considered minimal.

The only other Option I change in spacecraft hardware over the GOES I-M design is in the controls area. The proposed changes are minimal. They consist of increasing performance of the earth sensor, making minor improvements to the imager servo and tightening the momentum wheel tachometer noise specification. These changes are expected to result in improved pointing and Image Navigation and Registration (INR) performance. The expected performance improvements due to these modifications are discussed in detail in Section 10.3.

The resulting Option I spacecraft is 3-axis stabilized, with a design life of 5 years, and which is externally identical to the LAS GOES I-M system shown in Figure 7.2.2. The basic configuration is a rectangular box with approximate dimensions of 1.9 x 1.9 x 2.3m. A single wing solar array, which rotates through 360 degree every 24 hours, located on the south side of the spacecraft, has its solar pressure force balanced by a solar sail on a 16m boom located on the north side. An adjustable trim tab on the outer end of the solar array wing is used to fine tune the solar pressure torque against daily varying sun declination effects. The major earth viewing instruments, the imager and sounder, are designed to fit in a corner of the spacecraft such that their optical axes look earthward while their passive radiation coolers look northward, toward the solar sail. Antennas and other earth viewing instruments occupy additional space on the earth viewing panel. SEM instruments required to monitor the sun are attached to a tilt mechanism mounted on the yoke that attaches the rotating solar panel to the spacecraft body. Internal to the spacecraft is a central thrust tube which houses fuel tanks and serves as the basic structure for a truss network that supports instrument mounts and outside panels. On one end of the thrust tube is the apogee motor mount and the connect/separate mechanism for attaching the spacecraft to the launch vehicle.

The Option I spacecraft draws almost all of its heritage from the yet unproven LAS GOES-I. If GOES-I proves to be a well performing, reliable spacecraft after a reasonable time in orbit, then the Option I GOES-N spacecraft will be well-founded.

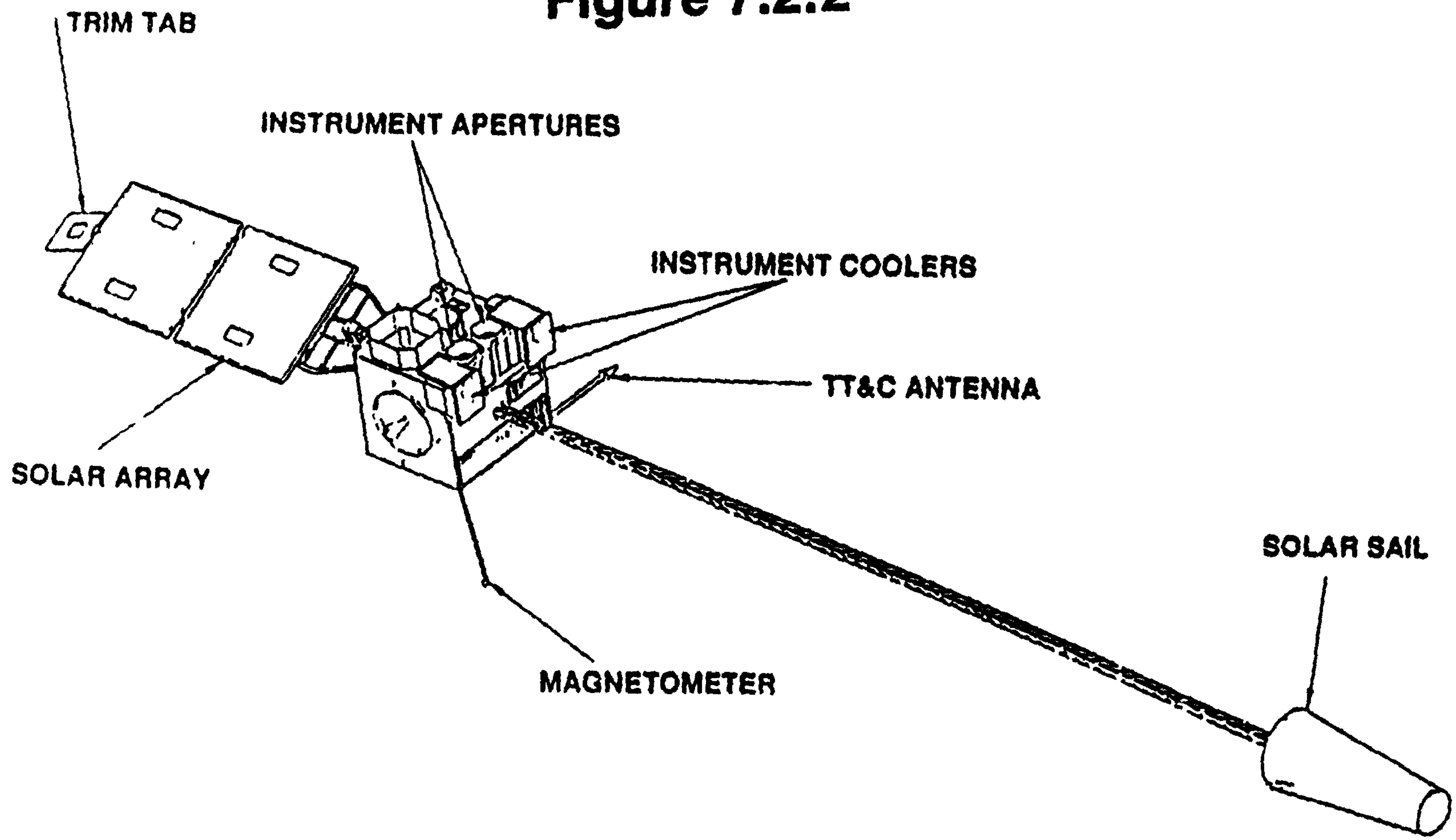
The foregoing brief description of the Option I spacecraft was intended to assist in identifying the major differences and/or similarities between Option I and the Options II and III spacecraft that are described in Section 7.2.2. and 7.2.3.

7.2.1.3 Option I - Ground System and Spacecraft Communications

Option I includes only one new instrument, the LPS. The data produced by this instrument would be transmitted to earth via the Multiuse Data Link (MDL). Since the MDL uses Quadraphase Shift Key (QPSK) modulation, the SXI data could be transmitted via the I channel and the LPS via the Q channel. No changes would be required on the spacecraft. The only changes required to the ground system would be at Environmental Research Laboratory (ERL) for handling the new instrument data.

GOES–N OPTION I
(ORBIT CONFIGURATION)

Figure 7.2.2



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There are a number of potential improvements to the GOES I-M communication system that should be considered. These improvements apply to the Option I spacecraft and ground system as well. Briefly, they are:

1. Eliminate the MDL and CDA on-orbit telemetry transmitters, multiplexing the data with the sounder data on the Q channel of the Sounder Data Link (SDL).

2. Eliminate the DCP Response (DCPR) transmitters and combine the DCPR band with the WEFAX signal, reducing intermodulation products in the vicinity of the DCPR band, which would reduce WEFAX signal Effective Isotropic Radiated Power (EIRP) by less than 0.5dB.

An additional third change that should be considered is elimination of the processed data relay (PDR or GVAR) link. This may be feasible if GVAR users can use remapped products distributed via the AWIPS. The other possibility is to have the AWIPS contractor distribute GVAR data.

Implementation of the first change would require an on-board multiplexer for the SDL, associated demultiplexers at the CDA, the SOCC, and ERL, and replacement of the MDL demodulators with SDL demodulators. The second change would require no ground system changes. The third change would be more radical in that the GVAR processing would be done at the World Weather Building Data Utilization Station (DUS) instead of at the CDA. In addition, a new ranging technique would be needed to replace the ranging signal imbedded in the GVAR signal.

7.2.1.4 Option I - Risk Identification

There are two major areas where risk is associated: performance and reliability. Performance risk weights the design adequacy of the instruments, spacecraft, communications, and the ground systems (including redundant units) to produce data that satisfy stated requirements. These risks can be offset by payload design improvements (i.e., include more or different sensors, channels/bands), addition of complementary/supplementary payload instruments and/or spacecraft design improvements (e.g., stiffer momentum bias systems, thermal insensitivity). Reliability risk encompasses productability, operating performance, and longevity of space hardware. This risk can be offset, primarily, by the use of flight proven designs, by the addition of redundant units and data paths, and the use of high reliability and radiation hardened parts. Life testing is also helpful to improve confidence levels. However, reliability of this type must be built in, not "tested" in.

The risk associated with improvements recommended for the Option I configuration are, by design, minimal, assuming GOES I-M is a successful program. With the exception of the LPS, all Option I payload instruments are GOES I-M instruments with relatively minor modifications/improvements. On the negative side of risk is the fact that the Option I configuration heritage is based almost entirely on a system that has no first generation flight history. On the positive side, however, there is some second generation heritage in the

GOES I-M system from the Indian Satellite (INSAT) spacecraft and instruments and Television Infrared Operational Satellite (TIROS) instruments. Items such as the basic GOES I-M structure concept, the Astromast solar sail, solar array design, fuel system design, and overall layout are heavily related to INSAT.

The imager and sounder designs are based on somewhat scaled versions of the INSAT imager and the TIROS Very High Resolution Radiometer (VHRR). The local plasma sensor, the only payload item without GOES I-M heritage, is considered low risk because both of the two designs proposed have previous heritage. The EPS is a modified GOES I-M design which also has heritage from previous GOES designs.

While it is difficult to quantify risk because of the fact that the GOES I-M heritage is not yet flight proven, it can be surmised that the modifications/improvements to GOES I-M proposed for Option I will not significantly change the risk level.

7.2.1.5 Option I - Launch Vehicle

Even though GOES I-M is planned to be launched on the Atlas I launch vehicle built by General Dynamics, the GOES-N Option I concept would utilize the Atlas II launch vehicle. This change is not due to the need for increased lift capability, but because General Dynamics has stated that the Atlas I launch vehicle will no longer be in production in the GOES-N time-frame (1999-2000) except for special orders at premium prices. By 1999, the Atlas II is expected to have a considerable flight history and should, therefore, be of minimal risk to the GOES-N mission. The Atlas II does provide an additional 340kg of payload lift capability to geosynchronous altitude transfer orbit.

7.2.1.6 Option I - Summary

The basic premise underlying the spacecraft system concept for Option I is that of a minimal cost program based almost entirely on the GOES I-M heritage. Changes to the spacecraft and instruments for the GOES I-M configuration are generally limited to those involving cost and/or efficiency improvements and instrument modifications that offer performance improvements without significantly impacting the spacecraft interfaces. Even though there is not necessarily a one-to-one correlation between the Option I concept and the Task 2 study goals, the recommended Option I modifications include most of the feasible cost and/or efficiency improvements studied during Task 2.

The Option I recommended modifications to the GOES I-M imager and sounder have little or no effect on existing GOES I-M interfaces. Controlling temperature of the aft optics can be done internal to the instruments and their electronics boxes. Lowering the focal plane temperature requires a different finish on the Astromast solar sail boom; the boom is external to the instruments.

Changes to the spacecraft control system for improved INR performance are all internal to the earth sensor, imager servo, and tachometer. Changes to the spacecraft structure involve increasing the thickness of skins and plates and thickening truss joints.

The effect on risk of implementing all recommended modifications for Option I is considered negligible. The level of risk cannot be quantified, however, until GOES I-M is a flight proven system because the Option I concept derives essentially all of its heritage from GOES I-M.

7.2.2 Option II (Figure 7.2.3)

7.2.2.1 Payload Concept Summary

The Option II concept is progressively more improved, costly and complex than Option I but less so than Option III. The constraint of utilizing modified GOES I-M designs for the most part is abandoned, but a theme of evolutionary improvements is maintained. The resulting Option II concept incorporates a different spacecraft bus modeled after the Hughes 601, an existing and seasoned design. The principal system enhancements recommended are:

- Improved passive cooler operation
- Improved INR performance
- Increased sounding resolution
- Lightning mapping
- Additional reflectance imaging channels

The HS601 concept is shown in Figure 7.2.4.

Referring to the Option II column of Table 7.2.1, the payload items that are different from Option I are the imager, sounder, lightning mapper (LM), WEFAX, and DCS. Each of these items is addressed in turn.

Imager changes were limited to those that did not require the GOES I-M design concept to be changed. The addition of the two channels (0.86μm and 1.65μm) specifically requested by NOAA can be implemented without impact to the cooler design. Modifying the imager to improve mirror pointing performance will be accomplished by swapping inductosyn mirror drives with optical encoder drives and limiting the encoder size to fit in the inductosyn space. This is a very productive change because of the greater inherent accuracy of the optical encoders. Neither of these changes causes an increase in sensor dimensions, but the GOES I-M imager electronics were slightly enlarged to accommodate circuitry for the additional spectral channels. Performance improvements gained by operating at a lower focal plane temperature were accomplished for this concept by completely eliminating the solar sail and by doing a half-yearly 180 degree yaw maneuver to minimize solar incursions on the passive cooler. Further details on the Option II imager can be found in Section 9.1.2.

The Option II sounder is called the High Spectral Resolution Sounder (HSRS). Its design is not tied to or restrained by the GOES I-M sounder concept. It is a Michaelson interferometer which is based on the High-resolution Interferometer Sounder (HIS) development as proposed by the University of Wisconsin, ITT, and SBRC for retrofit into the GOES I-M program. This particular approach was chosen over others (e.g., Fabry-Perot) because it is better suited to meet requirements for contiguous spectral information over the entire spectrum. Optics size has been increased by 2 inches to 14 inches as contrasted to the GOES I-M sounder with 12 inch optics.

FIGURE 7.2.3

SPACECRAFT OPTION II

(ESSENTIALLY SUPPORTS OPTIONAL REQUIREMENTS)

SPACECRAFT (DIFFERENT BUS)

- IRU SYSTEM (STAR SENSOR/GYROS) - 10 μr
- REACTION WHEELS
- ADDITIONAL BATTERIES
- IMPROVED SOLAR ARRAY

PAYLOADS

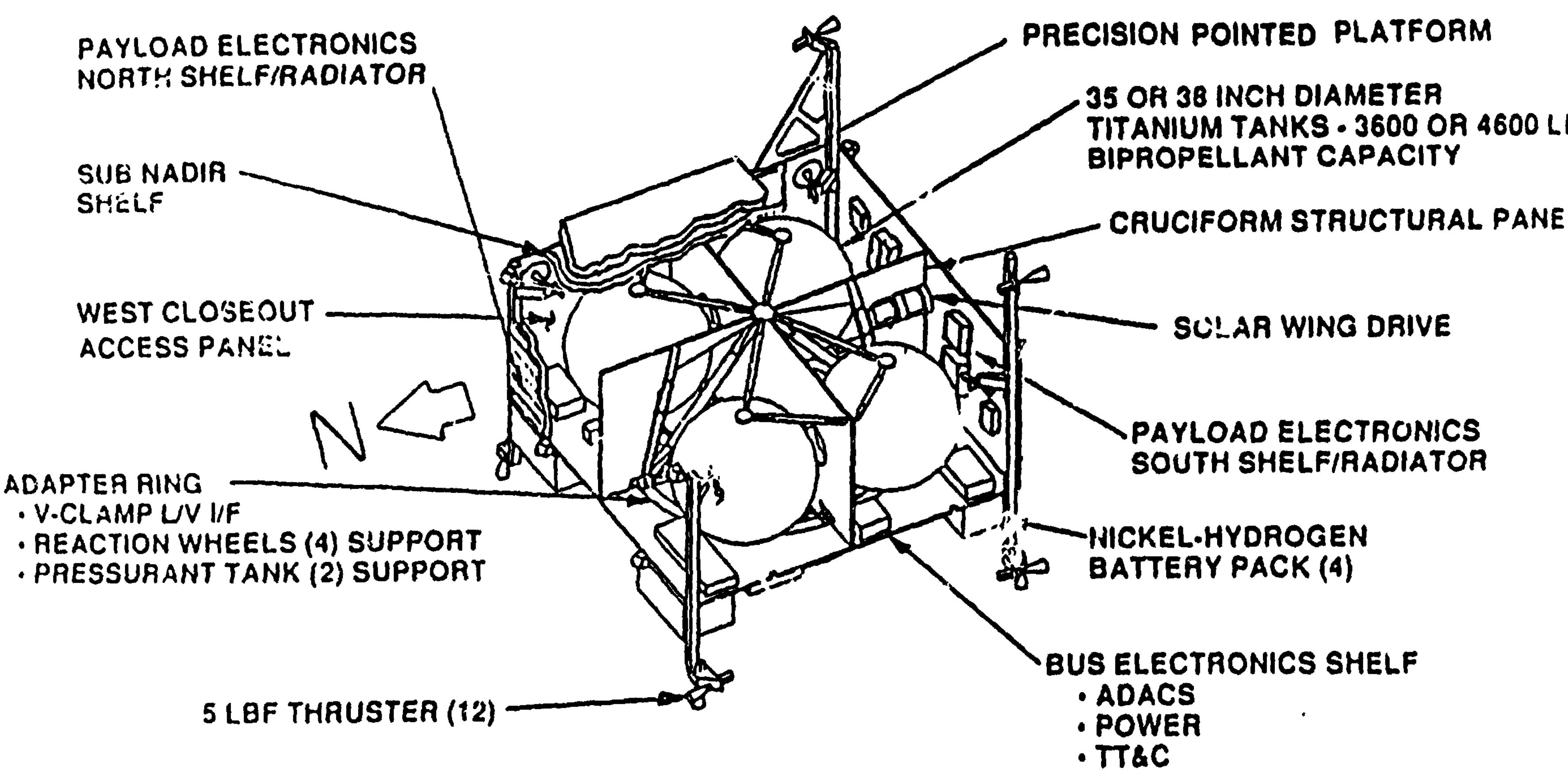
IMAGER*:	7 IR & 2 VIS. BANDS, IMPROVED SERVO., INCHWORM, MULTI FOCAL PLANE, CO-REGISTRATION MAY BE PROBLEM
ADV. SOUNDER:	HIGH SPECTRAL RESOLUTION
LIGHTNING MAPPER:	LIKE GOES M PROPOSAL
WEFAX:	ADDITIONAL CHANNELS
DCS:	INCREASED CAPACITY - NO LOCATION CAPABILITY
S&R:	LIKE GOES I-M - NO LOCATION CAPABILITY
SEM:	
EPS:	LIKE OPTION I
MAGNETOMETER:	LIKE GOES I-M
XRS:	LIKE GOES I-M
SXI:	LIKE OPTION I
LOW ENERGY PLASMA:	LIKE OPTION I

*REDESIGNED STRUCTURE MAY BE REQUIRED TO MINIMIZE DEFOCUSING EFFECTS

KEY FEATURES OF HS601 BUS

Modified For GOES-N

Figure 7.2.4



HUGHES

Because the Option II sounder is cooled passively, larger optics were needed to meet performance requirements. While considerably improved performance can be attained through the use of are refrigerator cooler, the Option II sounder was configured with the more conventional passive design because of its demonstrated long life. The higher risk refrigeration option was considered for the Option III sounder. As with the imager, the sounder performance is improved somewhat by the elimination of the solar sail and the semi-annual 180 degree yaw maneuver to keep the sun off the cooler. It should be noted that the baseline design approach for the Option II sounder is to send the digitized interferogram to the ground without in-orbit signal processing. Greater reliability is realized by ground processing, and the communication system can handle the required data rate without a significant downlink power increase. Greater detail on the Option II sounder is contained in Section 9.

The Lightning Mapper Sensor (LMS) proposed for Option II is essentially the same instrument that has been scheduled for flight on the GOES I-M series. MSFC is managing its development, supported by the development contractor, TRW. The procurement process is through Phase-B, but Phase-C/D is on hold pending final NASA/NOAA agreement on which GOES flight the instrument will fly. The LMS is the first sensor of its kind designed specifically to detect lightning from a geosynchronous satellite and locate it in terrestrial coordinates. Its FOV provides nearly full-disk earth coverage and it can output lightning data in real time. The LMS also has a commandable imaging mode which will be very useful for severe storm tracking. More information on the LMS is contained in Section 9.6.

WEFAX is another subsystem in the Option II column of Table 7.2.1 that is changed from GOES I-M and Option I. The present system consists of a single analog communication channel used to distribute low resolution data products to a number of user stations. The Option II (and Option III) configuration is changed to add three additional channels, for a total of four. The new channels are a second analog WEFAX channel, a digital WEFAX channel operating at 19.2kbps, and a 50kbps data channel referred to as the NOAA port. The stated purpose of the 50kbps channel is to broadcast DCS products from the CDA to DCS users and also to distribute some NOAA weather products. This channel will replace a leased Domestic Communications Satellite (DOMSAT) service, that will replace the dial-up service currently in use. An additional requirement is to have the WEFAX system operate during eclipse periods.

Two spacecraft communications system configurations to implement a full four channel WEFAX capability were considered. One consisted of separate transmitters for each channel and the other consisted of one transmitter for all four channels. Both configurations use a common S-Band uplink receiver. The four separate transmitter configuration was selected for Option II because the GOES-I WEFAX power amplifier design can be used directly for each of the channels, thus minimizing cost and risk. The most notable effects of this change over Option I system parameters are a 14kg increase in spacecraft weight and a 150W greater power consumption. Additional details on the Option II WEFAX system are contained in Section 11.3.

The final payload subsystem listed in the Option II column of Table 7.2.1 that is changed over the Option I configuration is the DCS. The present system consists of 200 1.5kHz data channels designed to operate at a data rate of 100bps. The Option II (also Option III) system is changed to accept 300bps and 1200bps DCP transmissions. The principal change from the Option I configuration is a 3dB increase in DCPR downlink EIRP, from 150 milliwatts to 300 milliwatts, to provide increased margin for the higher rate DCP channels. Two contiguous 1.5kHz channels would be needed for 1200bps users. This change should require very little modification to the existing GOES-I DCPR design. No changes to either the CDA or the DCP's are required for the Option II changes. Greater detail on the DCS is contained in Section 11.4.

7.2.2.2 Option II - Spacecraft Configuration and Heritage

The payload changes for Option II result in potential weight increases that could exceed the load carrying capability of both the baseline and modified versions of the GOES I-M spacecraft structure. For this and other reasons, a different spacecraft was selected. Some principal improvements desired for the Option II spacecraft are:

1) increased payload weight capability (i.e., structural strength, fuel capacity)
2) thermally and mechanically isolated sensor payload platform (an optical bench)
3) minimal solar pressure disturbances

A review of current aerospace industry spacecraft revealed that the existing Hughes HS601 spacecraft design incorporates many of the features desired with only relatively minor modifications needed to satisfy the GOES-N mission requirements. This design is used as the basis for the Option II (and Option III) spacecraft concept.

The most significant external modifications made to the existing HS601 communication satellite design to meet GOES requirements were to remove the nadir facing antenna mounting panel and replace it with an optical bench, and to go from a dual solar wing to a single wing solar array. The optical bench is a precision pointed platform on which all attitude sensors and the mission sensors are mounted in close proximity and alignment. The bench is "loosely coupled" to the spacecraft body with a three-point support, minimizing loading across the bench/bus interface. In the launch mode the optical bench faces upward in the launch vehicle shroud permitting the use of long non-deployable sun shades around the sensors' apertures. When the single wing array is deployed in space, its panels are close to the spacecraft body to minimize solar torques. This obviates the need for a solar sail which thermally loads the sensor IR coolers. With this design, there are no obscurations on the north (or cooler) side of the spacecraft.

Internally, the HS601 bus needs few modifications because it is already structurally able to carry the full-up Atlas IIAS capability-7500 pounds. Since it was designed to be a long life communications satellite (10 years), the propulsion tanks can carry fuel for 7 years capability even with the maximum GOES-N Option III payload. Sufficient battery power to allow full eclipse operation is easily provided in the existing design. Most of the internal modifications will consist of and be due to incorporating the Option II sensor electronics in place of the original payload of communication transponders and power supplies.

The philosophy used for the Option II (and Option III) control system was based on minimizing risk by using proven technology where possible. GOES I-M designs were not considered to be in the "proven" category because of their lack of flight experience and heritage from other proven designs. Therefore, a "clean slate" design approach was used for the Option II and III concepts.

The recommended control system is inertially referenced, using very stable gyros and star trackers to sense spacecraft roll, pitch, and yaw attitude. Pointing errors from all sources, including mirror motion, sensed by the star tracker/gyro system are processed by the attitude control electronics (ACE) to produce two sets of error signals for control of high and low frequency disturbances. The low frequency signals are used to control the speed and direction of a set of four reaction wheels, arranged in a tetrahedron, which are operated in a zero momentum bias mode to control basic spacecraft pointing. The reaction wheel momentum buildup is periodically unloaded by thruster firings. High frequency error signals are used to reposition the imager and sounder scan mirrors to compensate for the attitude errors that cannot be followed by the reaction wheel control subsystem. The operation of this "closed loop" control system results in smaller pointing errors than the open loop system used on GOES I-M and Option I. Other differences from GOES I-M and their contributions to better pointing from the Option II/III control system are:

1) having control system sensors (gyros and star trackers) mounted on the same optical bench as the mission sensors results in lower jitter error and thermal deformations to be corrected

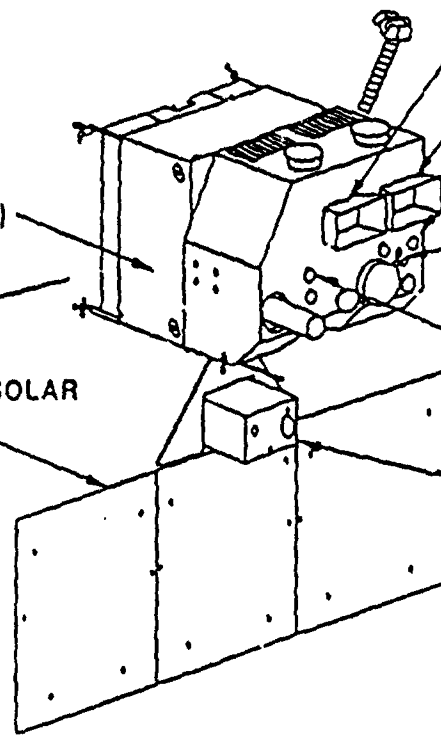
2) using star trackers instead of earth sensors for reference reduces errors (e.g., due to clouds)

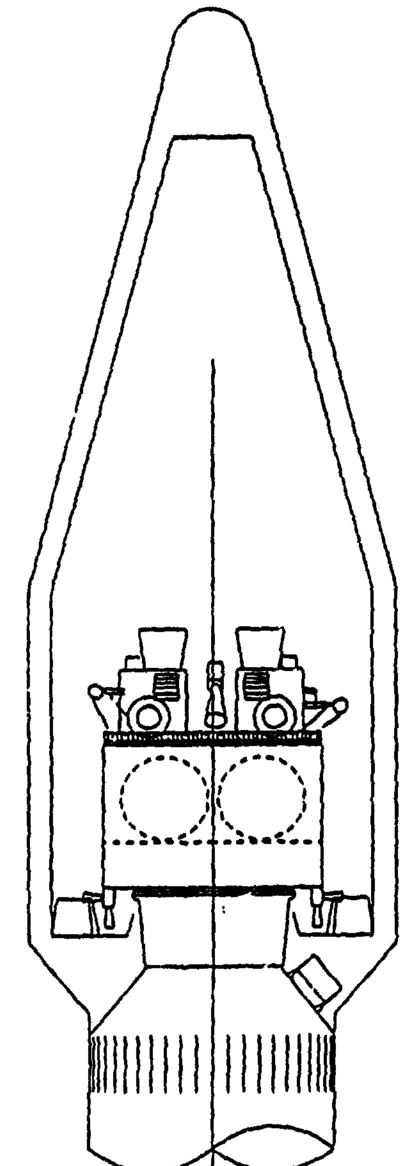
Whereas the current GOES I-M control system elements have never been used in applications requiring pointing performance as stringent as desired for GOES, the Option II/III elements are based on designs utilized for many of Goddard's high precision pointing spacecraft such as International Ultraviolet Explorer (IUE), Solar Maximum Mission (SMM) and Landsat. Implementation risk should therefore be lower with the recommended system. More details on the Option II control system are in Section 10.4.

The resulting Option II spacecraft is shown in Figure 7.2.5. It is 3-axis stabilized with a seven year design life and is a derivative of the Hughes HS601 series. The basic bus configuration is a cubic box with approximate dimensions of 2.4m per side. This bus is highly modularized to allow parallel processing and schedule flexibility when integrating various payload options. The central module is a truss and cruciform panel structure that supports four 35 to 38 inch diameter bipropellant fuel tanks, four reaction wheels, two pressurant tanks, thrusters and an adapter ring with launch vehicle attach clamps. It is sandwiched between an electronic shelf on the underside which holds batteries, other power electronics, communications electronics and control system electronics and, on the top, by the precision pointed payload platform (optical bench). All attitude and mission sensors are mounted in close proximity on the optical bench which attaches to the bus at three points with a combination of hard and flexible (kinematic) mounts. The attachment scheme "loosely couples" the optical bench to the bus such that mechanical and thermal loads are not directly transferred from the bus to the bench. The bench is constructed of sandwiched multi layer graphite panels resulting in very low thermal expansions. These measures minimize relative motion among payload and attitude sensors to greatly enhance spacecraft pointing knowledge and increase image navigation and registration accuracy over the Option I configuration. Because the optical bench is mounted such that the nadir face is looking up to the top of the shroud in the launch mode, it is possible to put sizable sunshields on many of the sensors to further improve their performance when the angle between the sensor optical axis and the sun is small.

OPTION II SPACECRAFT

Figure 7.2.5





OPTION II
Atlas IIA Launch Vehicle

The SEM instruments are mounted to a tilt mechanism on the solar array yoke much the same as in Option I. The solar array is mounted on the south side of the spacecraft. Unlike the Option I design in which the solar array panels are all deployed to the south, the Option II solar panels deploy in an east and west direction, thus minimizing solar pressure torques. Because the resultant solar pressure torque is manageable, the solar sail is eliminated, allowing the mission sensor coolers an unobstructed view of space.

Although the Option II spacecraft draws most its heritage from the Hughes HS601 spacecraft which, like Option I, is yet unproven in space. Twenty one HS601, have been ordered to date by various customers and nineteen are in various stages of construction. The fu t is scheduled for launch this year (1991).

This brief description of the Option II/III spacecraft is intended to show the major differences and/or similarities between the various candidate Option I, II and III spacecraft. Greater details about the candidate or several other spacecraft proposed by LAS, General Electric (GE), and TRW are beyond the scope of this study but can be developed during Phase-B. The HS601 was chosen as the preferred candidate for this study because it required fewer modifications for compatibility with the GOES-N mission and because the unique optical bench design offered the most flexibility for accommodating various payload options and configurations.

7.2.2.3 Option II - Ground System and Spacecraft Communications

Option II includes the LM, the additional three WEFAX channels (a second analog channel, a 19.2kbps digital WEFAX channel, and a 50kbps data channel), an improved imager, a high-spectral resolution sounder, a slightly higher EIRP DCP report channel, and the GOES-I S&R subsystem. In addition, a two-station ranging capability is needed to meet control system orbit determination accuracy requirements. This latter requirement was not identified until near the end of the study and will need to be addressed in future studies.

The total data rate of the Option II instruments, exclusive of processed (GVAR) data relay is about 12Mbps, compared to under 3Mbps for Option I. The majority of this data rate increase is due to the sounder. Accommodation of this data rate within the 20MHz band allocated at S-Band requires the use of compression techniques for the imager and sounder data and balanced QPSK modulation. Thus, an on-board multiplexer is needed to combine imager and sounder data, and the instruments need the capability to compress data and code forward-error-correction the data. The LM and ACS data could be downlinked directly to the SOCC and DUS via the MDL, along with telemetry data and the other SEM instrument data, avoiding the need to relay the LM and control system data via the GVAR link. An on-board multiplexer would also be required for this link to combine the various data streams. Associated demultiplexers would be required at the receiving ground stations.

Because of the increased imager and sounder data rates, the center frequency of the SDL will have to be changed from the frequency used for GOES-I. In turn, the center frequencies of the MDL and GVAR links will also need to be changed. The MDL and SDL demodulators will need to be modified or redesigned to handle the increased data rates. The GVAR link would require a change from Binary Phase Shift Key (BPSK) to unbalanced asynchronous QPSK (UAQPSK) modulation, with the processed imager data on one channel and processed sounder data on the quadrature channel. Likewise, demodulators at the SOCC and all direct GVAR receive stations would have to be replaced with UAQPSK demodulators.

In addition to the above changes to the spacecraft and ground station equipment, the following communication system improvements, some of which were recommended for Option I, should be considered:

1. Eliminating the MDL and CDA on-orbit telemetry transmitters by multiplexing these data streams with the imager and sounder data on the SDL. These changes would require an increased number of multiplexer/demultiplexer ports. The MDL demodulators would also have to be replaced with SDL demodulators.

2. Combining the DCP report band with one of the WEFAX channels to reduce intermodulation products within the DCP report band, thus improving performance and eliminating DCP report transmitters. The effect on the WEFAX signal EIRP would be a reduction of less than 0.5dB and would require no changes to the ground system. This recommendation applies whether single or separate transmitters are used for WEFAX.

3. Eliminating the processed data relay (GVAR) link. This may be feasible if GVAR users can use remapped products distributed via the AWIPS. The other possibility is to have the AWIPS contractor distribute GVAR data. This change would require that GVAR processing be done at the SOCC or DUS instead of at the CDA.

7.2.2.4 Option II - Risk Identification

With the exception of the new instruments, the risk associated with the configuration recommended for Option II is not significantly different from the Option I configuration. The spacecraft structure, thermal, power, and propulsion subsystem designs, like Option I, are based on a system that does not yet have flight experience. However, the Hughes HS601 series development is somewhat more mature than the LAS GOES-I, because the first one is scheduled for launch about a year earlier than GOES-I and because four to six times as many Hughes units are already in various stages of construction and test. On the balance, however, is the fact that LAS already has three-axis stabilization experience with INSAT, albeit to less stringent pointing requirements, while the HS601 will be a first experience for Hughes.

The increase in risk associated with imager improvements is small because those modifications do not require a change in the GOES I-M design concept nor a change in cooler design. Performance risk, on the other hand, should decrease with the incorporation of the more accurate optical encoder mirror drive. This type of drive was used on all of the preceding GOES series and has proven to be very reliable.

In contrast to the imager, the Michelson sounder is a new development for this application. While some experience has been gained with this design approach from instruments built by Bomem of Canada and operated on aircraft flights, it is insufficient to predict the characteristics of the Option II configuration in the GOES operational environment. Careful engineering and management decisions are needed to fully understand the areas of risk associated with selecting this new technology for an operational system. To help ease reliability risk, a passive rather than active cooler is proposed for the Option II sounder. This type of cooler cannot lower the focal plane temperature to the level required to approach the GOES-N sounding requirements, so the optics aperture size was increased by two inches to compensate. The larger optics adds some increased risk because of the greater difficulty required to maintain optical quality and scan efficiency. Overall, this approach is still judged to be less risky than smaller optics and the unknowns of a mechanical refrigerator system. Elimination of the solar sail and the addition of semi-yearly 180 degree yaw maneuvers will enhance the effect of the cooler and lessen performance risk somewhat.

The LM sensor is another new development for operation in geosynchronous orbit. A development program managed by MSFC has been on-going for some time to provide a prototype instrument for flight on GOES I-M. This program has only gone through the procurement cycle to Phase-B, and actual prototype hardware has not yet been built. Because the lightning mapper is a fairly simple instrument, being a staring sensor with no mechanical motion during its normal modes of operations, and because it has been analyzed through the Phase-B level, the risk of developing a successful prototype is probably not great. The mission risk is minimal since the lightning mapper is not a primary sensor critical to mission success.

Changes to the WEFAX and DCS involve adding channels to existing designs. The methods proposed for implementing the additional capability in the Option II configuration require minimal changes to the existing hardware designs and very little impact to ground systems. For these, and other reasons, the performance and reliability risks associated with meeting Option II requirements are small.

With the exception of the high spectral resolution sounder, the Option II risk can be quantified to be nearly the same as Option I and GOES I-M. However, the risk of a completely successful development of the interferometer sounder for geosynchronous operational use is high, in both performance and reliability.

7.2.2.5 Option II - Launch Vehicle

The Atlas IIA was selected for launch of the Option II concept. Improvements in the DCS, control system, a new sounder, and an additional sensor-the LM, have caused the weight and power requirements to increase over Option I. These increased needs require additional stationkeeping fuel and solar array and battery capacity. When all improvements and supporting capacities are accounted for, the Option II configuration weight estimate is 2602kg, 440kg greater than Option I but still within the lift capability of Atlas II, which is 2680kg. However, a 78kg margin is grossly inadequate at the offset of a program, especially when the program requires the development of two new instruments such as the sounder and LM; ergo, the selection of Atlas IIA. With the Atlas IIA for launch, the margin is estimated to be 208kg.

7.2.2.6 Option II - Summary

The basic premise underlying the system concept for Option II is to meet NOAA core requirements. The concept was not based on the GOES I-M system; the idea of evolutionary changes from the Option I configuration was the guideline in defining Option II. Choosing the Atlas class launch vehicle as a constraint limited most study activity to the evolutionary arena. The evolutionary concept drove selection of the spacecraft and payload designs to systems that are already in use or that are in advanced stages of development. The spacecraft, for instance was chosen because of the maturity of its design, its capability for larger payloads, and how well it can accommodate and support an optical bench. The optical bench concept provides not only greater image registration accuracy, it also provides a large measure of flexibility for varying payload configurations and greatly simplifies the integration and test process.

Payload items selected for Option II are generally based on modified or upgraded GOES I-M designs. The sounder and lightning mapper are exceptions, of course, but even they are based on well proven concepts that are in advanced stages of development. The resulting increased data rates will require that an on-board multiplexer be added to the spacecraft communication system and that some in-band frequency changes be made. These will require corresponding changes to the existing ground system (i.e., a new demultiplexer and new or modified demodulator). Most elements of the existing ground system can be used as is, which again testifies to the evolutionary nature of the Option II concept.

Exclusive of the new instruments, the effect on risk of implementing the recommended modifications for Option II is considered to be roughly the same as Option I and GOES I-M. The new sounder and lightning mapper have yet to be completely developed for a geosynchronous environment and, therefore, significantly increase the risk of the Option II mission. Sufficient weight and power margins have been planned for this concept to offset the risk of potential excess growth of these instruments during their development process. As with the Option I concept, the level of risk for Option II cannot be quantified until GOES I-M is flight proven, the HS601 is flight proven, and the new instruments have completed their development.

7.2.3 Option III (Figures 7.2.6)

7.2.3.1 Option III - Payload Concept Summary

The Option III concept continues the theme of evolutionary improvement over Option II by incorporating essentially the same spacecraft, control system, sounder, WEFAX, DCS, S&R and SEM instruments. While the improvements and additions increase implementation risks and costs, they also significantly increase performance capability. The matrix of Figure 7.2.1 will serve as a guide for discussion of the Option III improvements.

The first item that is basically different from its Option II payload counterpart is the advanced imager. It is a totally new design that incorporates all the additional spectral bands requested by NOAA and meets, in most cases, the desired spatial resolution for each band. This modest increase in capability contrasts to the significant changes in design over Options I and II which were made to improve pointing, registration, and thermal performance.

Perhaps the most significant change is the use of very low temperature coefficient materials (such as Graphite Fiber Reinforced Plastic (GFRP)) in the construction of the imager combined with more efficient structural geometry to lessen the pointing errors caused by diurnal thermal distortion. Not only will the use of GFRP minimize thermal deformation and/or thermal snapping, it also helps to raise the lowest fundamental structure frequency mode out of the instrument mirror servo controller bandwidth, thus enabling the design of a more stable controller.

Another significant change is the use of spatial separation for IR spectral channels in a common extended focal plane rather than spectral separation by beam splitters as implemented on GOES-I. This method greatly enhances the chances of maintaining fundamental co-registration accuracy during the fabrication process and in the operational thermal environment. It does, however, aggravate the problems of image rotation.

Image rotation is inherent in a two-axis single mirror scanner such as that used on GOES-I. It is a serious error source requiring correction in navigation and within-frame registration performance in the GOES-I concept, even with the smaller focal planes used there. Another significant change to the advanced Option III imager, therefore, is to eliminate image rotation by incorporating separate scan mirrors for the east-west and north-south axes. Along with this dual mirror scanner, operation in orbit at very small inclinations (0.05 degree or less) and resampling of the image data in ground processing would likely result in minimizing channel-to-channel misregistration. References to diagrams of the Option III advanced imager and greater detail on its configuration and expected performance can be found in Section 9.1.3.

The next major difference in the Option III payload is the addition of another imager, referred to as the "auxiliary" imager. The purpose of the additional imager is to provide continuous full-disk images in the event the advanced imager was being used in a limited areal coverage mode to observe a significant localized mesoscale event. This instrument would also provide a redundant imaging capability in the event of a primary imager failure. Several suggestions have been made for the source of the auxiliary imager including an INSAT, GOES-I, or an Applications Technology Satellite (ATS-6) Geosynchronous Very High Resolution Radiometer (GVHRR) type imager.

An alternate approach to the auxiliary imager is to double the number of visible channels in the primary imager so that it can cover the full-disk earth in half the time, thus freeing the remaining time for partial disk imaging. This alternate approach as well as the additional imager approach are described in greater detail in Section 9.1.4.

The focal planes of the Option III imagers are passively cooled. The sounder has also undergone a significant change from Option II. The optical aperture has been reduced back to GOES I-M size and a mechanical cooler system is used in place of the passive cooler to improve the radiometric performance beyond Option II. The focal plane is cooled by a Stirling cycle cooling system modeled after the units planned for the Atmospheric Infrared Sounder (AIRS) instrument on EOS. The Option III instrument weights approximately the same as the Option II unit because the smaller optics weight is nearly offset by the mechanical cooling system. However, increased power requirements and control electronics for the refrigerator do significantly increase the Option III sounder system weight. Cooling would be provided by a pair (two compressors) of refrigerators. A second pair is required for redundancy. The use of any mechanical refrigerators in long-life space applications is in a developmental stage. No flight proven hardware exists presently, but NASA is making a major investment in this technology for several instruments on the EOS program. Hopefully, when GOES-N needs mechanical refrigerators, they will have been fully developed and flight proven. Section 9.3.4 contains greater detail on the configuration and performance possibilities of the Option III sounder.

The final major payload difference from the Option II configuration is in the SEM area. Option III has an additional two instruments in the SEM package, a combination SVM/HαI and a radio beacon for measuring TEC.

The magnetograph is a technically challenging instrument for GOES because of its size and weight. To sense the magnetic fields at the photosphere of the sun, even with state-of-the-art detectors, requires co-registering multiple images to better than the pixel size of 1 arcsec over at least a 5 minute period for the needed sensitivity. This will require very sophisticated optics along with very precise platform servo control. Added to these already tough requirements is the necessity to do narrow band sensing measurements in multiple spectral bands if the Hα requirements are to be realized in the same instrument. Section 11.1.3.2.5 contains more detailed information on the combination SVM/HαI.

A Very High Frequency/Ultra High Frequency (VHF/UHF) radio beacon will be used to monitor total electron content along the line of sight between the spacecraft and a ground station. The technique will be to measure the differential group delay of a code sequence transmitted at two frequencies in the VHF/UHF radio bands. This technique is very simple to implement on the Option III bus. It is questionable, however, whether this capability is needed on GOES since the USAF has already implemented a similar capability on the widely distributed multiple spacecraft of the GPS. Further discussion of this system is contained in Section 11.1.3.2.6.

7.2.3.2 Option III - Spacecraft Configuration and Heritage

The Option III spacecraft is identical to the Option II spacecraft (modeled after the Hughes HS601) with a few exceptions. Internally, the only differences are in the size of the fuel tanks (38 inch versus 35 inch), data processing equipment to handle the combination SVM/HαI instrument, three radiometers instead of two, increased power handling and storage, and more communications equipment. Externally, the solar array is larger and the optical bench is configured differently to accommodate the three radiometers. The basic structure of the Option III spacecraft is not changed over Option II nor are the elements of the control system. The description of the spacecraft and its heritage, contained in Section 7.2.2.2, applies equally for Option III. Figures 7.2.7 show the resulting Option III spacecraft. The basic bus configuration shown in Figure 7.2.4 is common to both Options II and III.

FIGURE 7.2.6

SPACECRAFT OPTION III
(ESSENTIALLY SUPPORTS ENHANCED REQUIREMENTS)

SPACECRAFT (DIFFERENT BUS)

IRU SYSTEM (STAR SENSOR/GYROS) - 10μr (SAME AS OPTION II)
IMPROVED INR COMPARED TO OPTION II - NEW INSTRUMENTS (THERMAL/STRUCTURAL)

PAYLOADS

NEW IMAGER:	ADDRESSES ENHANCED REQUIREMENTS (1.0KM VIS, 4.0KM @10.7μm)
AUX. SOUNDER:	OR EQUIVALENT CAPABILITY
LIGHTNING MAPPER:	LIKE GOES-M PROPOSAL, MODIFY FOR LOW LIGHT IMAGING OPERATIONS, WITH 10KM IFOV
ADV. SOUNDER:	HIGH SPECTRAL RESOLUTION (WITH MECHANICAL REFRIGERATOR)
WEFAX:	ADDITIONAL CHANNELS (SAME AS OPTION II)
DCS:	(SAME AS OPTION II)
S&R:	GOES I-M - NO LOCATION CAPABILITY
SEM:	
EPS:	OPTION I IMPROVEMENT
MAGNETOMETER:	GOES I-M
XRS:	GOES I-M
SXI:	OPTION I (AS PROPOSED FOR GOES-M)
LOW ENERGY PLASMA:	OPTION I (NEW)
SOLAR MAGNETOGRAPH:	NEW (INCLUDES H-ALPHA IMAGER)
TOTAL ELECTRON COUNT:	NEW

7.2.3.3 Option III - Ground System and Spacecraft Communications

Option III includes an auxiliary imager, the combination SVM/HaI, four WEFAX channels, the Option II imager, a high-resolution sounder, a slightly higher EIRP, and the GOES-I S&R subsystem. As in Option II, a two-station ranging capability is needed to meet control system orbit determination accuracy requirements. This ranging requirement will need to be addressed in a future study effort.

The total data rate of the Option III instruments, exclusive of processed (GVAR) data relay, is about 14Mbps. Accommodation of this data rate within the 20MHz S-band allocation requires compression of the imager, auxiliary imager, and sounder data. The use of a bandwidth efficient modulation scheme for the SDL, such as 8-PSK (Phase Shift Key), is needed to reduce the channel bandwidth required. An on-board multiplexer is also needed to combine the imager, auxiliary imager, and sounder data into one data stream for input to the SDL modulator. Data from the remaining instruments would be transmitted via the MDL, as in Option II.

Because of the added instruments and higher instrument data rates, new center frequencies are needed for the SDL, MDL, and GVAR links. On-board multiplexers are needed for the SDL and MDL. For the ground stations, an 8-PSK demodulator is needed at the CDA to demodulate the SDL signal. A new QPSK modulator plus multiplexer is required at the CDA to transmit GVAR data. New QPSK demodulators and demultiplexers are required at all stations receiving the GVAR signal.

In addition to the above changes to the spacecraft and ground station equipment, the following communication system improvements (which were also recommended in essence for Option II) should be considered:

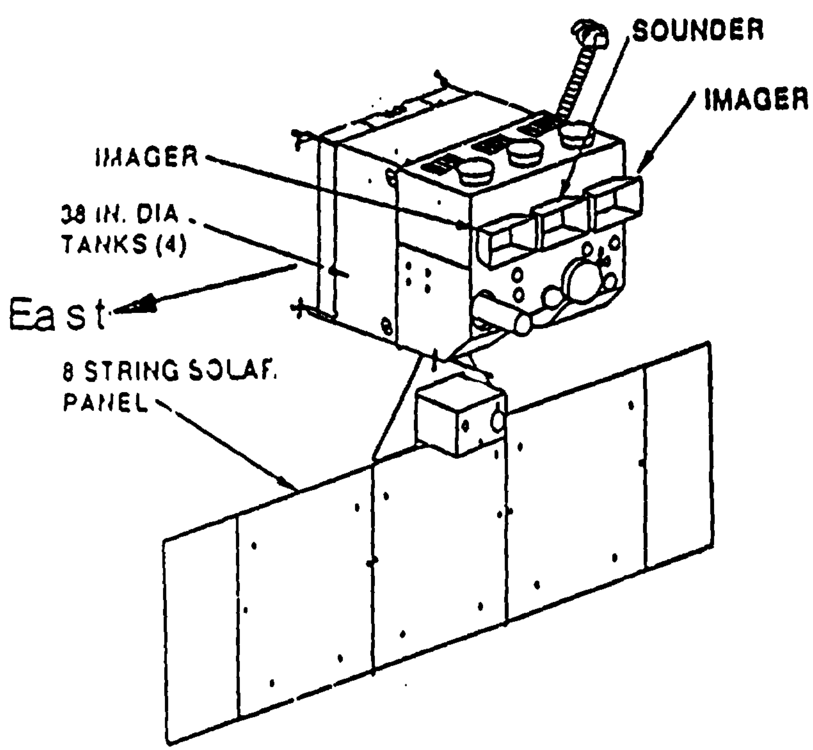
1. Eliminating the CDA on-orbit telemetry transmitter and adding the telemetry data to the MDL.

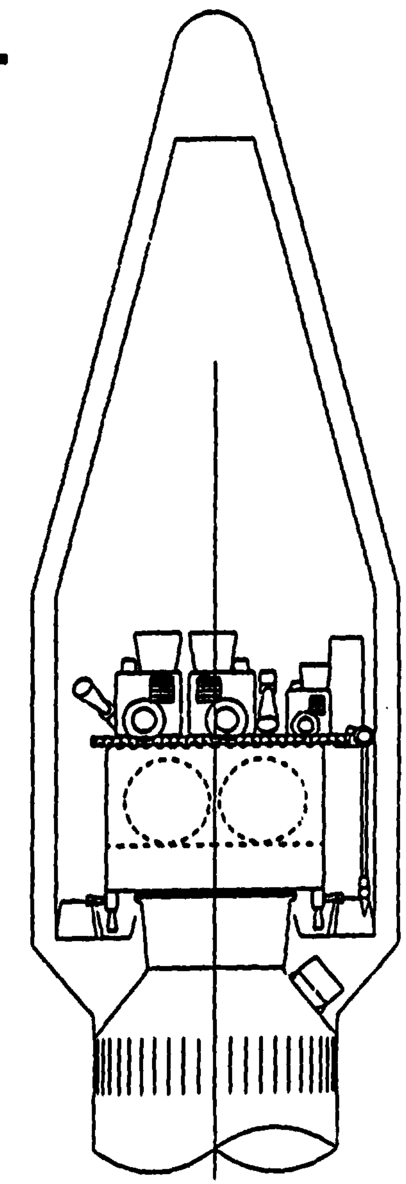
2. Eliminating the DCP Report transmitters and combining the DCPR band with the WEFAX signal, reducing intermodulation products in the vicinity of the DCPR band. This would reduce WEFAX signal EIRP by less than 0.5dB but would require no changes to the ground system.

3. Elimination of the GVAR link. This may be feasible if GVAR users can use remapped products distributed via the AWIPS. Alternatively, the AWIPS contractor could distribute the GVAR data. This change would mean that GVAR processing would have to be done at the SOCC, requiring greater EIRP on the SDL.

OPTION III SPACECRAFT

Figure 7.2. 7





OPTION III
Atlas IIAS Launch Vehicle

7.2.3.4 Option III - Risk Identification

The risk of successfully developing, implementing, and operating the proposed Option III configuration is significantly greater than either of the two previous options. Development risk is up primarily because of the new imager design, the new sounder mechanical cooler design, and the new SVM/HαI design. Implementation risk is higher because of the addition of a second imager and the SVM/HαI. Operational risk increases because of the complex dynamic interactions between the spacecraft and the various additional moving masses, such as the dual mirrors in the imager, the auxiliary imager mirror, the sounder mirror, the sounder mechanical refrigerators, and the additional SVM/HαI weight on the moving solar panel yoke. All these interactions will have to be controlled to very small system angular error values as will the orbit inclination. The net result of these increased risks shows up in a longer schedule and a higher cost for the Option III program. The benefits of potentially improved performance and the benefits of meeting more requirements, however, tend to offset some of the risk. Considering the new imager, some of the risks of a new design are offset by incorporation of proven concepts. For instance, utilizing two mirrors doubles the number of rotating masses over the single mirror with a dual axis used in GOES-I, but the single axis per mirror concept has been well proven on all previous GOES spacecraft. Using GFRP, with its hygroscopic tendencies, for most of the imager structure is a new concept that may be challenging to implement, but the offsetting potential performance gains can be enormous in the areas of thermal deformation and structural frequency response. Spatially separating the IR spectral channels in a common extended focal plane and eliminating numerous beam splitters eases the usual internal alignment problems and greatly enhances the chances of maintaining fundamental co-registration accuracy during the operational thermal environment.

The risk inherent in the sounder is as described in Section 7.2.2.4 with the additional risk of mechanical cooler implementation. The unknowns here are basic refrigerator reliability and lifetime and the effect of mechanical vibrations on INR errors. Another unknown is the difficulty of connecting two cooling systems (of two refrigerators each), one operating at a time, to the focal plane ensuring adequate heat transfer paths. Possibly, by the time GOES-N would need refrigerators, the concept will have been space proven by the EOS program. Offsetting the refrigerator risks are the potential for greatly enhanced sounding performance through lower focal plane temperatures and smaller, more accurate, optics.

The risk of building a SVM/HαI capability, both housed in a package of reasonable size and weight, is quite large. The multiple image co-registration accuracy required combined with the larger weight carried on the solar pointing platform, increase concerns that dynamic interactions with the spacecraft control system may adversely affect INR system errors. It is strongly recommended that a full study be conducted on this instrument before serious consideration is given to its inclusion into the spacecraft system. Without the results of such a study, it is doubtful that any validity can be given to a system pointing error budget that includes the combination SVM/HαI instrument. All these risks, however, can be offset by not including this instrument in the payload complement if the study results are not favorable, inasmuch as it was proposed to answer the needs of an adjunct NOAA requirement.

In summary, the developmental, implementational, and operational risks for Option III are greater, by far, than either Option I or II. The potential performance gains, however, are also far greater.

7.2.3.5 Option III – Launch Vehicle

The top of the line Atlas IIAS is required for launch of the Option III configuration. This is primarily due to the additional payload weights of the new imager, the sounder mechanical refrigeration system, and the combination SVM/HαI. To support this heavier payload, larger fuel tanks and solar arrays are also required. The total Option III weight is estimated to be 2974kg, which is 372kg heavier than Option II and 812kg heavier than Option I. The Atlas IIAS has a launch to Geosynchronous Transfer Orbit (GTO) payload capacity of 3490kg, resulting in a very adequate "start of program" margin of 516kg.

7.2.3.6 Option III – Summary

The underlying premise for the Option III system is to meet NOAA core requirements and as many optional and enhanced requirements as feasible within the constraint of making only evolutionary changes from existing system designs. Adhering to the evolutionary theme, the largest size of the same launch vehicle line was used as was the same spacecraft recommended for Option II, the Hughes HS601 with its optical bench concept. As seen in Figure 7.2.3, the only visible changes from the Option II spacecraft are a larger solar array and a modified optical bench to hold three instead of two earth observing instruments. Internal to the spacecraft, the major, yet evolutionary, changes are larger fuel tanks, larger batteries for eclipse operation, and more electronics for increased power and data handling. The control system remains essentially the same as in Option II.

With the exception of the primary imager, all the payload items of Option II are included in the payload of Option III. Also included in the Option III payload are the additional or auxiliary imager (which could be an Option I or Option II imager) and the combination SVM/HαI. The Option III sounder retains the same general concept and configuration as the Option II instrument except it has slightly smaller diameter optics (easier to build) and a mechanical cooling system (harder to incorporate) in lieu of a passive cooler. By far, the most important change over Option II is in the primary imager concept. The Option III imager, while a new concept and not flight proven, was chosen not only to improve performance, but to be easier to build, align, and maintain alignment in the space environment. For these and other reasons, the new imager concept can also be considered an evolutionary improvement. As in the case of Option II, modifications will have to be made to the spacecraft communications system to handle the increased data rates. This will require corresponding changes to the ground system, which will be very modest.

The effect on risk of implementing the Option III concept will be higher than the previous concepts. The new imager, sounder with refrigerator cooling, lightning mapper, and combination SVM/HαI are not developed for a geosynchronous environment and, therefore, significantly increase mission risk. Perhaps the largest contributor to risk is the unknown effect on controls and INR performance of the dynamic interactions among the mechanical refrigerators, multiple moving mirrors, and solar pointing platform mechanisms. In any event, if the Option III concept is properly researched, developed, scheduled and funded, it should result in significant performance gains over the present systems.

7.2.4 Feasibility, Risk, and Schedule Summary for Options I, II, and III

Table 7.2.2 provides a summary of feasibility, risk, schedule, cost, and performance assessments for:

- A replicate of GOES I-M in the GOES-N time frame
- Option I
- Option II (with and without prior R&D)
- Option III (with and without prior R&D)
- A replicate of GOES-7. (NOTE: The GOES-7 Replication study is contained in a separate report.)

7.2.5 Options vs Schedules

Figure 7.2.8 shows a proposed schedule of activities related to Phase-B, it includes:

- NOAA option selection (hybrid; I, II, or III; or Atlas)
- Focused Phase-A studies
- NASA Phase-B support during transfer
- NASA Phase-B procurement
- NASA Phase-B

Figure 7.2.9 shows an overall schedule to launch of GOES-N which includes time provisions for many of the issues under consideration;

- Engineering models of instruments
- Engineering models of spacecraft subsystems
- Protoflights (instruments and spacecraft subsystems)
- Phases-A and B for select instruments

Figure 7.2.10 is a preliminary schedule for the simpler Option I configuration which is an extension of the GOES I-M configuration with improvements based on current I-M status and state-of-the-art technology.

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TABLE 7.2.2

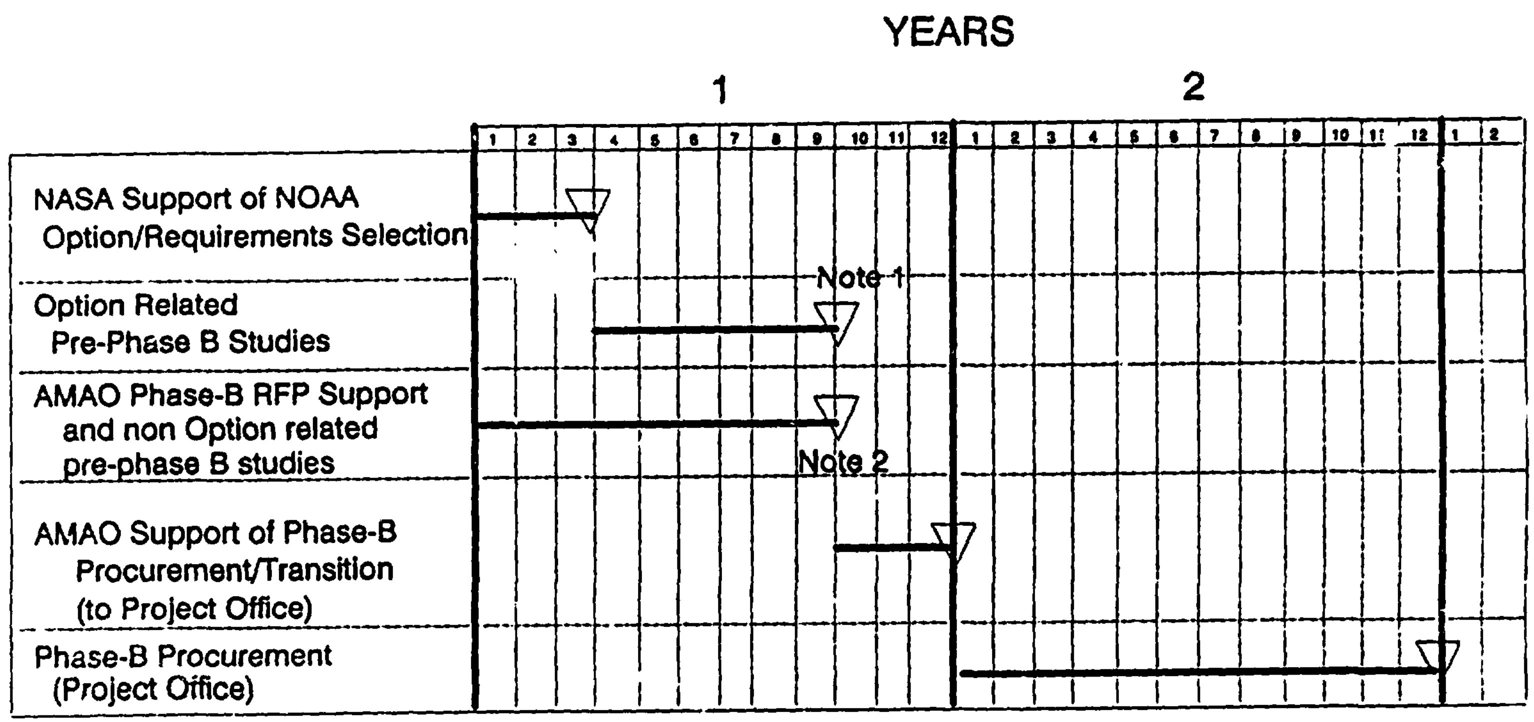
FEASIBILITY, RISK, SCHEDULE MATRIX

	FEASIBILITY	RISK	SCHEDULE	COST[1]	PERFORMANCE
REPLICATE GOES I-M	FEASIBLE, OPERATIONAL NO R&D	SAME AS GOES-M	SAME AS GOES-M	SAME AS GOES-M	GOES-M
OPTION I (EVOLUTIONARY)	FEASIBLE OPERATIONAL NO R&D	SLIGHTLY LESS THAN GOES-M	SAME AS GOES-M	SMALL INCREASE OVER REPLICATION	SLIGHTLY BETTER THAN GOES-M, MORE RELIABLE
OPTION II PRIOR R&D	UNKNOWN R&D OUTCOME FOR DEVELOPMENTAL INSTRUMENTS (e.g.,SOUNDER)	TOO RISKY FOR OPERATIONAL MISSION NEEDS PROTOFLIGHT OF INSTRUMENTS	SCHEDULE: 96 MONTHS TO LAUNCH		MORE CORE AND OPTIONAL NOAA REQUIREMENTS MET
OPTION II[2] NO PRIOR R&D	INCLUDE R&D PHASES-B & C/D, UNKNOWN OUTCOME	MORE RISK THEN OPTION II ABOVE	138 MOS. TO LAUNCH 48 MOS. PROTO C/D 42 MOS. ENGR. C/D 30 MOS. PROC. 18 MOS. PHASE-A/B	HIGHER COST	
OPTION III PRIOR R&D OPTION III[2] NO R&D	SAME AS OPTION II ABOVE BUT HIGHER COST, AND GREATER PERFORMANCE POTENTIAL			HIGHER COST	MORE OPTIONAL AND ENHANCED NOAA REQUIREMENTS MET
REPLICATE GOES-7	FEASIBLE	GOOD: SAME AS GOES-7 AND/OR GMS	60 MONTHS TO LAUNCH 42 MOS. PHASE-C/D 18 MOS. PROC.	MINIMUM NON-RECURRING	MAINTAIN CURRENT SERVICES WITH LESS PERFORMANCE THAN GOES I-M

[1] RAO COST INFORMATION PRESENTED SEPARATELY IS VOLUME 3
[2] OPTION II & III ARE NOT RECOMMENDED WITHOUT PRIOR R&D

AMAO PHASE B RELATED ACTIVITIES SCHEDULE

Figure 7.2. 8

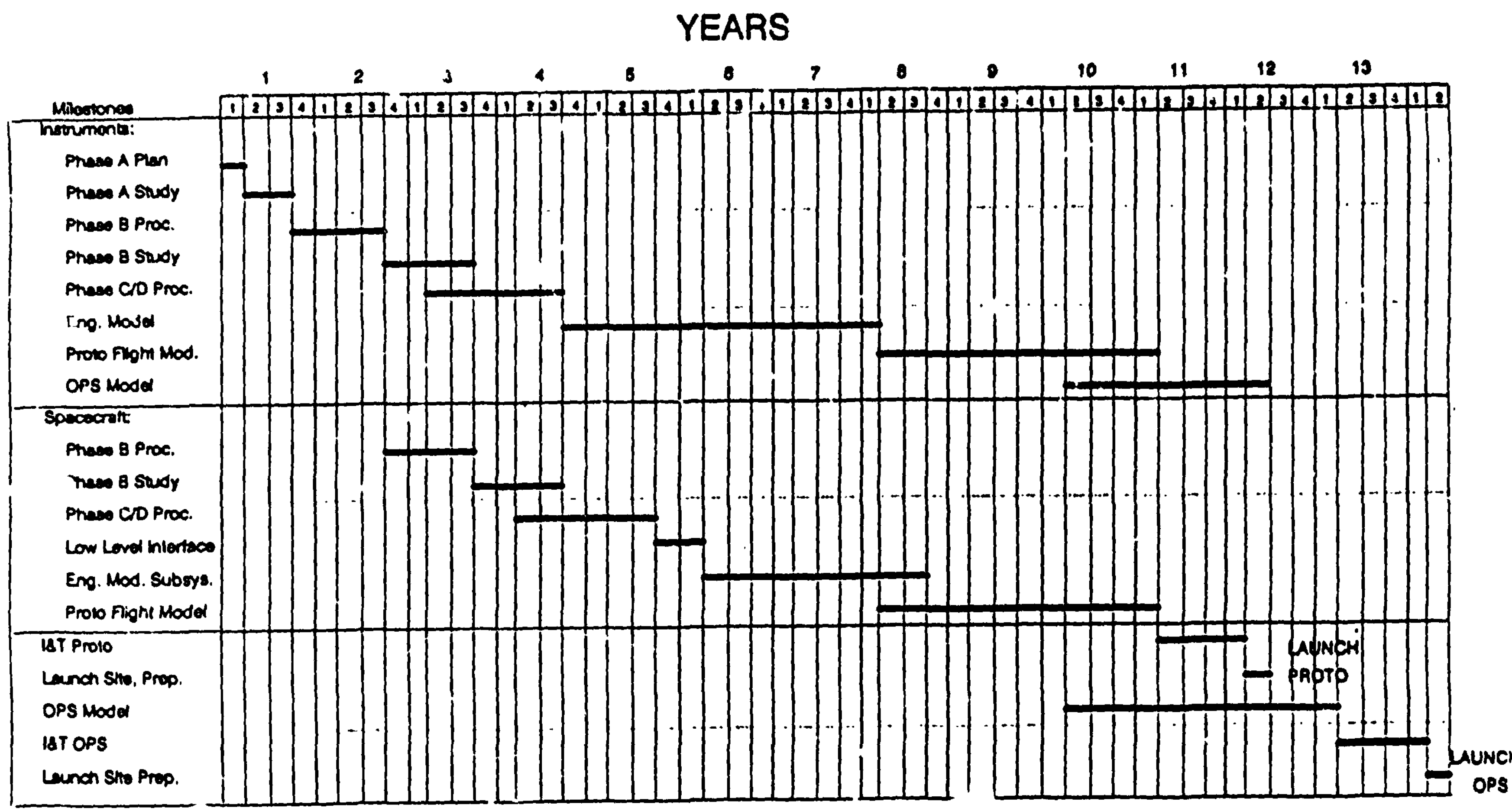


Notes:

1. Output includes ICD (instr. spec., S/C subsystem definitions), instrument selections (e.g. sounder type), and down-select criteria
2. RFP complete

pbshd

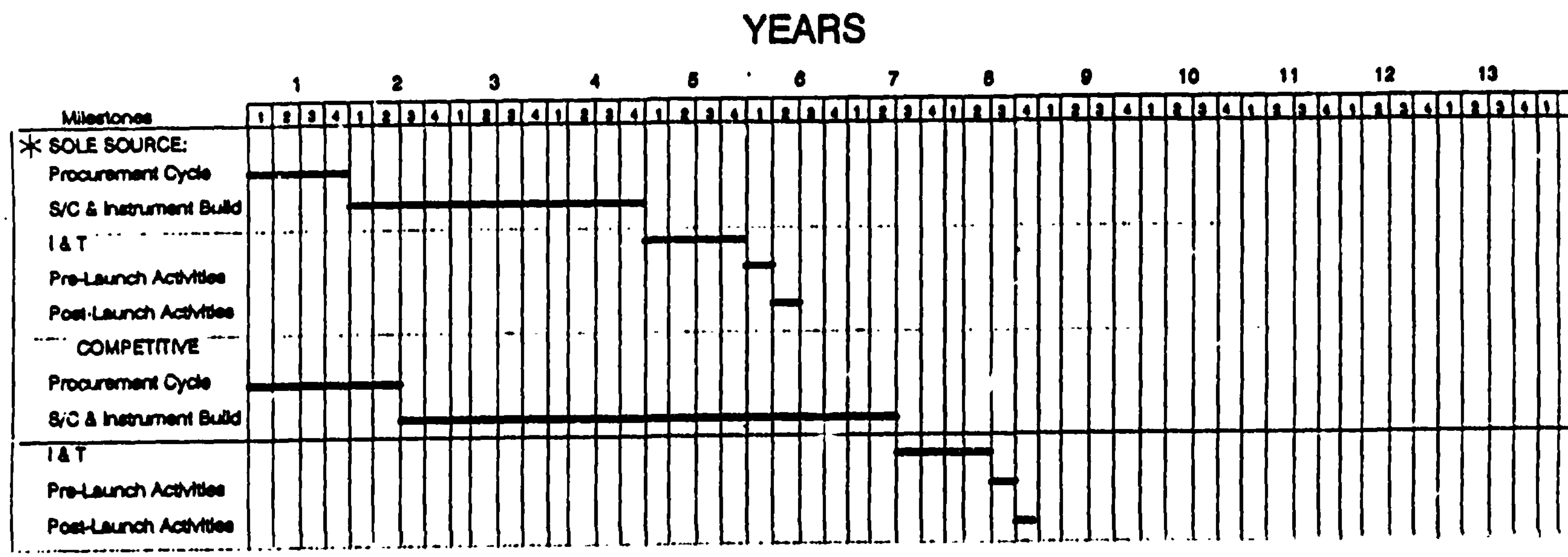
Figure 7.2.9
OPTIONS II OR III DEVELOPMENT



magn

Figure 7.2.10

OPTION I BUY



* How many could be bought non-competitively ?

magn2

7.3 "Unmet" Requirements

Subject to study constraints (Figure 7.3-1) and for a variety of other reasons, not all of the NOAA requirements could be met by the various Options (I, II, and III). Tables 7.3-1a and 7.3-1b contain assessments of the unmet requirements as a function of Options I, II, or III. Figures 7.3-2a through e present the reasons why the study team concluded that these requirements could not be met.

7.3.1 "Unmet" Image Navigation and Registration (INR) Requirements

The projected INR performances for the Option II and III systems are similar, with the system performance differences primarily due to improved thermal and structural performances brought about by a redesign of the imager and the use of a material with a low thermal coefficient of expansion (e.g., GFRP). The contributions from the individual error sources are all about the same magnitude. As a result, even if it were possible to provide a major improvement in one or two of the error sources, this would not result in an overall improvement that is anywhere near the 14μr desired performances. However, each error source has been reduced to the greatest extent possible by the selected system approach and design.

Future improvements will require an R&D effort to develop an integrated instrument and control system. An approach that has the potential to provide the desired performance is discussed in Section 10. This approach continually senses a ground based signal to determine the real time pointing error, which is then used to instantaneously correct the pointing. In effect this is an adaptation of the methodology used on current staring systems (e.g., Hubble Space Telescope (HST)) to an image scanning system to achieve the desired pointing performance.

The projected registration performances were obtained by extrapolating both the performance of current systems using star tracker/gyro control subsystems and the performance of a redesigned GOES-I instrument/servo. To account for unknown error sources and/or optimistic performance assumptions, a 50 percent margin was added to performance projections. These projections for the Within-Frame and Frame-Frame registrations are now recommended as the values to be used in subsequent GOES-N studies. However, as discussed in Section 10.1.1.2, future GOES-I flight experience could result in the need to reassess the current registration performances estimated herein.

The Core and Option/Enhanced INR requirements and expected performance are summarized in Table 7.3.-1a. As discussed in Section 10 and Appendix C, and shown in Table 7.3.-1a, the within-frame and frame-frame registrations cannot be achieved for the option or the enhanced requirements by any of the three options.

TABLE 7.3-1a

UNMET NOAA REQUIREMENTS VERSUS SPACECRAFT OPTIONS

GOES-I	SPACECRAFT OPTION I	SPACECRAFT OPTION II	SPACECRAFT OPTION III
	Essentially supports core requirements	Essentially supports optional requirements	Essentially supports enhanced requirements
		RO1: (1) Increased resolution unmet in 2 IR bands) (2) Add'l spectral bands: (low SNR in 13μm band)	Increased resolution unmet in 1 IR band. Diffraction limited to 4km in 10μm band. Low SNR in 13μm band
42μr, pixel-pixel (75)	RC3: 42μr, pixel-pixel (75)	RO3: 14μr, pixel-pixel (37)	(33)
28μr, chan-chan (60)	RC4: 14μr, chan-chan (50)	(40)	(30)
84μr, image-image (69)	RC5: 42μr, image-image (69)	RO5: 14μr, image-image (33)	(29)
Sensitivity performance (?)	RC7: sensitivity (? GOES-I)	RO7: sensitivity (? GOES-I)	Met in some channels
	RC8: cloud smear: new spec required	RC8: cloud smear: new spec required	RC8: cloud smear: new spec required
			RE13: cal. vis chan. (possibly)
			RE14: low light imager; modify lightning mapper; IFOV=10km
		RO18: 2km contemporaneous IR imaging	
		RO20: single pixel sounding	

Key: numbers are specified values or requirements; numbers in parentheses are expected performance

TABLE 7.3-1b
ASSESSMENT OF UNMET NOAA REQUIREMENTS VERSUS SPACECRAFT OPTIONS

GOES-I	SPACECRAFT OPTION I	SPACECRAFT OPTION II	SPACECRAFT OPTION III
	Essentially supports core requirements	Essentially supports optional requirements	Essentially supports enhanced requirements
			RE21: spatial resolution <=4km (diffraction limited)
Sounding rate: $(3000km)^2$ <40 minute. (39.3 minute.)		RO22: sounding rate: $(3000km)^2$ <=30 minute. (major problem: NEΔT)	(major problem: NEΔT)
	RC25: sounder: (1) match centroids to 2%/4.5μr (10μr) (2) half-power IGFOV <1%/2.2μr (20μr)	(10) (20)	(10) (20)
	RC31: (1) pitch angle distributions - protons & electrons above 30keV not provided. (2) alpha particle measurements not provided below 600MeV/N		
		RO33: solar EUV spectrometer not provided	
	RC35: S&R: no location	(no location)	(no location, under study)
	RC36: DCS: (1) additional channel (GOES-I) (2) no location	(no location)	(no location)
	RC37: WEFAX: (1) 4 channels (GOES-I) (2) no eclipse operations		

Key: numbers are specified values or requirements; numbers in parentheses are expected performance

FIGURE 7.3-1a

REASONS FOR UNMET NOAA REQUIREMENTS

TECHNICAL/STATE-OF-THE-ART

RC3/RO3: PIXEL-PIXEL REGISTRATION

- MECHANICAL INSTABILITIES AND NON-LINEARITIES

RC5/RO5: IMAGE-IMAGE REGISTRATION

- OVERALL LIMITATION FROM COMBINATION OF INSTRUMENT POINTING, SPACECRAFT CONTROL & THERMAL EFFECTS

RC25/RO25: MATCHING SOUNDER CENTROIDS & HALF POWER IGFOVS

- DIFFRACTION LIMITS DEGREE OF SIMILARITY OF SPATIAL WEIGHTING FUNCTION SHAPES
- FABRICATION & CALIBRATION TECHNIQUES LIMIT ACCURACY OF MATCHING CENTROIDS
- THERMAL & LIFETIME STABILITY OF BEAM SPLITTER OPTICS LIMITS STABILITY OF CO-REGISTRATION ACROSS 3 BANDS

FIGURE 7.3-1b

REASONS FOR UNMET NOAA REQUIREMENTS

IMPACTS TO SPACECRAFT JUDGED EXCESSIVE BECAUSE THEY VIOLATE EVOLUTIONARY CHARACTER OF STUDY

RO1: INCREASE RESOLUTION/ADD SPECTRAL BAND

- LARGER APERTURE TO MINIMIZE DIFFRACTION IN 10 μm BAND
- MUCH LARGER APERTURE TO MEET NEΔT IN 13 μm BAND

RC4: CHANNEL-CHANNEL REGISTRATION

- CALIBRATION/ALIGNMENT/FABRICATION LIMITATIONS
- THERMAL EFFECTS
- BEAM SPLITTER STABILITY
- INSTABILITIES ASSOCIATED WITH VIEWING CHANNELS AT DIFFERENT TIMES

RC7/RO7: SENSITIVITY (NEΔT)

- COLDER FOCAL PLANE REQUIRES MECHANICAL REFRIGERATION
- BETTER DETECTORS
- LARGER APERTURE

RC8: CLOUD SMEAR

- REWORD REQUIREMENT TO MAKE SPEC INDEPENDENT OF IFOV
- REQUIRES LARGER APERTURE FOR LONGWAVE CHANNELS

FIGURE 7.3-1c

REASONS FOR UNMET NOAA REQUIREMENTS

IMPACTS TO SPACECRAFT JUDGED EXCESSIVE BECAUSE THEY VIOLATE EVOLUTIONARY CHARACTER OF STUDY

RE13: VISIBLE CHANNEL CALIBRATION – POSSIBLE AT TIMES OF OPPORTUNITY

- VIEW SUN THROUGH ATTENUATOR
- USE MOON

RE14: LOW LIGHT IMAGER

- MODIFY LIGHTNING MAPPER RATHER THAN IMAGER; NON DEDICATED OPERATION
- MODIFIED LIGHTNING MAPPER PROVIDES 10KM IFOV
- PERFORMANCE COULD BE IMPROVED IN ADVANCED LIGHTNING MAPPER

RE21: SOUNDER SPATIAL RESOLUTION OF 4KM (MAJOR IMPACT TO LONGWAVE CHANNELS)

- MUCH LARGER APERTURE TO MINIMIZE DIFFRACTION AND MEET NEΔT

FIGURE 7.3-1d

REASONS FOR UNMET NOAA REQUIREMENTS

IMPACTS TO SPACECRAFT JUDGED EXCESSIVE

RO18: NIGHT TIME 4μm CLOUD DETECTION AT 2KM

- REFRIGERATION FOR 80 IR DETECTORS

RO20: SINGLE PIXEL SOUNDING

- INADEQUATE SIGNAL-TO-NOISE FOR THE REQUIRED TEMPORAL AND SPATIAL RESOLUTIONS AT SOUNDING RATE

RO22: SOUNDING RATE 3000 X 3000KM IN 30 MINUTES; 2500 X 2500KM IN 20 MINUTES

- COLDER FOCAL PLANE REQUIRES MECHANICAL REFRIGERATION
- BETTER DETECTORS
- LARGER APERTURE

RO33: SOLAR EUV SPECTROMETER

- MAJOR YOKE REDESIGN TO ACCOMMODATE ALL SOLAR VIEWING INSTRUMENTS

FIGURE 7.3-1e

REASONS FOR UNMET NOAA REQUIREMENTS

IMPACTS TO SPACECRAFT JUDGED EXCESSIVE

RC31: SEM/EPS

- <0.8MeV/n ALPHA PARTICLE MEASUREMENTS - COMPLETELY NEW SENSOR
- PITCH ANGLE DISTRIBUTIONS FOR PROTONS AND ELECTRONS ABOVE 30keV - TOTAL REDESIGN REQUIRED

RC35: S&R LOCATION CAPABILITY

- INTERFEROMETER BOOMS IMPACT OPTIONS I, II, & II CONTROL SYSTEM & AFFECT COOLER OPERATION

RC36: DCS ADDITIONAL CHANNELS & LOCATION CAPABILITY

- IMPACTS OPTION I POWER & WEIGHT
- LOCATION NOT FEASIBLE WITH UNFRIENDLY TRANSMITTER

RC37: WEFAX ADDITIONAL CHANNELS & OPERATION DURING ECLIPSE

- IMPACTS OPTION I POWER & WEIGHT

8.0 CONCLUSIONS AND RECOMMENDATIONS

8.1 Scope of Recommendations

As a consequence of this study, various recommendations emerged that could be grouped into three main categories. These are:

1. Programmatic level recommendations (Section 8.2) that influence the overall system, spacecraft subsystems, sensor payloads, and ground operations and data handling systems.
2. Studies recommended for completion prior to commencing Phase-B (Section 8.3). Many of these are within the original scope of the study but were not completed because of resource limitations. Also included in this category are new studies, not originally designated, the need for which surfaced during the course of the study.
3. System level recommendations (Sections 8.4 through 8.10) apply to spacecraft systems and subsystems, instruments (imager, sounders, SEM, DCS, S&R, and WEFAX), and ground systems including command, control, and data handling, (receiving, processing, distribution, user downlinks). Most of these studies are described in greater detail in Sections 9, 10, and 11.

8.2 Programmatic Level Recommendations

8.2.1 Recommended: Supporting NASA Research for Operational Environmental Missions

Evolving national needs for weather forecasting, meteorological and other atmospheric science measurements, and remote sensing from space in general are periodically translated by NOAA into requirements for geosynchronous earth orbiting GOES-type missions. The 1983 NWS and 1989 NOAA requirements were used as a basis for defining the GOES-N series configurations (Options I, II, and III) described in this report. In both cases, GOES I-M and GOES-N, satisfying NOAA requirements resulted in the need to specify instruments and some spacecraft subsystems that had little if any prior research heritage and no prototype flights previously conducted by NASA. The inherent risk of utilizing space hardware with no prior proof of flight worthiness is high and seems inconsistent with any operational space system.

The reason for this is that NASA terminated its research satellite and operational satellite improvement program in support of operational NOAA missions more than a decade ago. Also, in 1982 the NASA NOAA satellite improvement research program was canceled. The cancellation of Operational Satellite Improvement Programs (OSIP) was only the smallest and final part of the NOAA support that NASA stopped. The first step was the termination of the Applications Technology Satellites (ATS) which actually occurred in the early 1970s. The final ATS was flown in May 1974 (ATS-6). Then the decision was made at about the same time not to support future prototype operational satellite development using NASA funds (e.g., SMS). It is also worth remembering that these types of decisions also affected the low orbiting series (Nimbus and TIROS-N were the final members of those series). All these NASA policy decisions regarding research and operational prototype satellites were made not long after the 1973 NASA/NOAA agreement was signed stating that NASA had the responsibility to support and fund these satellites. Finally, OSIP also supported the entire operational program, not just the geosynchronous satellites.

The Advisory Committee on the Future of the U.S. Space Program (often referred to as the "Augustine Committee") in late 1990 recognized this situation and recommended that NASA re-institute an ongoing program of research to support these operational environmental missions. In January 1991, the NASA administrator announced that he would implement this committee's recommendation.

The recommendation described in this section is precisely that of the Augustine Committee and is in exact compliance with the NASA favorable response. Specifically with regard to GOES-N, the recommendation implies on-going NOAA oriented sensor research and technology development programs within GSFC accompanied by protoflights of advanced systems that precede flying these on NOAA operational missions. Based on a successful prior history (1960-1980) of a coupled research-operational approach, the implementation of this recommendation is almost certain to reduce cost, risk, and schedule uncertainties and result in satisfying newly emerging NOAA requirements on a continuing basis.

Results of the cost analyses contained in Volume 3 of this report indicate that the recommended research - operational sequential program for NOAA satellite will result in the benefits described above. In Volume 3, the RAO defines "Business as Usual" and "Preferred Strategy" approaches for GOES-N. "Business as Usual" represents the operational program under which the current GOES satellites are constructed. This is an extremely high risk approach for developing GOES-N as it does not allow for the research and development work necessary to achieve the technological requirements of the GOES-N satellites. Hence, this program is not recommended. The "Preferred Strategy" centers about preliminary research and development programs for the highly sophisticated sensors and spacecraft in the Options I, II, and III described in Section 7. Under this scenario, an initial investment of about 5 percent of total program cost is specifically allocated for research and development work in the first 3 years for Option I and the first five years for Options II and III.

This initial investment will allow for the development of the GOES-N state-of-the-art sensors and spacecraft. It will result in extending the life and increasing the reliability of the GOES-N series. The final reason for recommending the "Preferred Strategy" is that cost savings of about 25-40 percent will also be realized.

8.2.2 Recommended: Project Procurement of Instruments

It is recommended that instruments be procured by the NASA project office directly from instrument sources instead of via the spacecraft contractor. NASA should arrange for in-house or off-site acceptance level environmental tests of each sensor. This recommendation is one successfully followed on most GSFC space science missions, past and current. It places the responsibility for instrument Phase-C/D's in the hands of qualified contractors and the NASA project office. The spacecraft contractor remains responsible for defining the interface specifications, sensor integration into the spacecraft, and total system level environmental acceptance tests. The spacecraft contractor is freed of possible allegations of "conflict of interest" when responsible for both the host carrier and the payload. The NASA project office is understandably more unbiased in assessing schedule delay and cost overrun sources. This recommendation applies to all elements of this section as a general consideration.

8.2.3 System Configuration Recommendations

We should assess the benefits of flying spacecraft in a constellation that has 3 elements. An imager bus east and west, and a single sounder bus. Navigation will improve for the imager spacecraft. The sounder spacecraft can reduce the risks/impacts of bringing the new sounder on-line. The sounder spacecraft may even carry the auxiliary imager for full disk data support. In this scenario, the spacecraft can now remain within the Delta envelope and yet carry instruments that have grown physically to provide enhanced capabilities. This system may cost more, but there is a robustness that may warrant the expense.

8.3 Studies Recommended for Completion Prior to Initiating Phase-B and their Categorization

Of the eighty-one (81) studies originally defined as necessary to accomplish in order to complete the GOES-N study, about half were deferred due to the descoping discussed in Section 2.0. As the study approached its conclusion in the September-November 1990 time frame, re-examination of these studies indicated that some of them could be eliminated. Over the same time period, additional studies, primarily oriented towards better definition of the developmental instruments (e.g., imagers, sounders), emerged as being important to the study. As the analysis of the GOES-N system proceeded, several key studies were also identified as requiring further pre-Phase-B effort. Sections 8.4, through 8.10 contain additional studies recommended, arranged by subsystem or sensor.

8.3.1 Recommended Pre-Phase-B Studies

1. Assist in the technical review of NOAA requirements for the GOES-N Phase-B study:

This may be viewed as advising as to the technical implications and/or feasibility of proposed operational requirement specifications, accepting NOAA direction as to content of the NOAA requirements document for GOES-N, and drafting a final requirements document for submittal to NASA prior to beginning Phase-B.

2. Resampling:

Based on the results of a number of study efforts, it appears that ground resampling will significantly mitigate alignment problems and navigation/registration demands on spacecraft equipment. NWS is expected to have a requirement in the GOES-N time frame to remap sectors of GOES data in real time and distribute it via ground communications to the field centers. This recommended effort will evaluate the overall system required to achieve the current specification performance and desires at the output of the resampler/remapper. The initial effort in this area is to develop a quantitative estimate of potential gains from resampling in terms of risk, cost, and performance. Trade-offs between resampling/remapping algorithm complexities and output performance would be assessed, as well as the impacts on the instrument design in areas such as increased Modulation Transfer Function (MTF) requirements. Interrelationships of the resampling and remapping requirements, as they impact optimization of overall system performance, should be addressed as well as the impact on ground processing.

3. Solar viewing platform stability:

A dynamic model of the solar array yoke and bearing assembly and the burdened single axis positioner should be analyzed to demonstrate the dynamic stability and pointing accuracy of the solar viewing platform and its impact on earth viewing instruments. It is extremely important that this be done prior to release of the Phase-B Request for Proposal (RFP) to fully establish the compatibility of the solar viewing and earth viewing platforms. The effort should include:

a) Develop a two body bearing assembly NASA Structural Analysis Program (NASTRAN) structural model and define mode shapes and frequencies
b) Perform servo analyses of control loops for servo positioners in azimuth and elevation and determine stability margins and pointing performance

4. Option II sounder:

The Option II sounder with the passive cooler should be designed to allow in-flight selection to provide trades between coverage rate, completeness of coverage (fill factor), spectral resolution, and NEΔT in the various spectral bands. A Phase-A study is recommended which includes a detailed analysis of the technical feasibility and limitations of these trades with the objective of providing a passively cooled advanced sounder with a useful level of sounding performance for a mode in which a 3,000 x 3,000km area is covered in less than an hour for routine coverage as well as having available high performance modes for detailed assessments in limited areas.

5. Optical instrument layouts:

Phase-A studies of the principal new optical instruments are recommended to provide confidence in the technical specifications for a Phase-B system RFP. Such studies should be conducted for the imager, the high-spectral resolution sounder and the SVM/HαI, if appropriate.

6. Continuous stationkeeping:

Continuous stationkeeping, to maintain orbit inclination even lower than 0.1 degree, now appears highly desirable for the fundamental reasons of reducing (1) alignment problems and (2) navigation and registration demands on spacecraft equipment. This is also a potential alternative to the resampling of Item 3 above. This study was proposed as an efficiency measure at the outset of the study as a means of avoiding the spacecraft downtime associated with stationkeeping maneuvers, but was not funded. The study should address:

(a) Fuel usage impact as a f· ·ion of maximum allowable inclination and along track drift.
(b) Impact to spacecraft orbit determination (position error) as it contributes to navigation error.
(c) Frequency of maneuvers required as a function of maximum allowable orbit inclination.
(d) Parametric relationships between stationkeeping error and errors for various sized focal planes.

7. Orbit determination:

A major source of error in the INR performance is the determination of orbit and attitude. This effort would evaluate the improvement in navigation/registration performance from better determination of orbit and/or attitude (O/A). An assessment of the likelihood of achieving the required O/A errors using Deep Space Network (DSN) information, and/or multiple ranging sites with and without a GPS based timing system would then be prepared.

8. Instrument materials:

Provide further refinement on the advantages of using materials such as beryllium and GFRP for the instruments as a means of improving registration performance. This effort is to result in an assessment of different design concepts employing these materials and the resulting expected improvements on the location of structural nodes and thermal deformations.

9. Search and Rescue position determination:

Develop a spacecraft option incorporating the capability for position location for the S&R subsystem with accuracy of 60-100km. S&R position determination is not included in Options I, II, or III.

10. Star acquisition:

Evaluate actual star locations to determine the minimum star magnitude required to ensure a 99.7% probability of having a star in view of two of the three star trackers at all times. Noise Equivalent Angle (NEA), FOV, and actual star availability (not probability) would be determined.

11. Control system simulations:

Provide additional simulations to determine the performance of control systems based on improvements resulting from the additional control studies.

12. EPS extension:

Energy deposition analysis for heavy energetic ions in the existing EPS dome and telescope detectors should be performed to confirm the feasibility of the approach and to establish preliminary thresholds for the discriminators.

13. Electrostatic analysis:

The spacecraft electrostatic potential distribution should be modeled in typical synchronous orbit environments using a program such as NASA Charging Analyzer Program (NASCAP) to map the energy/spatial domain at the soft particle spectrometer detectors to that outside the spacecraft sheath. Electrostatic analysis can be deferred to Phase-B.

14. Ground system:

The ground system should be studied to assess the impacts of various Option II and Option III spacecraft configurations, including use of commercial systems for "GVAR" data distribution. This study should include estimates of the expected GOES-N products (e.g., type, coverage, frequency, etc). Also, the benefits of advanced workstations should be explored.

15. Communications:

At the fourth quarterly review, Mr. Larry Heacock of NESDIS informed us of impending negotiations to move NOAA out of S-band (in particular, the 2025-2035MHz band) to a higher frequency band. Subsequent conversations with Mr. James Fisher (NOAA frequency management) confirmed that statement. Such a move, if implemented, will take place in the GOES-N time-frame and will have a significant effect on spacecraft configuration and the Radio Frequency (RF) ground system. It is important for the GOES-N study team to develop spacecraft options that use X- or K-band frequencies. Such a study would provide NOAA with an estimate of the cost of making this transition. NOAA is expected to need such an analysis for use in the negotiation process.

The need for the Wallops Island phase of the program needs to be reassessed as well as the need for the GOES satellites to serve as their own communications satellite, once the data have undergone initial processing. The data stretching phase needed in the current program (e.g., GOES-7) certainly is altered for GOES-N (this is true even with GOES I-M), and, with powerful new three axis stabilized communication satellites coming on line in the 1990's, there is a question whether GOES should re-broadcast data and products or whether this should be done via new commercial satellites.

16. Minimization of "1/f" instrument noise

Study how to least minimize "1/f" noise of imagers and sounders on three axis stabilized platforms in GEO.

8.3.2 Categorization of recommended studies (Refer to Appendix 6A)

The original list of unfunded studies and new ones defined as recommended were categorized as follows and shown in Table 8.3-1:

1. RFP technical requirements:

A recommendation for GOES-N is to clearly specify in the RFP that non-compliant proposals will be rejected. Items that require compliance include provision of a safe-hold in-orbit mode (SC8) and the capability to test flight instruments at spacecraft levels in an ambient environment (SS39).

2. Design specific:

These are studies which are most logically performed during Phase-B when a particular design approach has definitely been adopted. This effort would not be as productive in a Phase-A environment where design approaches are much more tentative and therefore, deferral is recommended.

3. Included in Transition Phase-A/B:

These are studies suggested in whole or in part as part of Transition Phase-A/B recommendations. The list is broader in scope than the original set of unfunded studies.

4. New work needed:

These are efforts perceived as required to "complete" the original study. The list is not exhaustive, since it only addresses studies that were in the strawman list at the beginning of the study. It includes all applicable studies recommended as part of transition Phase-A/B.

5. Abandon:

These are studies which should be abandoned because they now appear to be out-of-scope or directed at approaches which are not compliant with NOAA's stated guidelines (e.g., reducing the number of sounding channels from 19 to 14).

6. Partial treatment:

Several "unfunded" studies were investigated to some extent during the course of the study because investigations naturally .ed to their consideration.

7. NOAA input needed:

These are studies which are substantially completed and where next steps are dependent on NOAA's assessment of study results.

TABLE 8.3-1

CLASSIFICATION OF UNFUNDED STUDIES

DESIGN REQUIREMENT	DESIGN SPECIFIC	INCLUDED PHASE A/B	NEW WORK NEEDED	ABANDON	PARTIAL TREATMENT	NOAA INPUT NEEDED
SC8	SC5	SC2	SS2.2	SC15	SC11	SS14
SS39	SS4.2	SC7	SC3	SS18	SD1	SS35
	SS8	SS2.2	SC7		SS11.7	
	SS44	SS5.1	SC9		SS12	
	SS47	SS5.3	SC11		SS14	
		SS12	SD1		SS19	
		SS19	SS5.1		SS21	
		SS21	SS5.3		SS22	
		SS22	SS12		SS23	
		SS23	SS19		SS31	
		SS31	SS21		SS35	
		SS36	SS22		SS36	
		SS40	SS23		SS40	
		SS43	SS31		SS43	
			SS36			
			SS40, SS43			
			SG1, SG2			

8.4 Sensor System Recommendations

8.4.1 Option I Recommendations

8.4.1.1 Imager Recommendations

1. Option I Imager – Cloud Smearing Specification Change:

The analysis showed that it is not possible to meet the requirement that the output must reach 98% of its final value within a distance of 1 IFOV. Instead, the requirement should be restated in terms of ground distance. For example, the output should reach 98% of its final value within a scan distance of X kilometers. When stated in this way, an appropriate combination of detector size, optics, and filtering could be chosen to satisfy the requirement.

2. Option I Imager – In-Flight Channel-to-Channel Alignment and Temperature Stabilization:

It is recommended that the aft optics be temperature stabilized to avoid the possibility of diurnal drift between channel centroids in the various spectral bands. This change could be incorporated with likely negligible impact to the spacecraft interface, and may ultimately be required to approach the specified performance requirements for channel-to-channel co-registration. In addition, it will have in-flight visible to IR adjustment capability and perhaps temperature stabilization of the relay optics containing the IR beam splitters. This will lead to the improved performance.

3. Option I Imager – DC Restoration on Every Available Space Look:

Overall image quality and calibration accuracy can be improved by DC restoring on every available space look, rather than at two minute intervals as was planned on GOES-I. This will significantly reduce the effect of 1/f noise, and is recommended for the Option I imager. For sectors that do not see the edge of the earth, some space looks at a regular interval will still be needed.

4. Option I Imager – Elimination of Discontinuities in IMC Signal:

The AOCE software must be modified to eliminate discontinuities in the IMC signal during scan turn-around. It is assumed that this modification will be incorporated at some point in the GOES I-M program. It is also assumed that at some point in the GOES I-M program a stable, full time Coherent Error Integrator will be developed. This may be necessary to achieve within frame registration requirements at end-of-life.

5. Option I Imager – NEΔT Improvement by Changing the Astromast Coating:

Improvement of the NEΔT for the imager through lower focal plane temperature should be achievable in Option I by simply changing the surface finish of the Astromast boom to a specular, low emissivity reflector. Analysis shows that this change alone results in a focal plane operating temperature advantage of nearly 10K to a control temperature of about 92K for either the imager or the sounder. Performance modeling for the imager in this report has been done only at the 85K control temperature we expect for Options II and III. For the detector noise limited performance expected, the 92K control temperature would result in improved NEΔT at all wavelengths, potentially by a factor of 2.5 relative to GOES-I.

6. Option I Imager - Channel - Channel Alignment During Thermal Vacuum Tests:

Although they were not identified as funded cost-cutting or efficiency studies early in the program, several suggestions have arisen during the course of the program that should be incorporated in the GOES-N imager. These are discussed in Section 7, and include improved procedures for accomplishing channel-to-channel alignment in instrument level thermal vacuum test through remote adjustment mechanisms and potential use of flex pivots in the east-west scan axis.

7. Option I Imager - Comprehensive Thermal Model Required:

An analysis was performed to determine the thermal gradients in the sunshield and the heat inputs into the scan mirror as the length of the sunshield is increased. It is difficult to draw conclusions from these results without knowledge of the thermal performance of the GOES-I,J,K scanner. A detailed model of the scan mirror and the elements in the scan cavity is needed to assess the effects of changes in the length of the sunshield and in its external surface properties.

8.4.1.2 Option I Sounder Recommendations

In keeping with the concept of the Option I spacecraft system as a minimal cost approach to GOES-N, changes to the spacecraft and instruments from the GOES-I configuration are limited to those for cost and/or efficiency improvements and those instrument modifications offering significant performance benefits without significant impact to spacecraft interfaces. The Option I sounder design concept is, therefore, identical to GOES-M.

1. Option I Sounder - NEΔN Improvement by Changing the Astromast Coating:

Significant improvement in the sounder to improve the NEΔN is limited by the focal plane temperature, which can be significantly lowered within the concept of a low cost, minimal impact system by simply changing the external finish of the Astromast solar sail boom as described in Sections 9.1.1 and 9.5.3.1. The same magnitude of performance gain as for the imager can be realized through this means, and a focal plane temperature of 92K should be realizable. Performance has been modeled only at the 85K temperature to be obtained with Option II and the 65K expected with Option III.

2. Option I Sounder - In-flight Channel-to-Channel Alignment and Temperature: Stabilization

Co-registration of the sounder channels to the stringent requirements of RO25 remains a major problem for GOES-N, as discussed in Section 9.4.1.3. It is recommended that improved means of alignment and co-registration of the sounder channels be developed for all spacecraft options, as discussed in Section 9.4.1.3.

3. Option I Sounder - Sounder Co-registration:

The GOES I-M sounder can be modified to improve co-registration performance without major changes to the sensor.

One modification would be to slow down the filter wheel by about 10% and increase the time allowed for the scan mirror to step and settle from 28 milliseconds to 38 milliseconds. This could reduce the motion of the line of sight during the time soundings are being measured from about 10μr to less than 7μr which causes misregistration of the sounding channels relative to the window channel. This would keep the south-north coverage of the sounding channels unchanged but will increase the time required to cover a given area by 10%. This will also simplify the fabrication of the sounder by allowing some reduction in the required performance of the east-west servo of the sounder.

4. Option I Sounder - Co-registration Verification In-Orbit:

The edge of the moon can be observed in the visible and sounding channels and used to verify co-registration in orbit. The moon has an albedo of about 0.07 to 0.1 and would be directly compatible with the visible and star sensor detectors. The sunlit portions of the moon reach temperatures of about 400K; thus, for the IR sounding channels, it will be necessary to incorporate a system to reduce the gain and to avoid saturation when observing the moon. With these design features incorporated, it should be possible to check the co-registration of the sounder in flight.

Another modification would be to temperature stabilize the aft optics beam splitting assembly to minimize diurnal and seasonal temperature variations which cause the 3 spectral bands to change their relative alignments.

5. Option I Sounder - 1km Visible for Cloud Clearing:

The GOES I-M sounder could be modified to provide cloud detection with 1km IGFOV visible detectors. The preferred approach is to use an area array of detectors (probably a Charged-Coupled Device (CCD)) to detect the clouds. The focal length of the sounder telescope is about 3.56 meters, which would require detectors 100μm on a side to provide a 1km IGFOV.

6. Option I Sounder - Areal & Single Pixel Sounding Clarification Needed:

This study has not addressed an error analysis for the retrieval process nor selection of optimal cloud clearing algorithms for control of those errors. Thus, there has been considerable discussion as to the correct interpretation of requirement RC28, which requires a sounding for a 60 x 60km area using 9 "clear" IFOVs, and RO28 which requires a "single" IFOV sounding.

8.4.2 Option II - Recommendations

8.4.2.1 Option II - Imager Recommendations

1. **Option II Imager - Cloud Smearing Specification Change - Same as Option I:**

2. **Option II Imager - In-flight Channel-to-Channel Alignment and Temperature Stabilization - Same as Option I:**

3. **Option II Imager - NEΔT Improvement by Eliminating the Astromast and Annual Spacecraft Flip:**

The elimination of the solar sail will improve the instruments' passive cooler operation and improve NEΔT. Refer to Section 8.4.2.2 for further discussion on performance improvements realized by removal of the Astromast.

4. **Option II Imager - INR Performance:**

The improvement of system INR performance will result through a zero momentum, stellar referenced spacecraft attitude control system (Section 10 contains details of these changes).

5. **Option II Imager - Addition of Two Uncooled Bands to Option I Imager:**

Changes to the GOES-I imager were limited to those that could be incorporated at modest cost to provide some of the additional performance requested or to provide significant performance improvement. The design concept was, therefore, not changed. Those additional channels requested by NOAA which can be realized with uncooled detectors, i.e., the 0.86μm channel (Si detector) and 1.65μm channel (InGaAs detector), are added because that change does not impact cooler design and performance and has relatively small physical impact on the instrument.

6. Option II Imager - Optical Encoder Replaces Inductosyn:

In the area of pointing performance of the instrument, the studies indicate that the single most productive change, short of a complete structural redesign of the instrument, is incorporation of optical encoders in lieu of the inductosyns used in the GOES-I scan mechanism. The Option II, 7 band imager will have 3 inch optical encoders to improve the pointing accuracy.

7. Option II Imager - In-flight Visible to IR Alignment and Temperature Stabilization:

There will be in-flight adjustments of the alignment of the warm focal planes, the relay optics will be redesigned to improve stability, it will be temperature stabilized, and some supporting structures may be changed to improve stability.

8.4.2.2 Option II - Sounder Recommendations

The Michelson approach was selected as the basis for determining size, weight, and power projections for the advanced sounder. Because there are problems with extension of the AIRS grating technology to geosynchronous orbit, it is not recommended. The principal reason for selecting the Michelson over the Fabry-Perot is the requirement for contiguous spectral coverage, which is very difficult to satisfy with Fabry-Perot technology. Should reexamination of NOAA's requirements lead to a much more restricted set of narrow spectral bands, which can be defined in advance, the question of the Fabry-Perot versus Michelson approaches should be reconsidered. The Option II sounder was configured to use a passive radiator with a reduction in its area coverage capability. To help the Option II sounder have better performance, we have increased the aperture from 30cm to 35cm.

1. Option II Sounder - Sounder Phase-A Study:

A Phase-A study of the sounder should be conducted prior to Phase-B. The purpose is to develop a data base which is sufficient to prepare the RFP and to prepare staff to monitor the competitive, parallel Phase-B sounder studies. At this point, the in-house information/knowledge base is inadequate to initiate a good Phase-B business arrangement with industry.

2. Option II Sounder - Co-registration Specification Change:

The sounder channel-to-channel or co-registration requirements, identified as RC25 for this study, were defined by NOAA as a core requirement to have the centroids of the Spatial Weighting Function (SWFs) for the various spectral channels matched to 2% of total IFOV width (1σ) and the half-power SWF channel widths matched within 1% (1σ). The initial assessment of unmet NOAA requirements versus spacecraft options that was presented at the GOES-N Study Final Review presented a predicted centroid matching to 10μr performance for all 3 options versus the 2% or 4.5μr requirement and a half-power IFOV of 20μr for all three options versus the 1% or 2.2μr requirement.

This specification can be rewritten so that the window channel in each band (long, middle and short wavelength) is the reference of registration. Thus, "the channel to channel registration for each channel within each band with respect to the window channel in that band must be such that the radiometric response centroids shall be within $\pm$ 2% of the total FOV width and that the half power FOV channels widths shall match each other to within the diffraction limit."

This is a significant modification of the requirement and, if accepted by NOAA, should make it feasible to match the centroids to the 2% required on the Option II and Option III sounder. Problems in making measurements of the width of the 1/2 power points of the FOV will preclude validation of performance to 1%.

3. Option II Sounder - Study to Verify Need for Contiguous Spectral Coverage from 3.9 - 15.5μm:

The highest priority change in instrumentation for GOES-N is the development of a new infrared sounder that has the projected potential to provide 1km vertical resolution in the troposphere with 1K temperature accuracy. The characteristics of this instrument have been defined as needing $0.5cm^{-1}$ spectral resolution in the $15.5\mu m$ ($660cm^{-1}$) spectral region with consistent high spectral resolution of $2.5cm^{-1}$ in the $3.9\mu m$ ($2564cm^{-1}$) spectral region. The spectral coverage has been enunciated as requiring contiguous spectral information over the entire spectrum. Additional work is required to verify that this last criterion has a good science basis.

4. Option II Sounder - Signal Processing Studies:

There are certain aspects of the signal processing impacts of the Michelson approach that have not been investigated. The experience with the aircraft instrument is inadequate to document the true characteristics in an operational environment. Because of the substantial difference in extracting radiance data from an interferogram and the concomitant increased focal plane performance requirements in the areas of linearity and dynamic range for the Michelson, careful engineering and management decisions are needed to fully understand the areas of risk associated with selecting this new technology for an operational system. In addition, a detailed assessment of data processing requirements and impacts should be initiated. It is probably desirable to have an independent entity take the proposed retrieval algorithm and verify the accuracy of the technique. If no algorithm exists, development should begin.

5. Option II Sounder - Design and Breadboard of Critical Components:

With regard to the new sounder, it is recommended that NASA immediately begin the design and breadboard of critical components (e.g., laser position devices, focal planes, coolers, etc.).

6. Option II Sounder - Contemporaneous Cloud Clearing Data:

Contemporaneous visible data at 1km IGFOV can be included in the sounder, but contemporaneous IR is not recommended for an instrument using a passive radiator.

7. Option II Sounder - Aft Optics Design:

As discussed in Section 9.3.3, further analysis is required before committing to the aft optics design based on the GOES I/M HSRS feasibility study. The performance of an alternate design replacing the common field stop with individual field stops in each focal plane but retaining the in-flight adjust mechanisms and thermal control of the aft optics should be evaluated in light of the reduced emphasis likely to be placed on band-to-band co-registration. This evaluation should include an optical layout to demonstrate that the adjust mechanisms recommended in any case can be physically incorporated within a reasonable aft optics volume.

8. Option II Sounder - Foreoptics Design:

This study has not addressed alternatives to the foreoptics design presented here. There are potential advantages to an off-axis, three mirror type foreoptic which may far outweight the larger volume which would be required relative to the Cassegrain foreoptics. The principal advantage is that direct illumination by sunlight of the secondary mirror suspended on a high thermal impedance spider is avoided, significantly easing the thermal design problem for three-axis stabilized spacecraft. Second, the extended FOV of such designs is potentially considerably better than that for Cassegrain or Gregorian systems, easing constraints placed on focal plane technology. Third, the unobscured optics will result in less diffraction for a given optical aperture than for the obscured Cassegrain. Further study should be carried out to select a preliminary design for the three mirror foreoptic and to determine the relative advantages of these two approaches.

9. Option II Sounder - In-flight Band-to-Band Alignment and Temperature Stabilization:

The in-flight band-to-band adjustment mechanisms, recommended in any case, become mandatory with the approach described in Section 9.3.3, also thermal control of the aft optics to improve band-to-band co-registration, is required.

10. Option II Sounder - Fast Fourier Transform Performed on Ground:

The baseline signal processing approach is to send the digitized interferogram to the ground without performing any in-orbit signal processing such as the Fast Fourier Transform. The communication subsystem can accommodate the required data rate within the existing spectrum allocation, albeit at some increase in power requirements. It is the study team opinion that unless there is overriding need to put this processor in the satellite, better reliability will be realized by ground processing.

11. Option II Sounder - 1km Visible for Cloud Clearing:

An approach similar to the Option I sounder could be used to provide 1km IGFOV visible for cloud clearing for the HSRS used in Option II or III. The CCD array must accommodate the specific focal length of the telescope and IR array size used in the HSRS.

12. Option II Sounder - Radiometric Performance Improvement by Elimination of Astromast and Annual Spacecraft Flip:

To enhance the Option II sounder capability, the GOES-N spacecraft concept is designed to eliminate the solar sail parasitic heat into the passive radiator, and the spacecraft performs a semi-annual 180 degree yaw maneuver to keep the summer sun off of the cooler. These two factors allow a modestly sized cooler to be implemented that operates in the 85K temperature regime. The elimination of the Astromast (solar sail) will improve the instrument passive cooler operation and improve the performance by lowering NEΔT. The focal plane temperature modeled is 85K, leaving quite a gap in performance against NOAA objectives. A 14 inch (35.6cm) optical aperture is incorporated to provide some compensation for the relatively poor performance. Increasing the collecting area is an expensive method of improving performance, due to the rapidly increasing weight penalty and the need to maintain optical quality and scan efficiency of the larger optics and scan mirror. Further increases in the optical aperture are not recommended, since they would severely stress the technology for this instrument approach.

It has been shown that the elimination of the solar sail and the incorporation of the half-yearly 180 degree yaw maneuver discussed in Section 10 yields confidence that the 85K operating temperature used for performance modeling in Section 9.2.2 can be achieved. In fact, the study results promise that further work in the cooler area is justified to achieve even lower operating temperatures without resorting to mechanical coolers.

From the work of Annable of ITT, the current GOES-I,J,K radiative cooler design should be capable of operating at a controlled patch temperature of about 75K without modification if the astromast is removed from the FOV of the cooler cone and if the spacecraft is flipped at equinoxes to prevent sunlight from impinging on the shield/housing radiator and into the cooler cone. From the work of Annable, an increase in the joule heating from added detectors in the advanced sounder can be accommodated by increasing the size of radiators by a comparable amount. One may also want to consider the circular configuration of the radiators as proposed by Annable but without the rotating sunshield. Temperatures lower than 75K may be feasible, but further study is required to consider methods to reduce the heat inputs by conduction and radiation to the rear of the patch, radiator, and shield/housing.

13. Option II Sounder - "Venetian Blind Coverage":

With the focal plane array of Figure 9.3.3-3, for instance, a "vertical venetian blind" coverage for IR pixels can be obtained by stepping the array in object space by three IGFOVs, rather than the single IGFOV used for contiguous coverage. IR spatial fill factor of 33.3% will be generated, but the contiguous 1km IFOV visible data necessary for cloud clearing will be available in the background. Other possibilities are clearly available, depending on what combinations of sparse sampling modes are desired.

14. Option II Sounder - Encircled Energy:

Achieving the requested encircled energy fraction of 0.83 or better at all wavelengths implies optimal system performance for a 30cm aperture and essentially zero despace tolerance. This performance level can be obtained with margin given the larger aperture (35cm) and a suitable instrument thermal design contemplated for the Option II sounder. For the Option III sounder, even with a good thermal design, there is no margin for error due to its 30cm aperture. Consideration should be given to either relaxing the requirement for encircled energy to around 0.80 at 1.25 IGFOV or encouraging the use of a larger aperture for the sounder.

8.4.3 Option III Recommendations

8.4.3.1 Option III - Imager Recommendations

The Option III imager, will be an all new design using a GFRP structure, a two mirror scanner, optical encoders, and an extended focal plane. The two mirror scanner does not introduce any image plane rotation with scanning so that it is feasible to lay the detectors for the various spectral bands one after another (Figure 9.1.3-1). Because of the wide angular extent (approximately 0.15 degree) of the set of IR detectors the speed of the optical beam must be slower, typically with an f# of 2 or 3. This increases the detector noise, because larger detectors must be used, but the layout allows for time delay and integration techniques by using more detectors along the scan direction for those few spectral bands that require better performance than can be achieved by a set of single detectors. This design also incorporates the spectral defining filters directly over the detectors and does not use any beam splitters. This increases the throughput so that more signal photons fall on the detectors and helps compensate for the performance loss due to detector size. The co-registration alignment then occurs primarily during the fabrication of the focal plane and in control of the telescope focal length and sample timing so that the improved co-registration can be achieved.

1. Option III Imager - Imager Phase-A Study:

A Phase-A study of the advanced imager should be conducted prior to Phase-B. The purpose is to develop a data base which is sufficient to prepare the RFP and to prepare staff to monitor the competitive, parallel Phase-B imager studies. At this point, the in-house information/knowledge base is inadequate to initiate a good Phase-B contractual arrangement with industry.

2. Option III Imager - Passive Cooler Design:

The addition of more IR bands to the imager will be a significant impact to cooler design. A detailed study is needed to quantify the required changes to add the additional IR bands. The study probably should address the performance with the solar sail still in the FOV as well as performance with the Option III spacecraft attitude control system.

3. Option III Imager - Analytical Model:

To insure that RFP performance levels are realizable, an analytical structural model of the advanced imager must be constructed and its thermal/structural stability evaluated.

4. Option III Imager - Sunshield:

Another improvement, extending the sunshade, does limit direct exposure to the sun, but more work is required to develop an engineering design that keeps the sunshade itself from being a major heat load into the aperture cavity.

5. Option III Imager - Ground Resampling and Low Orbit Inclination:

As discussed in Section 9.1.3, implementation of the advanced imager depends on maintaining low orbit inclination and/or ground resampling of the data for satisfactory performance. The corresponding study tasks were not performed as part of the study. The study cannot be considered complete in this respect until the system impacts of these requirements are evaluated.

6. Option III Imager - Recommended Cloud Smearing Specification Change - Same as for Options I and II:

7. Option III Imager - In-flight Channel-to-Channel Alignment and Temperature Stabilization - Same as Options I and II:

8. Option III Imager - NEΔT Improvement by Eliminating the Astromast - Same as Option II:

9. Option III Imager - Spacecraft Altitude Control - Same as Option II:

10. Option III Imager - In-flight Co-registration Mechanisms:

The RO2 navigation requirement for the imager of 2km (3σ) at 45 degree latitude corresponds to a pointing knowledge of 33μr (7 arc seconds) at nadir. Indeed, the thermal modeling of the instrument and spacecraft together shows that thermal effects give rise to diurnal pointing dislocations of the order of 1000μr peak-to-peak, necessitating the assumption of day-to-day repeatability to enable image motion compensation for that effect as well as the effect of orbit inclination. Thus, the effect of diurnal variations in temperature gradients on pointing of a single IFOV in the GOES I-M system is quite large. As the aft optics design becomes more complex, the problems of obtaining and maintaining optical alignment become more difficult. In this situation, depending on the susceptibility of a particular design and the requirements for co-registration of the multiple IFOVs, consideration must be given to the use of in-flight control mechanisms to compensate for the effects of the launch vibration environment and possible gravity release misalignments. Further, for differentiated optical systems, it may be necessary to employ precise thermal control to avoid diurnal or seasonally driven pointing errors between IFOVs.

It is therefore recommended that an alignment mechanism be incorporated to provide for in-flight registration of the focal planes, and that the aft optics be thermally stabilized to prevent diurnal and seasonal misregistration effects.

11. Option III Imager - Recommend Detailed Co-registration Study:

Specific approaches for co-registration of the focal planes have not been addressed in the study since detailed optical system designs have not been performed for the developmental instruments. However, several approaches might be employed. For simple adjustment of the lines of sight, a tilt control of reflective optics such as a fold mirror in a particular optical path could be used, as was done in the TM design. Lateral shifts of such elements can also be used to obtain a single degree of freedom in image location. Lateral shifts of optical elements with optical power, such as a relay lens, present another possibility although the optical design is considerably more complex. Much more difficult would be a lateral shift of the focal planes, particularly where cooled detectors are involved. Mechanisms for implementation of the adjustments include "inch-worms", as used in TM, and motorized micrometers, as used in the enhanced TM. Further study of the application of such mechanisms to the developmental instruments for GOES-N is recommended for Phase-B.

12. Option III Imager - Use of Zero Temperature Coefficient Materials:

Improving operations around local midnight probably should be addressed by major changes in the design and materials selection used in the imager and sounder, as has been recommended for both advanced instruments. There have been estimates that total thermal distortion within the GOES-I imager could be reduced by an order of magnitude through this change, but they have not been verified by analysis.

The first significant change is the use of near zero temperature coefficient materials and more efficient structural geometry to improve the pointing errors induced by diurnal thermal distortion. In this manner the dynamic range of correction for these effects to be applied by the IMC subsystem can be greatly reduced. More importantly, the non-repeatable portion of the thermal distortion, which cannot be corrected, will also be reduced. These changes are described in more detail in Section 10.4.1.3.

13. Option III Imager - Extended Focal Plane:

The second major change is the use of spatial separation of IR spectral channels in a common extended focal plane rather than the separation by beam splitters as implemented on GOES-I. It appears unlikely that the accuracy and stability of co-registration required for GOES-N can be practically realized with the complex aft optics required by the beam-splitter approach, particularly as one adds more of the requested spectral bands. Figure 9.1.3-1 shows the extended focal plane proposed for GOES-N. With this extended focal plane, the fundamental co-registration accuracy (within the limitations of the optical extended FOV) is determined by the accuracy of the fabrication process used to assemble the focal plane, a more manageable problem than maintaining the mechanical stability of multiple beam splitter paths in the aft optics. One beam splitter is still envisioned to separate the warm and cold focal planes, but this beamsplitter has incorporated precise thermal stabilization and an in-flight alignment adjustment mechanism to superpose the two focal planes in object space.

The warm and cold focal planes of Figure 9.1.3-1, while shown separately, are intended to be co-registered in object space. The model includes redundant detectors for all channels, which are not shown in the figure, but would be obtained in the same manner as for Option II; i.e., the detectors arrays are doubled in the north-south dimension. The visible channels are shown as 1km IFOV channels, rather than the 0.5km requested (RO1). The higher resolution is feasible in the instrument, using time-delay integration (TDI) to achieve the required signal-to-noise, but has a large impact on spacecraft communications and power and on ground processing. For this reason the 1km IFOV was retained in the model. A very similar situation exists with respect to the 3.9μm channel where a 4km IFOV is provided rather than the 2km requested since the required NEΔT is not compatible with a single 2km detector.

With extended focal planes, the problems associated with image rotation inherent in a two axis, single mirror scanner such as that used in GOES-I are exacerbated. It is preferable to eliminate the image rotation at the outset, which is accomplished by the next significant design feature of the advanced imager, the incorporation of separate scan mirrors for the east-west and north-south axes. The magnitude of channel-to-channel misregistration is proportional to orbital inclination. Channel-to-channel registration within the spacecraft system to 14μr, as being attempted on GOES-I, would require orbital inclinations no greater than 0.05 degree. Alternatively, since the channel-to-channel misregistration is deterministic the problem could be addressed by resampling the data stream in on-ground processing. Either approach appears feasible, although the image re-sampling and continuous stationkeeping studies proposed for other reasons in Section 8.3 but not funded at the beginning of the GOES-N study should be completed for confirmation.

There is a problem with an extended focal plane when IMC corrections are applied to the scan. East-west accelerations can be compensated for by dynamically adjusting the sampling rate to maintain co-registration. North-south accelerations will cause mis-registration that can be compensated for by either rotating the image dynamically during the east-west scan, limiting the maximum inclination angle or resampling the data on the ground. Dynamic rotation compensation introduces many undesirable complications into the design. The approach selected for Option III is to keep the inclination below 0.05 degree. The approach is to correct the inclination error, which grows about 0.002 degree daily, every day when the wheels are being unloaded from the solar pressure effects that occur because the Option III spacecraft does not use a solar sail. Keeping the inclination down to these levels will keep this effect to about 5μr and allow the performance projected in the table above. To maintain INR performance it will be necessary to have continuous two station ranging data about every 10 minute with an update of the orbit every few hours. It should be noted that, with these small inclinations, the required IMC signals to compensate for orbital effects are very low and should present no problems to the pointing system.

8.4.3.2 Option III Sounder Recommendations

The Option III sounder also utilizes the Michelson approach, uses a cryo-refrigerator to achieve focal plane temperatures in the 60K-65K temperature regime, and has a 12 inch aperture. It has a significant performance advantage over the Option II sounder, but is considered to have higher risk due to the lack of a demonstrated refrigerator lifetime in the current time frame.

Recommended Option II studies 1 through 14 listed in Section 8.4.2.2 also apply to the Option III sounder. Studies 15 and 16 below are unique to Option III.

15. Option III Sounder - 2km IR for Cloud Clearing at Night:

The Option III sounder uses mechanical refrigerators to provide the cooling of the IR focal planes. The refrigerators proposed for the Option III sounder have sufficient capacity at a low enough temperature to make technically feasible the inclusion of an IR array to provide a 2km IGFOV IR detection system operating in the 3.8μm spectral region. This IR array must steal a little light from the Short Wave spectral region of the sounder and be imaged on an IR detector array as shown in Figure 9.3.4-2.

The IR array may be implemented as a linear or area array using an approach similar to that proposed for the visible cloud clearing detector arrays.

16. Option III Sounder - Mechanical Refrigerators:

The issue of the technical risk of cryogenic refrigerator technology in the GOES program can only be addressed by observing the progress of the technology over the next several years. The NASA Earth Observing Program is committing significant resources to develop refrigerators with 5 year life. This activity should benefit NOAA instrumentation at some time in the future. In addition, a British instrument will fly a cryo-refrigerator with a multi-year life within the next two years.

Without positive results from these activities, NOAA should not plan on using refrigerators in the operational environment. However, if the mission requirement drives the need for focal plane temperatures below 80K, then this technology will have to be considered. It may be possible to design an interface that allows a passive radiator to be used initially while later units use a refrigerator to improve performance.

8.4.3.3 Option III Auxiliary Imager Recommendations

The desire for an additional imager has been identified as an enhancement in the NOAA document and as RE15 in this study. This full disk imager could relieve the conflicts for observation time expected to develop with increasing mesoscale imaging requirements if only the basic primary imager were to be available. It would also provide redundancy and assure continuing service if the primary imager failed. The only explicit requirements in the NOAA document call for full disk imaging with resolutions of 2km in the visible and 6km in the IR.

1. Option III Auxiliary Imager - Phase-A Study:

A Phase-A study of the auxiliary imager should be conducted prior to Phase-B. The purpose is to develop a data base which is sufficient to prepare the RFP and to prepare staff to monitor the competitive, parallel Phase-B auxiliary imager studies. At this point the in-house knowledge base is inadequate to initiate a good Phase-B contractual arrangement with industry.

2. Option III Auxiliary Imager - New or Modification of GVHRR:

An additional instrument to provide these capabilities could be built based on a new design or on the ATS-6 GVHRR and INSAT heritage. The INSAT VHRR is still in production at ITT and served as the primary basis for the estimates of the auxiliary imager for GOES-N. Significant modification of the instrument in the optics, detectors and signal processing are required in that the INSAT resolutions are 2.75km in the visible and 11km in the IR. Further modifications are required to the INSAT imager to meet the INR requirements of GOES-N. The auxiliary imager can be an upgrade of the GVHRR on the INSAT, but major design changes are needed to incorporate the INR capabilities that are now part of the GOES. These changes would be low risk, but would incur moderate non-recurring expenses.

3. Option III Auxiliary Imager - Double Imaging Rate of Primary Imager and Time Share it With Auxiliary Imager:

This is a proposed alternate approach to achieve the functional capabilities of the auxiliary imager, Enhancement RE-15, with a low cost, light weight modification of the GOES I-M imager (for any spacecraft option) that will provide the full spectral, radiometric, and INR capabilities of the primary imager with enhanced redundancy in the primary imager.

The basic concept is to provide "continuous" full disk capability as well as small sector capability by making the primary imager have twice the coverage rate of the present imager and time sharing the system on a predefined schedule so as to provide full disks every 30 minutes, and have no time discontinuities in the data used for wind determination. (c.f., Section 9.1.4.3 for additional information.)

The imager's coverage rate will be doubled by adding 8 visible detectors to the present 8 detectors (as has been done for the Option III imager already) and activating the redundant IR detectors that are already in the focal plane and adding the necessary amplifiers, multiplexers, etc. This will allow the imager to step 16km north-south after every line rather than the present 8km. The east-west scan rate will remain the same. Assuming that the cooler can be modified to accommodate the extra heat load, the radiometric and geometric performance will be unchanged from the present capabilities. This will, of course, double the data rate from the instrument.

8.4.3.4 Option III Night Visible Operation Recommendations

The sensor is conceived to use a 1000 x 1000 pixel solid-state imaging device with an F/3 optic (6cm aperture). The IGFOV of each element is 2km. The following signal-to-noise performance can be provided:

This sensor would be smaller than the lightning mapper instrument and have better resolution. It may be possible to modify the lightning mapper to provide this capability through a separate focal plane using the same optics. However, the present configuration places the bandpass filter for the lightning event detection in front of the optics to be able to achieve and maintain the narrow spectral bandpass. If the filter remains in this position, then modification of the lightning mapper is not recommended and a separate sensor should be developed. The technology risk is low.

Night visible can be implemented in a low risk technology using solid-state imaging arrays in a separate sensor designed for this purpose. Modification of the lightning mapper is not recommended due to the impact to its implementation.

1. Option III Night Visible Phase-A Study.

A Phase-A study of the night visible sensor should be conducted prior to Phase-B. The purpose is to develop a data base which is sufficient to prepare the RFP and to prepare staff to monitor the competitive, parallel Phase-B night visible sensor studies. At this point the in-house knowledge base is inadequate to initiate a good Phase-B contractual arrangement with industry.

8.5 Control System and Image Navigation and Registration (INR) Design Consideration Recommendations

8.5.1 Introduction and Background

The major GOES-N study issue, considered the significant study shortfall, is the lack of GOES-I flight performance data to substantiate the INR performance concept. Without GOES-I performance data to substantiate the LAS derived INR performance budgets, the GOES-N Option I performance budgets are unproven. In contrast, the Options II and III designs are on somewhat firmer ground due to the experience gleaned from the IUE, SMM, HST spacecraft and the Ultraviolet Imaging Telescope (UIT)/Astro Observatory.

To minimize the design risk associated with achieving INR requirements, the use of proven technology for each element of the design was used as a guideline. As a result, even though the proposed design has never been implemented for a geosynchronous earth pointing spacecraft, the recommended star trackers, reaction wheels, etc. and the design concepts all have been proven on other spacecraft.

Since the Option I spacecraft was defined to be an evolution of the GOES I-M series (which falls considerably short of achieving NOAA's Optional and Enhanced INR requirements), it was decided that the Option II and III control subsystem designs were not to be constrained (except for the use of flight proven elements).

8.5.2 Option I - Control and Pointing System Recommendations

8.5.2.1 Option I - Small Redundant Reaction Wheel for Yaw Control

The Option I spacecraft will retain the basic three-axis, momentum bias configuration of GOES I-M. Two large momentum capacity wheels arranged in a V-shaped configuration provide gyroscopic stiffness and primary control torque capability along the spacecraft pitch and yaw axes. In the event of a failure of either wheel, the remaining yaw control would be inadequate. For redundancy, therefore, it is recommended that a smaller, 2 ft-lb-sec reaction wheel be mounted along the spacecraft yaw axis to replace the yaw component of either of the momentum wheels.

8.5.2.2 Option I - Improved Earth Sensor Noise Characteristics

It is recommended that modifications be made to the GOES I-M earth sensor to improve the noise characteristics by a factor of about 1.4. The noise of the present sensor is quite high as compared to the expected spacecraft end-to-end performance. Predicted performance of the Option I system is slightly improved over the GOES I-M system. All of the improvement is due to the inclusion of an improved earth sensing system in the Option I design which leads to a reduction in attitude stability error.

8.5.3 Options II and III control and pointing system recommendations

Listed in the following table are all of the design changes recommended for Option II, which are also incorporated into Option III along with additional Option III instrument improvements:

Table 8.5-1 Option II/III improvements with respect to Option I/GOES-I

AREA OF CHANGE	IMPROVEMENTS
OPTION II	
STAR TRACKER/GYRO	SPACECRAFT JITTER YAW CONTROL
ZERO MOMENTUM BIAS/REACTION WHEELS	DYNAMIC INTERACTION STATIONKEEPING RECOVERY TIME
OPTICAL BENCH	THERMAL DEFORMATIONS, STRUCTURE/ MODAL FREQUENCY PERFORMANCE
SPACECRAFT MOTION COMPENSATION REPOINTING	REALTIME MIRROR COMPENSATION (FOR ALL DYNAMIC INTERACTION)
INSTRUMENT SERVO - 3° OPTICAL ENCODER	IMPROVED INSTRUMENT POINTING
SOUNDER REDESIGN	THERMAL DEFORMATIONS, STRUCTURAL/ MODAL FREQUENCY PERFORMANCE
BIANNUAL YAW FLIP	IMPROVED COOLER PERFORMANCE*
RECONFIGURED SOLAR ARRAY	MINIMIZE SOLAR TORQUE EFFECTS
OPTION III	
ALL OF THE ABOVE	
INSTRUMENT REDESIGN - IMPROVED INSTRUMENT POINTING 5° OPTICAL ENCODER	THERMAL DEFORMATIONS, STRUCTURAL/ MODAL FREQUENCY PERFORMANCE
INSTRUMENT FOCAL PLANE COOLING REFRIGERATORS	SIGNIFICANTLY IMPROVED FOCAL PLANE TEMPERATURES/DETECTOR PERFORMANCE

* BIANNUAL SPACECRAFT YAW FLIP WILL NOT BE REQUIRED FOR OPTION III BECAUSE A MECHANICAL REFRIGERATOR AND REDESIGNED IMAGER ARE USED

8.5.3.1 Options II and III - Star tracker/gyro inertial reference system

It is recommended that the Option II/III spacecraft utilize an inertially referenced system, using star trackers and very stable gyroscopes to maintain the spacecraft attitude in roll, pitch and yaw. The advantage of this implementation over the GOES I-M earth reference, earth sensor system is a significant reduction in jitter. Also, the pitch axis is maintained parallel with the earth's north-south axis throughout the orbit. However, since this implementation is not an earth reference system, it is more sensitive to orbit errors, requiring better orbit determination. As a result, two remote sites to receive ranging data contained in the processed data stream will be required. These sites could be unmanned or be located at sites that already receive processed data.

1. Options II and III - Three star trackers:

The recommended subsystem utilizes 3 star trackers spaced at 120 degrees around the pitch axis and canted down 35 degrees from the celestial pole. Failure of a single star tracker only causes slight attitude performance degradation; thus, full redundancy is maintained for this configuration. Candidate trackers include the Ball Aerospace CT-601, the Hughes Danbury ASTRA-II, and the Jet Propulsion Laboratory (JPL) ASTROS tracker.

2. Options II and III - Redundant Inertial Reference Units (IRU):

The recommended IRU is the redundant Dual Redundant and Inertial Reference Unit (DRIRU II) which has been flown on a number of spacecraft. The DRIRU II inertial reference unit developed by Teledyne was selected for its excellent drift properties and extensive flight heritage.

3. Options II and III - New attitude control electronics (ACE) equipment:

The ACE proposed for GOES-N is based on the Small Explorer Data System (SEDS) computer developed at GSFC for the small explorer program. The SEDS uses an 80386-based processor with an 80387 co-processor operating at a clock speed of 16 MHz. Data input/output (I/O) functions between the processor and the sensors and actuators are performed using the MIL STD 1773 data bus architecture.

8.5.3.2 Options II and III - Zero momentum bias/reaction wheels

A set of four reaction wheels is the recommended torque actuation system for the on-orbit mode. In contrast to the Option I system, the wheels do not provide a momentum bias to the spacecraft but operate near the zero momentum condition. The wheels are set in a pyramidal arrangement to provide redundancy.

8.5.3.3 Options II and III - Optical bench

It is recommended that a spacecraft designed to accommodate an optical bench (e.g., Hughes HS-601) be utilized for the Option II/III payload. The bench would be made of a low thermal conductivity honeycombed (for stiffness) material which would be loosely coupled to the spacecraft body to minimize thermal and mechanical load paths. The bench is a precision pointed platform on which all attitude sensors and the mission sensors are mounted in close proximity, thereby minimizing alignment variations between the instrument focal plane and the star tracker/gyro system.

8.5.3.4 Options II and III - Closed loop sensor mirror servo control system

It is recommended that the Option I/GOES I-M open loop mirror motion control (MMC) be replaced by a closed loop sensor mirror control system. This uses the realtime error signal sensed by the star tracker/gyro to correct for any higher frequency mispointing errors that cannot be compensated by the control system, resulting in improved pointing and image registration.

1. Options II and III - Feed-forward compensation filter for sounder servo controller:

In order to improve the sounder step and settle performance, a pre-filtering/feed forward compensation scheme is recommended. The purpose of feed-forward compensation is to improve the closed-loop system's slow response (in situations where low bandwidth is required for stability) to achieve faster response to a command signal.

2. Options II and III - Digital sounder servo controller:

It is recommended that the servo controller design be digital. The major benefit of a digital implementation is its ability to be tuned on-orbit. This reduces the risk of degraded servo pointing performance due to structural mode frequency shifts that may result from launch vibration, thermal and/or zero gravity effects.

8.5.3.5 Options II and III - Optical encoder instrument mirror drive systems

As for Option I, the use of optical encoders is recommended for the Option II and III instrument mirror drivers. For the Option II and III sounders and the Option III imager the use of a 5 inch disk optical encoder is recommended. For the Option II imager, which is a derivative of the GOES I-M, a 3 inch disk optical encoder is recommended to avoid forcing a major instrument redesign. Therefore, the optical encoder becomes the sensor of choice for the redesigned instruments of Option II and III due to its improved accuracy and resolution, reduced electronics sensitivity (especially to noise), and reduced cost.

8.5.3.6 Options II and III - Use of Graphite Fiber Reinforced Plastic (GFRP) material in the Option III imager and Option II/III sounders designs

It is recommended that the sounders be redesigned using GFRP material in an attempt to reduce the structural control interaction difficulties found in the GOES-I design. This new sounder design will produce a stiffer instrument that is also much less susceptible to thermal distortion. The mechanical configuration of the new design may employ either a two mirror system or a single mirror two axis scan assembly, depending on the results of future study of these concepts. The new configuration will still have motors and shaft angle sensors on opposing sides of shafts, because it was found that locating them on the same side aggravates stability problems of the servo. The Option II imager, which has a less demanding scan profile than the sounder, will employ the same structure that will be used in GOES-I. In Option III, the imager structure will also be redesigned using GFRP material.

GFRP materials are recommended to raise the lowest frequencies of the structure and increase their separation from the controller bandwidth.

The GFRP design concept was also motivated in part by a desire to minimize thermal effects on instrument pointing. GFRP has a coefficient of thermal expansion that is an order of magnitude less than that for beryllium or aluminum. An instrument redesign employing GFRP material can therefore be expected to exhibit less thermal snapping and cyclic deformation than the GOES-I design.

8.5.3.7 Options II and III - Twice per year yaw rotation

As a means of further lowering the passive cooler operational temperatures by reducing the amount of reflected heat from the sun, it is recommended that the spacecraft be "flipped" about the yaw axis biannually. Large angle slew maneuvers have been performed on all inertial pointing spacecraft and, therefore, yaw rotation is considered a safe procedure.

8.5.3.8 Options II and III - Elimination of solar sail and trim tab

It is recommended that the Option II/III spacecraft not have a solar sail and trim tab, which results in an improvement in the passive cooler performances. Thruster firings will be used about once per day to unload the wheel momentum resulting from the absence of the solar sail and trim tab. These thruster firings will be ~ 0.5 seconds in duration from two 5 pound thrusters; and the improved control system will accommodate these firings without an interruption in service. The solar array will be redesigned to move the center of pressure closer to the spacecraft body to reduce the solar torque effect.

8.5.3.9 Options II and III - Continuous stationkeeping

It is recommended that the spacecraft inclination be maintained within tight limits by increased thruster firings for continuous stationkeeping, thereby minimizing the magnitude and rate of change of the required IMC correction. As a result, larger instrument focal plane arrays can be used as a means of minimizing the time required for fabrication and alignment.

8.5.3.10 Option III focal plane refrigerators

A Stirling cycle cooling system modeled after the units planned for the AIRS instrument on EOS is recommended for the Option III sounder focal plane cooling. One pair of these units operating simultaneously is required for normal operation. For redundancy two pair are recommended.

8.5.4 Recommended Pre-Phase-B additional studies/research

8.5.4.1 Recommended Studies

The following list summarizes the INR related studies/investigations that are recommended to be completed before the start of the Phase-B effort:

- Dynamic interaction
- Attitude control - ephemeris uncertainty
- Attitude control
- Semiannual 180 degree spacecraft yaw flip
- Servo performance - two mirrors, GFRP structure
- Optical bench
- Wheel mounts

A brief description of the purpose and expected results of each study is provided below:

1. Dynamic Interaction Study:

The purpose of the dynamic interaction study is to determine the impacts to the spacecraft controller resulting from a S&R interferometer, a mechanical refrigerator, and solar pointing instrument motion. A primary effort in this study is the development of a spacecraft structural model, which can then be tailored to determine the dynamic interaction effects of a S&R, refrigerator and solar pointing instrument motion.

The primary concerns with the S&R interferometer are the potential for thermal snapping and potentially undesirable modal frequencies. For the mechanical refrigerator, the normal pumping motions would be investigated to determine the impact on INR performance. Similarly, the motion from solar pointing instruments needs to be evaluated to determine the effects on the spacecraft pointing.

2. Attitude Control - Ephemeris Uncertainty:

The effects of orbit determination uncertainty need to be further analyzed to determine the performance degradations resulting from ranging at candidate sites selected by NOAA. This analysis would be done parametrically to assess the uncertainty based on the use of different sites and different ranging accuracies associated with different implementations.

The placement of thrusters to eliminate/minimize contamination of both instruments and coolers, while providing the capability to unload the daily wheel momentum buildup, needs to be carefully evaluated. As a part of this effort, the capability to use the daily wheel unloadings to also provide continuous stationkeeping would also be examined. If this is determined to be impractical, separate thruster firings for nearly continuous stationkeeping would be evaluated.

If the use of thrusters for continuous stationkeeping is not feasible, it will then be necessary to evaluate the use of resampling as a means of providing fixed grid images with a large focal plane. That is, either continuous stationkeeping to keep the inclination within tight bounds to minimize IMC rate changes or resampling is required to support the IMC corrections needed for fixed grid images when a large instrument focal plane is used. Note that resampling will be studied only if some form of continuous stationkeeping is not practical.

However, it is strongly recommended that resampling also be evaluated, because of its potential to correct or mitigate unexpected problems. An investigation of resampling would include an assessment of how to best combine the INR resampling requirements with current NWS resampling activities to provide different map projections for users. IMC rate changes or resampling is required to support the IMC corrections needed for fixed grid images when a large instrument focal plane is used.

3. Attitude Control:

The needed attitude control studies are:

- Simulations of housekeeping/stationkeeping maneuvers to ensure that recovery times are a fraction (¼ or less) of an hour
- Further investigation of an Attitude Control System (ACS) interferometer to determine if this is practical
  (e.g., geographical locations to mitigate weather effects, obtaining a frequency allocation) and a more cost effective approach than star detectors; if it is, then the study will provide an evaluation of an interferometer for providing the ephemeris
- Refinement of the impacts of magnetic control on spacecraft weight and power
- Detailed definition of the control system and instrument interfaces
- Description of the ACS computer and system bus

4. Semiannual 180 degree Yaw Axis Flip (Star availability):

This procedure to provide the lowest passive cooler temperatures, requires that an in depth analysis of star availability in both the northern and southern hemispheres be performed to ensure the required availability of stars.

5. Servo Performance for a Two Mirror, GFRP Instrument:

An analysis of the servo performance that is obtainable for an instrument with two mirrors and designed with GFRP is needed. This analysis would first develop a structural model from which the overall servo performance could be determined. The thermal performance of the new structure also needs to be determined.

6. Performance of an Optical Bench:

The determination of the performance of an optical bench requires that both a structural and thermal model be developed for the proposed types of mountings.

7. Evaluation of Wheel Mounts:

A tradeoff comparison study between wheel soft mounts and magnetic bearings is required. This study will result in the selection of the best reaction wheel mounting scheme for GOES-N considering performance, risk and cost.

8.5.4.2 Recommended Research

In order to achieve the within-frame and frame-frame registration requirements of 14 μr a significant change in the instrument design will be required to overcome the current error sources. Study results have shown that the primary error in the within-frame registration is due to the instrument pointing and for the frame-frame registration is due to thermal variations.

One approach to reduce both these errors is to provide real time error position sensing through the instrument. This technique is an adaption of the approach used on missions that require very accurate pointing/registration such as HST. The adaption is necessary to extend the technique from fixed pointing applications (e.g., staring at a star) to imaging the earth. Conceptually, this approach continuously determines the difference between an earth reference signal (e.g., a beacon) at a known location and the expected pointing position of the instrument with respect to that reference signal. By nearly continuous monitoring of the measured (observed) difference between the known signal and the current pointing pos... a "continuous" pointing error can be developed that is referenced to the earth. This error generat... is analogous to the generation of a servo error using an Inductosyn encoder or optical encoder, except that the feedback path and error signal are now referenced to the earth and include the pointing error. Like any closed loop servo, errors in pointing due to many causes (e.g., thermal effects, instrument pointing) will be attenuated in near real time.

For the near term, it is recommended that a research and development effort be initiated for an instrument concept with the capability to nearly continuously sense the position of an earth beacon at a known location and determine the error in pointing, if any, with the desired pointing position. One approach based on current technology would use a 1000 x 1000 or a 2000 x 2000 visible detector array in the instrument to continuously monitor the location of a beacon. The array(s) in the near term would not be used for imaging.

For the long term, the development of large visible detector arrays to both image and be the sensor portion of the pointing error detection should be undertaken.

8.6 Space Environment Monitor (SEM) Recommendations

8.6.1 Space Environment Monitor (SEM) Overview

The GOES I-M SEM includes a magnetometer, an EPS, and an XRS. Options I and II contain a magnetometer, an improved EPS, an XRS, and an SXI. Option III is configured the same as Options I and II with the addition of an SVM/HαI and an EUV.

The requirements for the magnetometer and the full disk XRS are unchanged from the specified performance for GOES-I. Because the existing instruments are expected to meet those requirements, no effort has been devoted to alternate instrumentation approaches.

Addition of the SXI, the EUV Spectrometer, the SVM/Hα to GOES-N would result in a dramatic increase in the solar observation capabilities of GOES-N relative to current spacecraft. The spacecraft solar observation platform was sized to accommodate the core XRS and SXI instruments and one other significant (i.e. 20kg class) solar observing instrument. The SVM was arbitrarily selected for inclusion in the Option III spacecraft model because more definitive information was available at the time than for the other solar observations and because it appeared feasible to incorporate an Hα imaging mode in the same instrument, thereby partially covering at least one additional requirement.

8.6.2 Options II and III - Magnetometer system considerations

GOES-N will undoubtedly have more sources of magnetic interference; therefore attempts should be made to reduce the signature of as many sources as possible. Partly for this reason, it is recommended that Option II and III spacecraft magnetic torquers be replaced with thrusters for reaction wheel unloading. A six meter magnetometer boom is also recommended. At six meters, and with no magnetic torquing, the magnetometer data on GOES-N should be free of any significant spacecraft field contamination for the first time in any GOES spacecraft.

In order to avoid problems with multiple boom segment deployment and stability, Astromast style booms are recommended.

Long deployable booms cause concern with regard to the stability of the frame of reference for the magnetometer and with the dynamics of the flexible spacecraft structure. Therefore a study of interactions of the attitude control subsystem with a flexible spacecraft structural model is recommended.

The spacecraft level zero field magnetic test requirement should be restored, at least for the qualification spacecraft test. Boom and sensor packages must be acceptance tested separately in a zero field test facility (including post perm/deperm tests) to verify the magnetic stability of the sensor assembly.

8.6.3 Options II and III - Solar pointing platform - Attitude Control System Interactions

The Option II and Option III attitude control system concept, with its on-board sensing and correction of spacecraft motion, should allow stepping the solar pointing platform by the required 16 or 32 arc minutes to allow the image of the solar corona to be generated, followed by an immediate return to the solar disc monitoring mode. The impact to the XRS and the SVM should be negligible. However, the dynamic response of a flexible spacecraft model to this stimulus has not been modeled, nor has the stability of the system even in the absence of such stimuli.

Recommended with regard to the solar pointing platform are studies including: preliminary electromechanical and structural SPP designs, stability and pointing performance analyses for both earth and solar viewing instrument platforms, and development of interface specifications.

8.6.4 Options II and III - Energetic Particle Sensor (EPS)

Perform EPS energy deposition analysis in the current telescope/dome/High Energy Proton and Alpha Detector (HEPAD) to confirm logic, thresholds and energy/atomic number separation performance for the $Z \geq 3$ channels. Study a separate time-of-flight EPS sensor to monitor alpha particle flux for 30keV/n to 800keV/n alpha particles.

The Medium Energy Proton/Electron Detector (MEPED) which is included to provide coverage above 30keV only has two defined directions. The rather broad acceptance angle of the MEPED insures the integrity of the measurement, i.e., there are no broad directional components of the population which are not sampled by the instrument, but the pitch angle resolution obtained is correspondingly coarse. This issue should be revisited by the NOAA to clarify the requirements for spatial resolution in this energy regime.

8.6.5 Option III - Solar Vector Magnetograph (SVM)

The SVM is by far the most technically challenging of the enhancements under consideration for the GOES-N SEM. Several design requirements involve technical requirements at the state-of-the-art for optical system design. A Phase-A study is recommended for the candidate instruments considered.

All measurements must be taken within the spectral bandwidth of the magnetically sensitive resonance line, which requires realization of very narrow spectral bandwidth filters in the measurement instrument. A number of alternative approaches have been proposed, some of which have been flight and/or ground proven, and others more developmental. A more detailed study should be conducted to select the best cost/risk/performance alternative.

The Solar Heliospheric Observatory (SOHO) Michelson Doppler Imager (MDI) fits into the allocated volume, but significantly exceeds the allocated weight. A more thorough modeling of the optics and electronics associated with the SVM for GOES (which does not require all of the optics and electronics included in MDI) must be done before committing to a system design with the weights allocated as in the spacecraft model.

8.6.6 Option III - Extreme Ultraviolet (EUV) Spectrometer

The indication is that a multiple sensor package can be defined which would be compatible with the weight and volume available as a replacement for the SVM. An extensive SVM/HαI development in-flight calibration program would be necessary to achieve the 5% calibration requirement. If SVM/HαI cannot be developed, the EUV spectrometer provides a fallback sensor.

In view of the lack of confidence in achieving the required absolute calibration accuracy of the SVM/Hαl, it is recommended that the EUV requirement for GOES-N be addressed by a single small grazing incidence spectrograph covering the spectral range from perhaps 100 to 1200Å. A combination of stellar calibration and sounding rocket under-flights would be used to maintain the absolute accuracy. A program to develop small, low power, reliable in-flight calibration sources to enable improving the absolute accuracy of EUV measurements (±5%) is recommended.

8.6.7 Options I, II, and III - X-Ray Sensor (XRS)

Confirm in-flight performance expectations on GOES-I. Develop concepts for boresighting the XRS to other solar observing instruments.

8.6.8 Options I, II, and III - Solar X-Ray Imager (SXI)

1. Perform an SXI detector trade-off study to identify the preferred approach.
2. Prepare a specification for the SXI grazing incidence mirror and obtain cost/schedule quotes from potential suppliers.
3. Perform preliminary SXI thermal/structural design and materials selection for metering structure and evaluate thermal effects on optical system performance.
4. Perform preliminary SXI data processing electronics design and update power estimates.
5. Update SXI mass estimates.

8.6.9 Space Environment Monitor (SEM) - System Considerations

Substantial additional analysis is necessary to predict quantitative performance expectations for the instrument concepts in such areas as (1) the sensitivity, spectral resolution, total spectral range and calibration accuracy of the EUV Spectrometer; (2) sensitivity, MTF, signal processing analysis and algorithm validity analysis for remotely sensed solar magnetic fields (and Hα images) for the SVM/Hαl; (3) atomic number and energy band discrimination capability and contamination analysis for the desired heavy ion analysis in the EPS; and (4) detailed optical performance analysis and detector performance and reliability trade off for the SXI. In most areas, however, the desired performance levels are comparable to or less than that achieved by or specified for the prototype instruments which have been surveyed. A notable exception is the absolute calibration accuracy of the solar EUV monitor.

8.7 Search and Rescue

8.7.1 Options I, II, and III - Search and Rescue

User identification embedded in the distress beacon transmission relayed through the GOES spacecraft will provide information that might help in pinpointing an area where the distress beacon was activated. But without a position location capability (or coordinate data embedded in the beacon message derived from a navigation system), determining the distress beacon's position would still require a Soviet Ministry of Merchant Marine (MORFLOT) Search and Rescue Space System (USSR)/Search and Rescue Satellite (COSPAS/SARSAT) flyby.

The desire to reduce lost time waiting for a COSPAS/SARSAT passby to locate an active distress beacon is the reason for providing a location capability on geosynchronous spacecraft. However, geosynchronous spacecraft are not the total answer. The zero elevation angle for geosynchronous spacecraft occurs at about 80 degrees latitude, meaning that polar coverage cannot be provided from geosynchronous orbit. Three geosynchronous spacecraft will provide worldwide equatorial coverage, but on the order of six spacecraft would be needed for adequate coverage at latitudes above 60 degrees. An alternative to using geosynchronous spacecraft is to deploy a constellation of low earth orbit dedicated COSPAS/SARSAT spacecraft to provide more frequent coverage. Another, but less desirable, alternative is to require that vehicles have on-board navigation systems interfaced to the distress beacon transmitter providing updated position data. In the event the distress beacon is activated, the latest position would be available to rescue teams.

8.7.1.1 Search and Rescue Interferometer

The S&R interferometer was not included in the Option III cost analysis. It was studied for technical feasibility only.

An interferometer was proposed for use on geosynchronous spacecraft. NASA Technical Report 2907, ***Geostationary Position Location Alternatives for 406 MHz Distress Beacons***, dated March 1. 1990 describes an interferometer requiring two booms providing ten meter long orthogonal baselines, each with two antennas to receive distress beacon signals. An associated on-board electronics package would compute the difference in phase between the signals received by the various antennas. The phase information would be downlinked to the S&R system receive station on the ground for computation of the position of the transmitting distress beacon and distribution of the position information to the United States Mission Control Center (USMCC). The interferometer described in the report would provide a position location uncertainty of about 50 kilometers at the subsatellite point, with the uncertainty increasing with latitude. However, by averaging phase difference information over multiple distress beacon message transmissions, the position uncertainty would be reduced by the square root of the number of messages over which the measurement is made.

A follow-on NASA study, ***GOES-N Search & Rescue Interferometer Feasibility Study***, dated January 14, 1991 investigated the feasibility of implementing an interferometer on the GOES-N spacecraft. Quoting from the conclusions presented in this study, "... A zero momentum active ACS for GOES-N can accommodate the necessary appendages for the S&R interferometer. There does not seem to be any major show stoppers that would prevent the S&R interferometer implementation on the GOES-N with the active ACS option [Option II and III spacecraft]. This does not imply that it is easy to do. A conclusion that may be drawn from this study is that the GOES-N mission is already a very difficult and challenging one, and the addition of the S&R interferometers does not add substantially to this challenge. Further study is recommended to refine the system parameters and spacecraft impacts in terms of power, size, weight, and antenna/Astromast stowage configuration..."

As a result of discussions at the third quarterly GOES-N study review, a S&R interferometer was incorporated into what was to be an additional spacecraft option (Option IIIA) to be studied after the GOES-N study was completed. As a result of that agreement, the st dy team conducted an independent analysis of the position location problem and developed an alternative configuration that did not require long Astromast booms. The position location accuracies computed for this configuration were on the same order as those in the NASA study.

The feasibility of the 406 MHz S&R system has been adequately proved via experiments conducted using the GOES-7 spacecraft. The use of interferometers for determining the location of distress beacons from geosynchronous orbit, on the other hand, has not been tested. The conceptual studies performed to date indicate that the technique should work, and that more study and a flight experiment are warranted. The study team believes, however, that the GOES program, with its stringent pointing and stability requirements, is not the appropriate vehicle for this research. Furthermore, before proceeding with additional development of an interferometer, a tradeoff analysis should be performed to determine whether or not a constellation of small, dedicated, low earth orbiting satellites, which would provide global coverage would not be a more economical solution.

8.8 Weather Facsimile (WEFAX)

8.8.1 Options II and III - Weather Facsimile (WEFAX) Second Analog Channel

The push worldwide is to phase out analog WEFAX in favor of digital WEFAX, with the late 1990's as a target date for NOAA. The second analog WEFAX channel therefore, appears to be a weak requirement for the GOES-N time-frame. NOAA should reexamine this requirement.

8.8.2 Options II and III - Weather Facsimile (WEFAX) Eclipse Operation

Requirement for operation through eclipse may be very weak. NOAA should give this requirement thorough consideration because of its large impact on the spacecraft power generation and storage system. Any reduction in eclipse operation will result in spacecraft platform weight and cost reduction.

8.8.3 Options II and III - Weather Facsimile (WEFAX) Transmitter and Spare Unit

Hughes Aircraft Company (HAC) selected a separate transmitter per channel approach and LAS selected a single transmitter approach. Both approaches have their merits although it appears that the single transmitter approach is better for four channels from a weight and spacecraft complexity standpoint. For this reason we baselined a single transmitter plus spare for the cost study. If the second analog channel is dropped, the difference between the two alternatives would be less. Our recommendation is that it should be left to the spacecraft manufacturer to decide which approach to implement after appropriate analysis and project office review.

We would also recommend tightening the S-band receive antenna gain-to-temperature ratio (G/T) specification from the GOES-I value of -25dB/K to the GOES-I predicted value of about -15dB/K. This value appears to be easily met with current technology.

8.9 Data Collection Systems (DCS)

8.9.1 Options I, II and III - Data Collection Systems (DCS) Channel Interference

Locating DCS interferers from geosynchronous orbit would be a difficult undertaking, requiring an interferometer approach similar to that proposed for the S&R system. Given what appears to be a low priority placed on locating interferers and the large effort that would be required to implement a location scheme, it was decided not worthwhile to pursue interference location.

8.9.2 Options I, II, and III - Data Collection Platform Response (DCPR) Link Performance and System Impacts

The principal change to the DCS in the GOES-N time frame is an increase in the number of higher rate (1200 bit per second) DCP requiring 3kHz-wide channels. A 3dB increase in DCPR channel downlink EIRP, from 150 milliwatts to 300 milliwatts, is recommended so as to provide increased margin for the 1200bps platforms. This should require very little modification to the existing GOES-I DCPR design and should be incorporated in all three GOES-N options.

The study team examined the possibility of assigning the 1200bps platforms to a separate band about 60kHz wide, suitable for twenty 3-kHz channels. This separation would reduce the potential adjacent channel interference between the 100bps and 1200bps platforms. This band could be accommodated between the WEFAX channel(s) at 1691MHz and the CDA telemetry channel at 1694MHz.

In the latter stages of the GOES-N study, we learned that the performance of the DCS platform response channel (DCPR) suffers from degradation due to adjacent channel interference and intermodulation distortion. The study team examined a technique for reducing intermodulation levels in the DCPR channel. The technique consists of introducing a carrier at saturation into the channel, with the carrier appropriately separated from the DCPR signals. The effect of the saturated carrier is essentially to generate the intermodulation products around it, suppressing the intermodulation products within the DCPR band. One method of implementing this concept would be to combine one of the WEFAX channels (at saturation) with the DCPR band. This would have the benefits of not only reducing intermodulation product levels in the DCPR band but would also eliminate the DCPR transmitter and spare. The effect on the WEFAX signal would be about 0.3dB.

We recommend that the effects of adjacent channel interference and intermodulation distortion be measured for the existing DCS to obtain a better estimate of the degradation for use in determining required improvements for the GOES-N spacecraft.

The principal changes to the DCS system at the CDA will be additional DCS Automatic Processing System (DAPS) ingest equipment to support the growth of 300 and 1200bps DCPs and the installation of additional user-provided demodulators if new channels are activated.

8.9.3 Options I, II, and III -- Data Collection Platform Response (DCPR) Channel Consolidation with a Weather Facsimile (WEFAX) Channel

Multiplexing of the DCPR downlink with a WEFAX signal should be studied because of its potential for significantly reducing the effects of intermodulation distortion effects within the DCPR band. With proper carrier spacing, the power level of intermodulation products within the DCPR band would drop by about a factor of ten with a negligible effect on WEFAX channel performance. An additional benefit of implementing this approach is the elimination of the DCPR transmitters, saving weight, space and prime power.

8.10 Products, Process, and Communications

8.10.1 Options I, II and III - Multiuse Data Link (MDL) and Telemetry

The MDL implementation on GOES-I provides no redundant transmitter. Redundant transmitters are baselined for th GOES-N spacecraft. The S-band multiplexer is expanded to provide a port for the MDL output signal, reducing transmission line losses about 2.6dB compared to the GOES-I implementation.

The multiplexing of on-orbit telemetry data on the MDL link is recommended. This would eliminate the CDA telemetry transmitters on the spacecraft and would permit increasing the DCPR channel bandwidth if additional channels are desired (e.g., to provide a separate band for 1200 bps channels). For Option I, an on-board multiplexer would be required to combine the SXI, LPS, and telemetry bit streams, as well as demultiplexers at Boulder, the SOCC, and the CDA. The GOES I-M MDL demodulator should be usable with minor, if any modification. In Options II and III, an on-board multiplexer is required to combine data streams from the SEM instruments. Thus, the impact of adding telemetry data to the MDL is an additional multiplexer (and demultiplexers on the ground) port.

As in GOES I, redundant . 3N transponders are included in the GOES-N configuration for transfer orbit and emergency operations. It is recommended that the output power of these transponders be increased from 1 watt to 2.5 watts to provide increased link margin.

The telemetry and command (T&C) system was not analyzed to any extent during the survey period. However, feedback from the GOES-I team indicates that the T&C system has reached the full capacity point; few, if any, spare commands and few spare telemetry points are available for expansion. An expanded command set is recommended for GOES-N. An expanded telemetry system with more available telemetry points, a longer minor frame, and an increased telemetry rate is also recommended to provide greater flexibility.

8.10.2 Options I, II, and III - Sounder Data Link (SDL) and GOES Variable data format (GVAR) Links

The imager and sounder data rates proposed for Options II and III are about a factor of five higher than for Option I, and an auxiliary imager is proposed for Option III. The use of data compression algorithms with forward error correction coding and bandwidth-efficient modulation techniques will be necessary to operate within the allocated frequency bands.

Elimination of the processed sensor data relay link, alternately called the GVAR or PDR link, should be studied. Elimination of this link would require direct reception of the raw imager and sounder data at the SOCC and the GVAR processing at the DUS at the World Weather Building. GVAR data could still be made available to users on a non-real-time basis via magnetic tape or perhaps even real-time via the AWIPS as a separate service provided by the satellite services contractor. Alternatively, GVAR users could receive the raw data and perform the GVAR processing themselves.

Another possibility that should be studied is to consolidate the SDL and the MDL (including the on-orbit telemetry) onto one QPSK carrier. The imager data could be transmitted via the I channel and the sounder plus MDL data via the Q channel. The obvious benefit would be the reduction in spacecraft complexity from the elimination of the MDL transmitters. Another benefit is that the SDL center frequency could be moved to provide a wider guard band between the data downlink and the 1660-1670MHz Radio Astronomy band. In Options II and III, SDL and MDL link consolidation may be viable only if the GVAR link is eliminated, due to the higher imager and sounder data rates. Additional study is recommended.

8.10.3 Options I, II, and III - Impact of Change from S-Band to X-Band

It was commented at the Fourth Quarterly Review that the GOES program may have to move from its present S-band allocation to X-band (7 to 10GHz), as the TIROS program appears to be doing. If serious consideration is being given to such a move, it is critical that the implications be analyzed. Another alternative could be the incorporation of a GPS receiver into the GOES-N spacecraft to provide ranging information. One advantage of using GPS is that orbit determination computations could be performed directly by the on board computer (OBC). Use of Advanced Tracking and Data Relay Satellite Systems (ATDRSS) or GPS would eliminate the need for terrestrial ranging stations, reducing system operations costs.

8.10.4 Options II and III - Controls: Orbit Determination Accuracy

The attitude control system being proposed for Options II and III requires a two-station ranging capability to provide sufficient orbit determination accuracy. This requirement was not stated until the end of the study effort and, as a result, was not analyzed. A study is needed to develop alternative ranging system configurations and their cost. Implementation of this two-station ranging may eliminate the need for using the GVAR link for ranging. The use of the NASA Advanced Tracking and Data Relay Satellite Systems (TDRSS) spacecraft to provide ranging services should be studied. These new spacecraft are being designed with the capability to communicate with geosynchronous spacecraft.

9.0 INSTRUMENT DESIGN CONSIDERATIONS

9.1 Imager Configurations

9.1.1 Improved GOES-I Imager (Option I)

When the study team defined the three options presented in this report as strawman spacecraft systems, the concept underlying the Option I spacecraft was that of a minimal cost program based almost exclusively on the GOES I-M heritage. This implies that GOES-N would be virtually identical to GOES-M in all respects, with changes only where cost and efficiency improvements could be made. The assumption is therefore that GOES-M instruments will meet the core requirements, which in most cases are those currently specified for GOES-I. There have been, however, some problems with the GOES-I development, the *de facto* heritage for this study, which led to broadening the Option I concept to allow instrument changes where the fundamental design approach is not changed and where the changes do not alter the spacecraft interface, i.e., power, weight, volume, footprint, telemetry, etc.. The changes to be incorporated were subjects of many of the study tasks, and so could not be specified until the completion of those studies. However, as reported in this and other sections of this final report, they included such things as relocation of the east-west shaft encoder to the motor side of the shaft, a two-point mirror mount,the use of optical encoders in lieu of inductosyns, the use of different structural materials and changes which might be identified which could offer improvement of the signal-to-noise ratio of the instruments.

Studies of the effects of relocation of the east-west shaft encoder and incorporation of a two point mirror mount were carried out with (surprisingly) negative results; i.e., those changes did not improve the pointing performance of the instrument scanner. The optical encoder trade study (Section 10.4.2.2.1.2) produced more positive results, but, based on significant non-recurring costs, this modification was deferred to the Option II instrument. The redesign of the structure using low temperature coefficient materials (Section 10.4.1.3.1) offers significant improvements in pointing performance, but violates the guideline that the Option I instrument is to be essentially the same design concept as GOES-I. This modification is deferred to the Option III imager. The studies have identified the focal plane temperature as the principal driver of signal-to-noise performance.

One modification which is recommended and not incorporated currently in the GOES I-M program is positive temperature control of the aft optics. This change could be incorporated with likely negligible impact to the spacecraft interface, and may ultimately be required to approach the specified performance requirements for channel-to-channel co-registration. Overall image quality and calibration accuracy can be improved by dc restoring on every available space look, rather than at two minute intervals as was planned for GOES-I. The GOES-I bus has been modified to dc restore on every other space look when imaging a full disk and optional space look every 9.2 and 36.2 seconds on smaller frames. This will significantly reduce the effect of 1/f noise, and is recommended for the Option I imager. The AOCE software must be modified to eliminate discontinuities in the IMC signal during scan turn-around. It is assumed that this modification will be incorporated at some point in the GOES I-M program. It is also assumed that at some point in the GOES I-M program a stable, full time coherent error integrator will be developed. This may be necessary to achieve within frame registration requirements at end-of-life.

Improvement of the NEΔT for the imager through lower focal plane temperature should be achievable in Option I by changing the surface finish of the Astromast boom to a specular, low emissivity reflector. Analysis shows that this change alone results in an operating temperature advantage of nearly 10K to a control temperature of about 92 K for either the imager or the sounder. The detector noise limited performance at the 92K control temperature would result in improved NEΔT at all wavelengths, potentially by a factor of two relative to GOES-I.

Although they were not identified as funded cost-cutting or efficiency studies early in the program, several suggestions have arisen during the course of the program that should be incorporated in the GOES-N imager. These are discussed in Section 7, and include improved procedures for accomplishing channel-to-channel alignment in instrument level thermal vacuum test through remote adjustment mechanisms and potential use of flex pivots in the east-west scan axis.

Figure 9.1.1-1 shows the general instrument arrangement and important spacecraft interface information for the Option I imager. Although the concept had been to maintain the spacecraft interface unchanged, the weight allocation allows modest growth over the GOES-I instrument to accommodate the changes recommended. The remainder of the information in Figure 9.1.1-1 reflects the status of the GOES-I imager.

The optics and focal plane arrays for the Option I imager are identical to the GOES-I imager. Collected light is spectrally separated through dichroic beam splitters and individual filters to 1 visible and four IR focal planes, with detector arrays in each focal plane acting as field stops. All individual focal plane arrays are required to be co-registered in object space, placing stringent requirements on the stability of the complex aft optics. Figure 9.1.1-2 shows the required superposition of focal plane arrays in object space for the Option I imager. The redundant IR detectors are realized by utilizing linear detector arrays of four elements (two elements in the case of the 8km IFOV channel 3) and only utilizing half of them at any time. The eight visible channels, as in GOES-I, are not redundant in the Option I imager.

9.1.2 Seven-band Imager (Option II)

In the progression of cost and complexity of the successive spacecraft options, the principal improvements incorporated in the Option II spacecraft system are:

1. the elimination of the solar sail to improve the instruments' passive cooler operation and
2. the improvement of system INR performance through a zero momentum, stellar referenced spacecraft attitude control system (Section 10 is for details of these changes), and
3. the incorporation of a high resolution sounder, as described later in this section.

Changes to the GOES-I imager were limited to those that could be incorporated at modest cost to provide some of the additional performance requested or to provide significant performance improvement. The design concept was therefore not changed. Those additional channels requested by NOAA which can be realized with uncooled detectors, i.e., the 0.86μm channel (Si detector) and 1.65μm channel (InGaAs detector), are added since that change does not impact the cooler design and performance and has relatively small physical impact on the instrument. In the area of pointing performance of the instrument, the studies indicate that the single most productive change, short of a complete structural redesign of the instrument, is incorporation of optical encoders in lieu of the inductosyns used in GOES-I scan mechanism. (3 inch diameter encoder discs are modeled to be compatible with the existing scan drive structure).

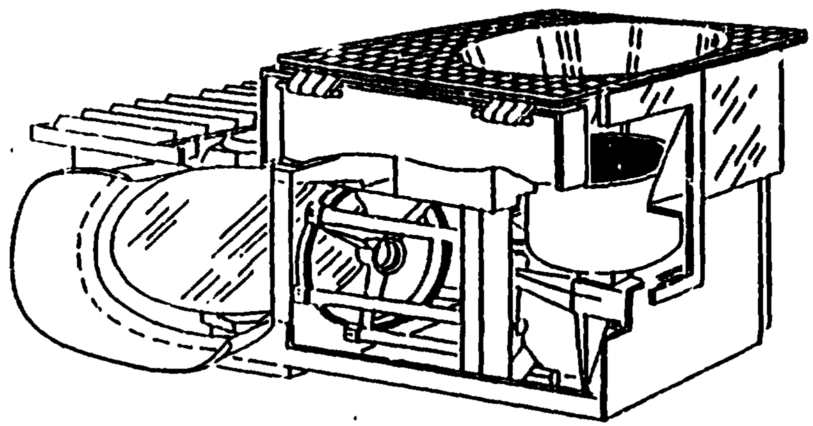
As stated before, the elimination of the solar sail and the incorporation of the half-yearly 180 degrees yaw maneuver discussed in Section 10 yields a high degree of confidence that the 85K operating temperature can be achieved. In fact, the study results promise that further work in the cooler area is justified to achieve even lower operating temperatures without resorting to mechanical coolers.

Figure 9.1.2-1 shows the spacecraft resources allocated in the cost model. Sensor module physical dimensions are identical to the Option I imager, while the electronics module has been slightly enlarged to accommodate the additional spectral channels. It is estimated that either version could be built within the same allocated weight. Power is increased modestly to accommodate the additional spectral channels.

Figure 9.1.2-2 shows the added spectral channels in object space. The two additional channels are made redundant in the cost model, following the pattern for the 4km IFOV cold IR channels which are unchanged from Option I. The visible channels are still not redundant in this model, but it is highly recommended that the temporal performance improvements which could be realized by incorporating the eight additional detectors and powering all detectors be investigated if the Auxiliary Imager of the Option III system is not incorporated.

9.1.3 Advanced Imager (Option III)

The Advanced Imager is conceived as a totally new instrument design with the capability to provide all of the additional spectral bands requested by NOAA, in most cases at the requested spatial resolution, and to provide significant improvements to the pointing performance, channel-to-channel co-registration and thermal stability of the sensor module. While the instrument is considered a totally new design, it has several design features which address limitations in the GOES-I design approach when the stringent requirements for GOES-N are imposed. These differences form the basis for the discussion of the proposed Advanced Imager.



GENERAL CONFIGURATION: GOES-I
- SINGLE MIRROR SCANNER
- 1 VISIBLE, 4 IR BANDS
- SEPARATE FOCAL PLANES (BEAMSPLITTER APPROACH)
- IR COOLER-RADIATIVE 92K (LOW EMISSIVITY ASTROMAST)
- AVERAGE/PEAK POWER 130/162 W
- MOUNTING FOOTPRINT
  - SENSOR: 46X116 cm
  - ELECTRONICS: 38X66 cm
  - POWER SUPPLY: 16X20 cm
- TOTAL WEIGHT 125 kg
- TOTAL VOLUME 0.631 m^3

FIGURE 9.1.1-1
Option I Imager Configuration

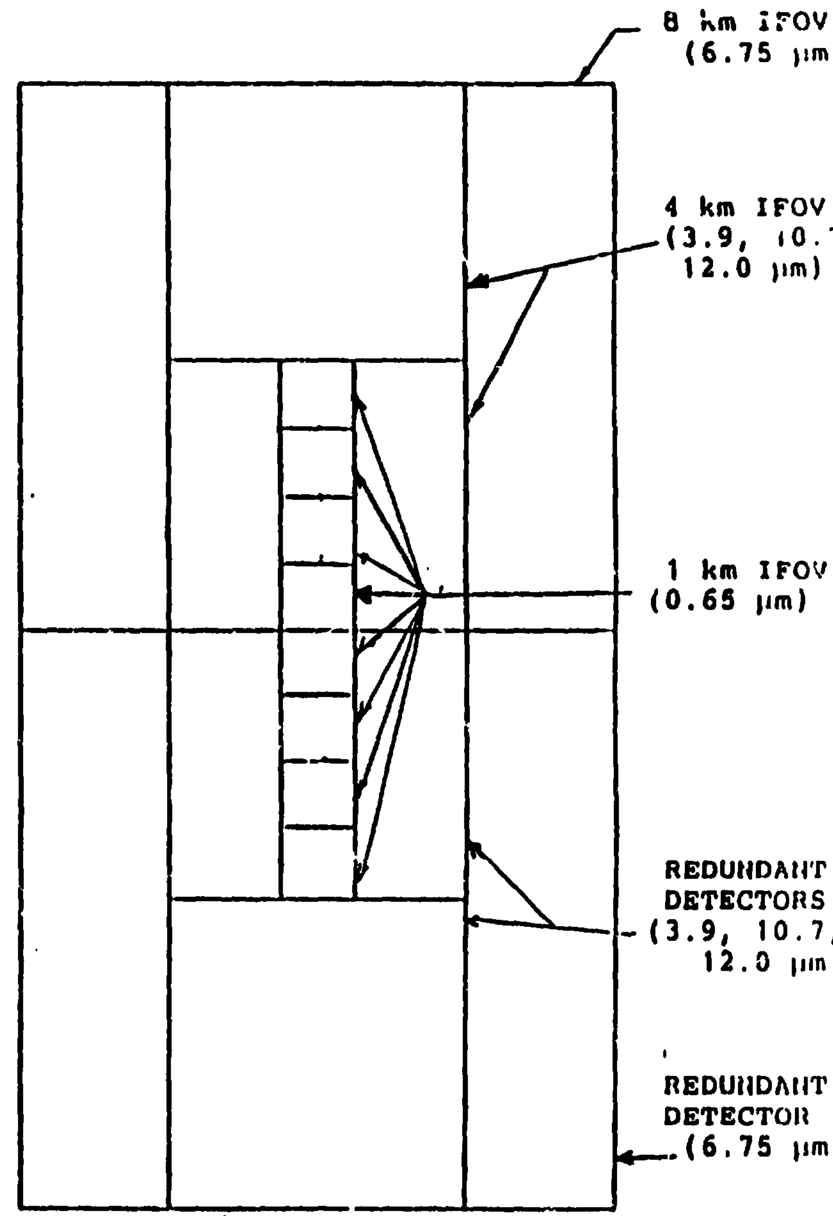
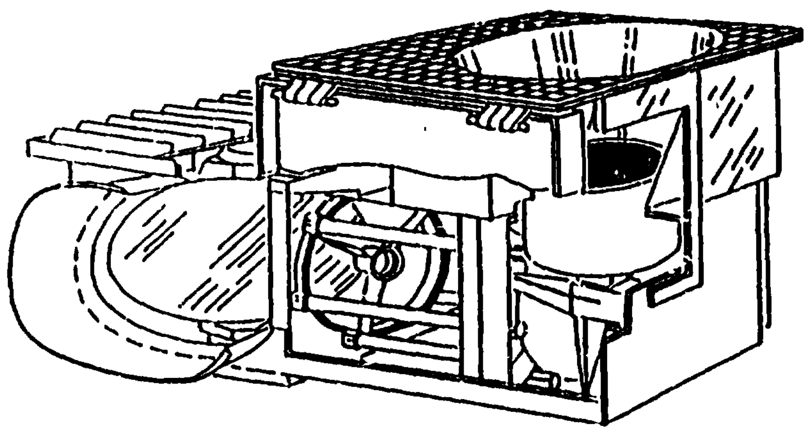


FIGURE 9.1.1-2
Option I Imager Focal Plane Arrays



GENERAL CONFIGURATION: GOES-I
- SINGLE MIRROR SCANNER
- 3 VIS/NIR, 4 IR BANDS
- SEPARATE FOCAL PLANES (BEAMSPLITTER APPROACH)
- IR COOLER-RADIATIVE 85K (NO ASTROMAST, 180° YAW EACH 1/2 YEAR)
- AVERAGE/PEAK POWER 135/167 W
- MOUNTING FOOTPRINT
  - SENSOR: 46X117 cm
  - ELECTRONICS: 38X74 cm
  - POWER SUPPLY: 16X20 cm
- TOTAL WEIGHT 125 kg
- TOTAL VOLUME 0.639 m^3

FIGURE 9.1.2-1
Option II Imager Configuration

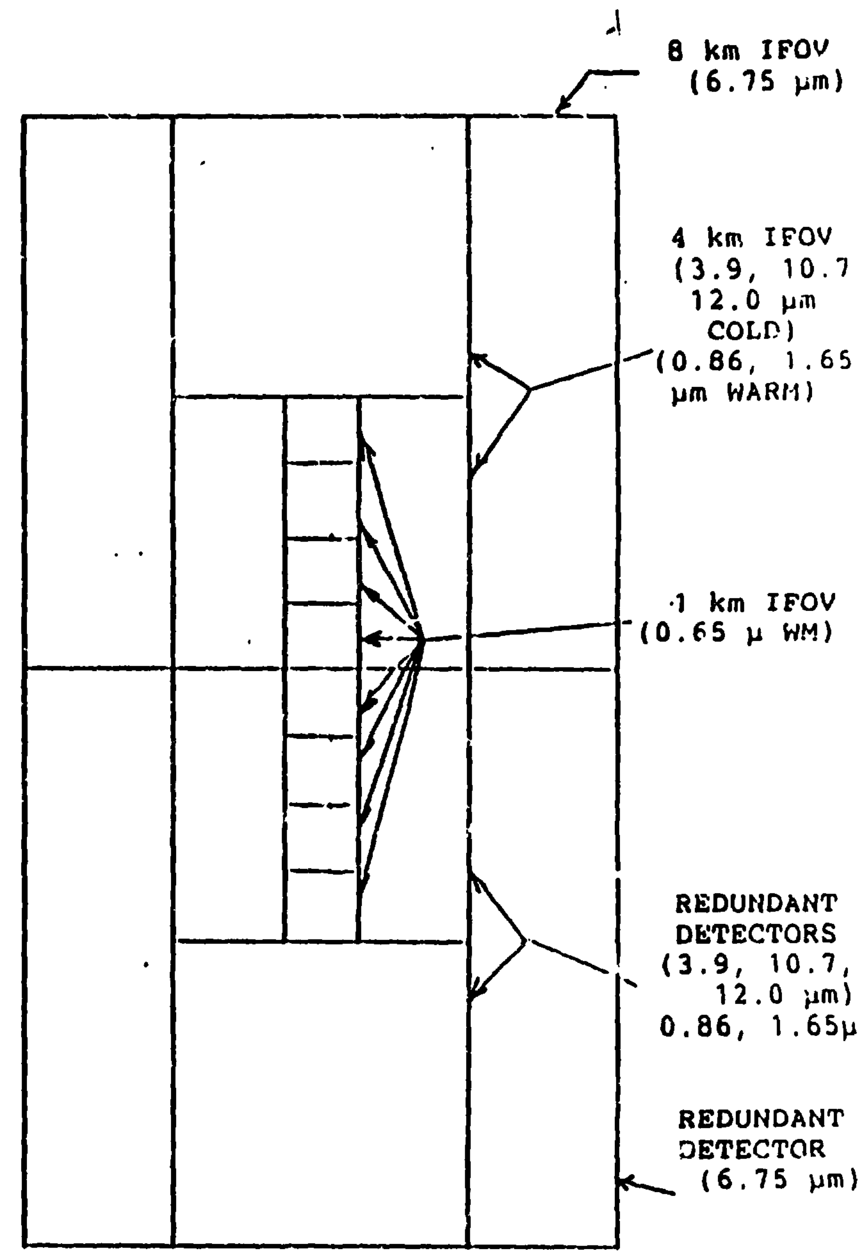


FIGURE 9.1.2-2
Option II Imager Focal Plane Arrays

The first significant change is the use of near zero temperature coefficient materials and more efficient structural geometry to improve the pointing errors induced by diurnal thermal distortion. In this manner the dynamic range of correction for these effects to be applied by the IMC subsystem can be greatly reduced. More importantly, the non-repeatable portion of the thermal distortion, which cannot be corrected, will also be reduced. These changes are described in more detail in Section 10.4.1.3.

The second major change is the use of spatial separation of IR spectral channels in a common extended focal plane rather than the separation by beam splitters as implemented on GOES-I. It appears unlikely that the accuracy and stability of co-registration required FOR GOES-N can be practically realized with the complex aft optics required by the beam-splitter approach, particularly as one adds more of the requested spectral bands. Figure 9.1.3-1 shows the extended focal plane proposed for GOES-N. With this extended focal plane, the fundamental co-registration accuracy (within the limitations of the optical extended FOV) is determined by the accuracy of the fabrication process used to assemble the focal plane, a more manageable problem than maintaining the mechanical stability of multiple beam splitter paths in the aft optics. One beam splitter is still envisioned to separate the warm and cold focal planes, but this beamsplitter has incorporated precise thermal stabilization and an in-flight alignment adjustment mechanism to superimpose the two focal planes in object space.

The warm and cold focal planes of Figure 9.1.3-1, while shown separately, are intended to be co-registered in object space. The model includes redundant detectors for all channels, which are not shown in the figure, but would be obtained in the same manner as for Option II, i.e., the detectors arrays are doubled in the north-south dimension. The visible channels are shown as 1km IFOV channels, rather than the 0.5km requested (RO1). The higher resolution is feasible in the instrument, using TDI to achieve the required signal-to-noise, but has a large impact on spacecraft communications and power and on ground processing. For this reason the 1km IFOV was retained in the model. A very similar situation exists with respect to the 3.9μm channel where a 4km IFOV is provided rather than the 2km requested, and the required NEΔT is not compatible with a single 2km detector.

With extended focal planes, the problems associated with image rotation inherent in a two axis, single mirror scanner such as that used in GOES-I are exacerbated. Image rotation is one of the more significant error sources requiring correction in navigation and within-frame registration performance in the GOES-I concept, even with the smaller focal planes used there. It could be compensated by an optical image de-rotater in the instrument, a complex mechanism which would have its own problems. It is preferable to eliminate the image rotation at the outset, which is accomplished by the next significant design feature of the Advanced Imager, the incorporation of separate scan mirrors for the east-west and north-south axes. Unfortunately, as discussed in Section 9.2.1.2, even with a dual mirror scanner, the extended focal plane envisioned for the

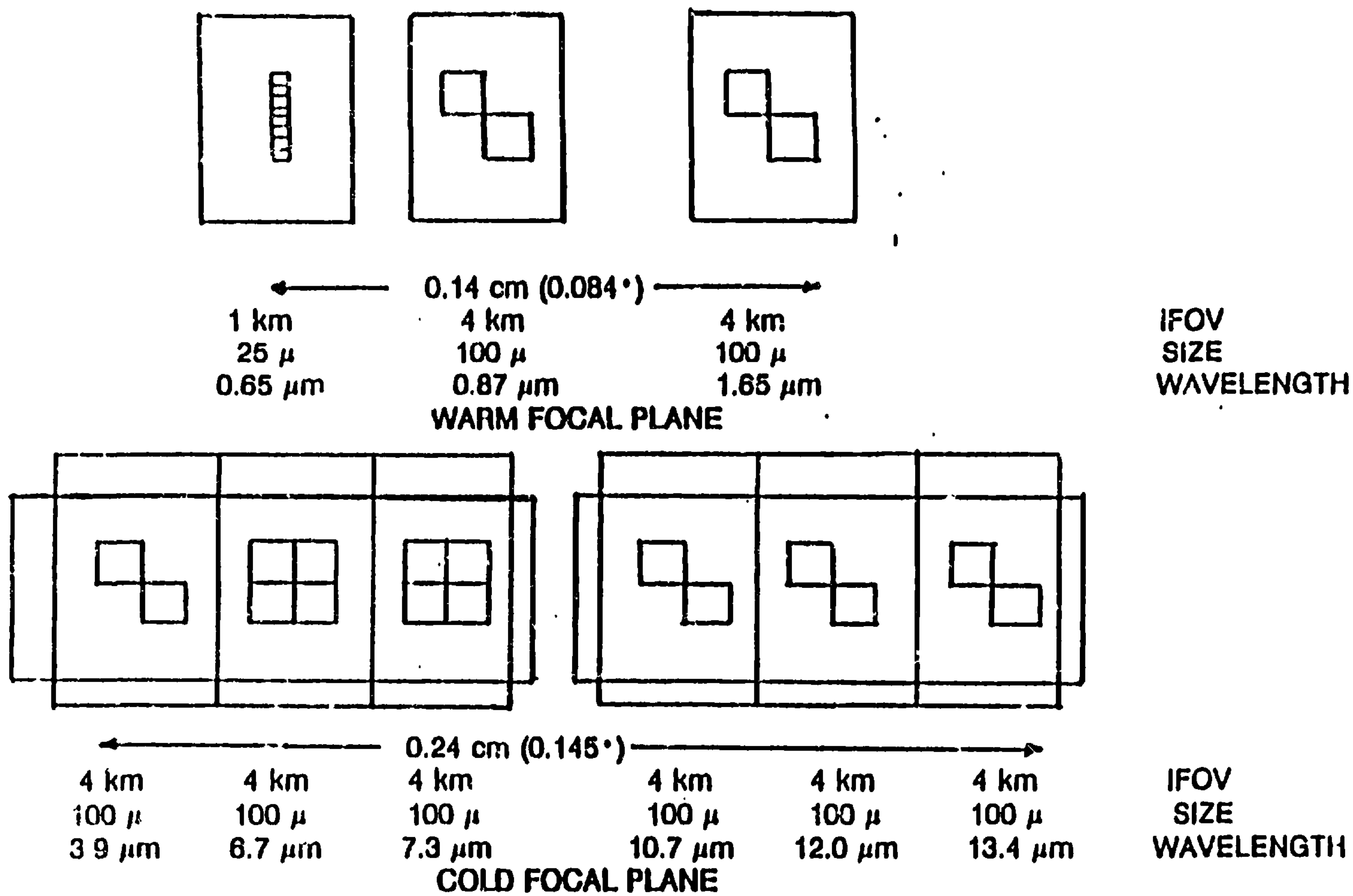


FIGURE 9.1.3-1
Option III Imager Focal Plane Array

Advanced Imager remains a source of channel-to-channel misregistration if one uses the concept of on-board IMC. The magnitude of misregistration is proportional to orbital inclination. Channel-to-channel (IMC) registration within the spacecraft system to 14μr, as being attempted on GOES-I, would require orbital inclinations no greater than 0.05 degree. Alternatively, since the channel-to-channel misregistration is deterministic, the problem could be addressed by resampling the data stream in on-ground processing. Either approach appears feasible, although the image re-sampling and continuous stationkeeping studies proposed (for other reasons) but not funded at the beginning of the GOES-N study should be completed for confirmation.

Absolutely limiting the inclination to 0.05 degree necessarily result in loss of mission life (or degraded performance) at the end of the mission. The optimum performance during the principal part of the spacecraft lifetime and satisfactory performance during the last year or so of operation can be obtained by providing both capabilities, i.e., limit the inclination during the "mission success" lifetime and provide resampling to extend the lifetime after the thruster north-south stationkeeping phase of the mission is complete. Note that discussions with NOAA have indicated that resampling on the ground before data distribution is currently part of NOAA planning, independent of this GOES-N study.

Figure 9.1.3-2 shows the configuration of the Advanced Imager. Incorporation of the second scan mirror is the principal cause of the growth in volume and weight relative to the Option II imager. The weight allocation was obtained by scaling up from the Option II Imager, and thus does not reflect significant weight savings which should be realized with GFRP fabrication. Power has been increased to allow for the additional spectral channels and scan drive.

The optical performance of the Ritchey-Chretian telescope has been modeled, rather than the conventional Cassegrain of GOES-I, and it performs quite adequately over the extended focal plane which covers only ± 1.5mr of the telescope extended FOV, as described more fully in Appendix D.5. However, an off-axis telescope, three mirror design has the potential for much reduced sensitivity to the thermal distortion problem as well as an even broader FOV. This possibility, as well as the structural design considerations for carbon composites, should be studied more extensively in a full Phase-A/B/C/D instrument development.

9.1.4 Auxiliary Imager (Option III)

The desire for an Auxiliary Imager has been identified as an enhancement in the NOAA document and as RE15 in this study. This full disk imager could relieve the conflicts for observation time expected to develop with increasing mesoscale imaging requirements if only the basic primary imager were to be available. It would also provide redundancy and assure continuing service if the primary imager failed. The only explicit requirements in the NOAA document call for full disk imaging with resolutions of 2km in the visible and 6km in the IR. This is identified as a highly desirable enhancement but concerns were expressed as to the size, weight, power, cost and data rate impacts on the system.

APERTURE:	30.5 CM (12 IN)
SCANNER:	2 MIRROR
FORE OPTICS:	RITCHEY-CHRETIAN
FIELD OF VIEW:	±3 MILLIRADIAN
SPECTRAL BANDS:	2 VISIBLE/NIR 7 IR
IR COOLER:	RADIATIVE - 85K
SPECTRAL DIVISION:	VIS/IR - BEAM SPLITTER IR - EXTENDED FOCAL PLANE
FOOTPRINT MOUNTING:	66X119 CM (26X47 IN)
ENVELOPE:	150X81X81 CM (59X32X32IN)
WEIGHT:	SENSOR 105 KG (231 LB) ELECTRONICS 50 KG (110 LB)
AVERAGE POWER:	180 W

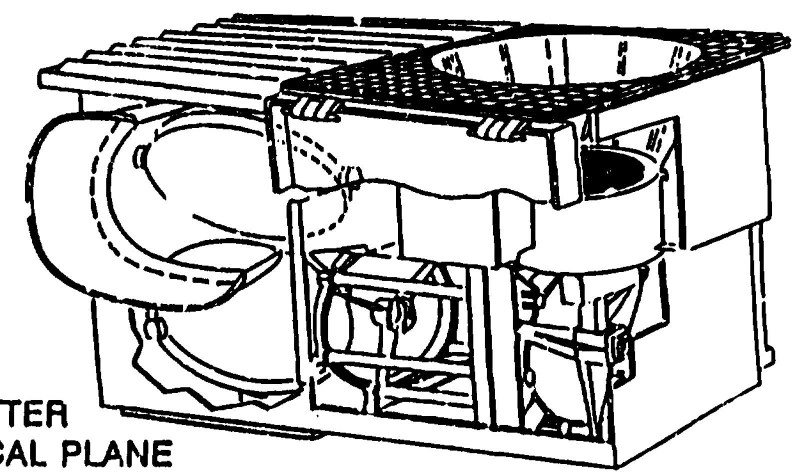


FIGURE 9.1.3-2
Option III Imager Configuration

9.1.4.1 Auxiliary Imager - Requirements

BASIC REQUIREMENTS:		
2 BANDS	1 VISIBLE	1 IR
IGFOV	2 km VISIBLE	6km LWIR
DERIVED REQUIREMENTS		
IMAGE NAVIGATION & REGISTRATION	2X NEW IMAGER	
RADIOMETRY	SAME AS NEW IMAGER	
CO-REGISTRATION	SAME AS GOES-I SPECIFICATION	
COVERAGE	"FULL DISK" 30 MINUTES MAXIMUM,	
COMMANDABLE PARTIAL NORTH-SOUTH SCANS	INCLUDING ALL OVERHEAD	
SAME SCAN RATE AS "FULL DISK"		

9.1.4.2 Auxiliary Imager - Conventional Implementation

An additional instrument to provide these capabilities could be built based on a new design or on the ATS-6 GVHRR and INSAT heritage. The INSAT VHRR is still in production at ITT and served as the primary basis for the estimates of the Auxiliary Imager for GOES-N. Significant modification of the instrument optics, detectors and signal processing are required in that the INSAT resolutions are 2.75km in the visible and 11km in the IR. Further modifications are required to the INSAT imager to meet the INR requirements of GOES-N.

To assure that the sensor can meet the INR requirements, a diurnal thermal analysis must be conducted to establish that the diurnal pointing distortions are within the INR allocations. INR thermal shields may have to be added to bring the rate of change of the line of sight to acceptable levels.

The INR system will require significant modifications to the INSAT imager in the command and control of the pointing of the instrument. A star look capability is required which will require adding command registers and modifying the servo system, detector signal processing, and the wideband data formatter to flag the operating modes.

There are two alternative approaches to providing the IMC and MMC corrections in the Auxiliary Imager.

1. If these corrections are provided in a manner similar to GOES I-M, then an analog (or possibly a digital) input must be provided for the IMC (+MMC) signal to be generated by the AOCE computer. The imager must also add a new output which will provide the "present scan address" information to the AOCE computer that it requires to compute IMC corrections. Additional modifications may be required to the instrument to accommodate the north-south and east-west pointing servo requirements to apply the orbital effects IMC as well as timing delays in the system, such as the extra 3 or 4 "dead" scan lines after star or space looks, etc.

2. If the IMC corrections are provided using an INR computer in the primary imager then the auxiliary imager should be designed to incorporate an INR computer capability. In this mode of operation the equivalent of the GOES-I Orbit and Attitude Tracking System (OATS) on the ground would generate the IMC information and upload it to the INR computer in the Auxiliary Imager via the spacecraft command system. The Auxiliary Imager must be modified to accept inputs from the AOCE computer which contain spacecraft motion compensation (SMC) information and Orbit Position information. The SMC signal provides corrections to the line of sight to the pointing mirror for disturbances that are sensed by the AOCE system but not fully corrected. The orbit position information is needed by the INR computer in the auxiliary imager to generate the corrections to the instrument pointing to compensate for the distortions of the scene resulting from deviation of the spacecraft in orbit from its ideal geostationary location.

9.1.4.2.1 Auxiliary Imager - Summary of Implementation Impact Using an Additional Instrument

INSTRUMENT	30 X 65 X 30cm, PLUS COOLER
ELECTRONICS	30 X 45 X 25cm
TOTAL WEIGHT	46kg
POWER	60W
DATA RATE	1.75 Mpbs
TECHNICAL	LOW, BUT SIGNIFICANT MODIFICATION OF EXISTING DESIGN
NON-RECURRING COST	MODERATE TO HIGH
RECURRING COST	HIGH

9.1.4.3 Auxiliary Imager - Alternate Approach

This is a proposed alternate approach to achieve the functional capabilities of the Auxiliary Imager, Enhancement RE15, with a low cost, light weight modification of the GOES I-M imager (for any spacecraft option) that will provide the full spectral, radiometric and INR capabilities of the primary imager with enhanced redundancy in the primary imager.

The basic concept is to provide "continuous" full disk capability as well as small sector capability by making the primary imager have twice the coverage rate of the present imager and time sharing the system on a predefined schedule so as to provide full disks every 30 minutes, and have no time discontinuities in the data used for wind determination.

The imager coverage rate will be doubled by adding 8 visible detectors to the present 8 detectors (as has been done for the Option III imager already) and activating the redundant IR detectors that are already in the focal plane and adding the necessary amplifiers, multiplexers, etc. This will allow the imager to step 16km north-south after every line rather than the present 8km. The east-west scan rate will remain the same. Assuming that the cooler can be modified to accommodate the extra heat load, the radiometric and geometric performance will be unchanged from the present capabilities. This will, of course, double the data rate from the instrument.

It should be noted that the concept described above could be applied to the seven-band imager or to an Advanced Imager using 2 scan mirrors and an extended focal plane.

The unmodified imager takes about 25 minutes to cover a ± 60 degree "full" disk image. The high speed imager, described above, will cover the same area in less than 13 minutes. This leaves 17 minutes of each half hour available for other observations, star looks and calibration. Following is a time line to illustrate a 1/2 hour interval:

Minutes (read vertically)

```
0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9
__________________________________xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

       "Full" Disk                         Other Observations
```

Note – "x" represent time available for other observations
"B" is the time for a black body calibration

This provides a gap free full disk every 1/2 hour for wind field determination and other uses, but the time distribution for other observations may not be optimum.

If it were desirable to get the other observations on a more uniform spacing, i.e., every 10 minutes, the following schedule could be used.

The time continuous data from the "full disk" image that would be used for wind field determination could be acquired in 3 segments. The first would begin on the hour or 1/2 hour, start at or near the north pole and scan down to 15 degree latitude, and take less than 5 minute. The next 5 minute are available for other observations. Starting at 10 minute past the hour or 1/2 hour the central 1/3 of the image could be acquired, but with an overlap of about 128km between the end of the first 1/3 image and the start of the second 1/3 of the image. The next 5 minute are available for other observations. Starting at 20 minute past the hour or 1/2 hour the last 1/3rd of the full disk image could be acquired with another 128km of overlap with the end of the middle 3rd of the image. The wind field determination would be done on the third disk images which are continuous in time and uniformly spaced every 1/2 hour. The overlap will assure that no cloud moves off the set of images over the time between images. A single image of a full disk would have two small discontinuities, of 5 minute of cloud motion each, in the image at about 15 degrees north and south latitude.

Following is a time line to illustrate a 1/2 hour interval:

Minutes

```
0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1 1 1 1 1 2 2 2 2 2 2 2 2 2 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0
__________xxxxxxxxxxx_________xxxxxxxxxxx_________xxxxxxxxxxxB

1/3 Disk                      1/3 Disk                  1/3 Disk
```

Note – "x" represent time available for other observations
"B" is the time for a black body calibration

With the imager running at "double rate" in a single 5 minute interval it could observe two 3,000 x 3,000km regions and five 1,000 x 1,000km regions. This set of observations could be repeated every ten minutes.

The improved imager could operate and provide full capabilities in this faster mode until a detector fails. After a failure, the instrument could either operate with gaps in the data due to a missing detector or the imager commanded back to the old mode of stepping 8km north-south after every line and provide a reduced coverage rate with gap free data. This proposed system would provide full redundancy for the visible detectors, which currently have no redundancy.

9.1.4.3.1 Auxiliary Imager – Summary of the Implementation Impact Using an Alternate Implementation

The following are increases or deltas to the 7 band or new imager to accommodate the changes to provide the alternate implementation Auxiliary Imager capabilities.

SIZE DELTA	~ 15 X 10 X 10cm
WEIGHT DELTA	~ 2kg
POWER DELTA	~ 5 W
DATA RATE	TWICE THAT OF THE PRIMARY IMAGER
TECHNICAL RISK	LOW, BUT SIGNIFICANT MODIFICATION TO 7 BAND DESIGN
NON-RECURRING COST	MODERATE TO HIGH
RECURRING COST	MODERATE

9.2 Imager Performance

9.2.1 Imager – Spatial Performance

9.2.1.1 Imager – Resolution and Cloud Smearing

The resolution of the imager is limited by three factors: telescope optics, electronic filtering, and IFOV (detector size). These factors tend to blur the details within each scan line, causing sharp vertical edges to appear as more gradual changes.

An analysis was performed on each of the five imager channels. GENII software was used to model the optical characteristics of each channel, and in-house software by Swales & Associates was used to model the electronic filters. A complete description of the analysis is presented in the Appendix D.1 entitled "Cloud Smearing Study."

The analysis showed that it is not possible to meet the requirement that the output must reach 98% of its final value within a distance of 1 IFOV. Instead, the requirement should be restated in terms of ground distance. For example, the output should reach 98% of its final value within a scan distance of X kilometers. When stated in this way, an appropriate combination of detector size, optics and filtering could be chosen to satisfy the requirement.

If it is of interest to measure the absolute radiance of cloud tops, the system output must not only achieve steady state, but it must maintain it long enough to ensure that a sample is taken while the output is at steady state. The analysis showed that clouds must be 2–3 IFOV's wide in order to have confidence in absolute radiance measurements.

The normal choice for the 3dB cutoff frequency of the electronic filter is the Nyquist frequency: $f_{Nyquist} = 1 / (2\ T_{IFOV})$, where T_{IFOV} equals the dwell time, or the time required for the IFOV to scan its own width. This choice yields the maximum achievable signal-to-noise at the Nyquist frequency, and results in a filter MTF of 0.707. In order to increase the MTF of the filter to 0.95, the cutoff frequency must be increased by a factor of 2.2. This will result in a substantial noise penalty, and is not a recommended way of improving the resolution of the system. In fact, it could be argued that in the long wavelength bands (channels 4 and 5) even tighter filters should be used since diffraction and optical aberrations are substantially bandlimiting the system response. Using tighter filters would lower system noise with a minimal penalty to the system response time.

In addition to smearing the details of a scan line, the optics and filters will delay the entire line. east-to-west (east-west) scans will be delayed to the east, and west-to-east (west) scans will be delayed to the west. These delays can be easily corrected within the instrument, given precise control of sample timing, so that their effects can be negligible in the reconstructed image.

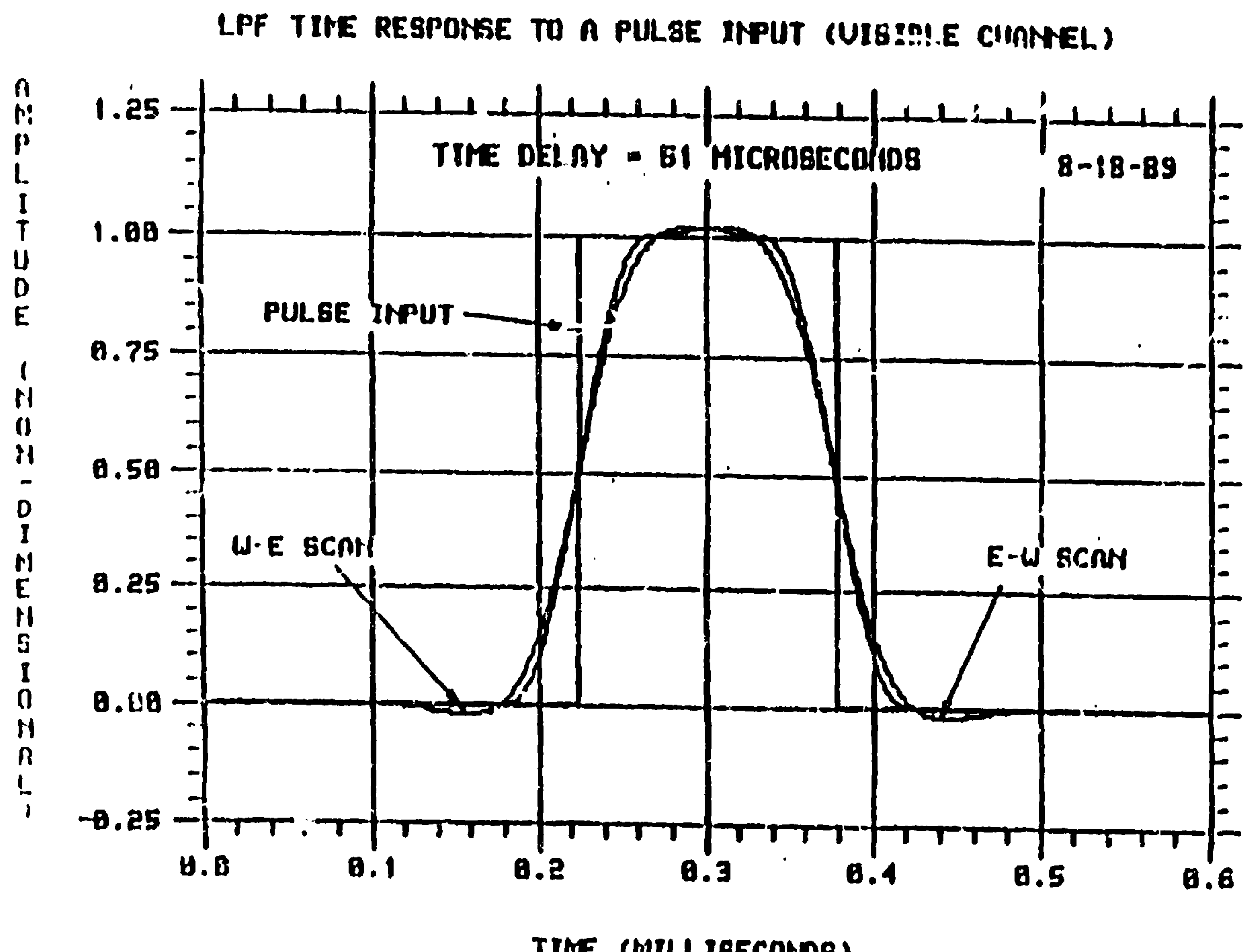


FIGURE 9.2.1-1 EFFECT OF BI-DIRECTIONAL SCAN ON IMAGE QUALITY

Shows a cloud approximately 3 IFOVS wide as seen in the visible channel from a W-E scan compared to the same cloud viewed from an E-W scan after correction for 51 microsecond channel delay. From ITT Internal memo, R. Krishna to C. Young, August 21, 1986.

The only remaining differences between east-west and west-east scans will be caused by asymmetries in the response of the electronic filter. The Thompson-Butterworth filters that are being used in GOES-I have very little overshoot and exhibit excellent symmetry properties. Figure 9.2.1-1 illustrates the asymmetry for channel 1 when bi-directionally scanning over a cloud that is approximately 3 IFOV's wide.

As one moves to longer wavelength channels, the effects of diffraction become more significant and the effects of the filter become even less, as demonstrated by the spatial weighting functions for the five GOES-I bands in Appendix D.1. Figure 9.2.1-1, therefore, represents the worst-case effect of bi-directional scanning on image quality. Because spacecraft options assume use of the Nyquist criterion for a given IFOV and spectral band, this analysis applies to all three instrument options.

9.2.1.2 Imager - Co-registration

The channel-to-channel registration requirement is to have a mis-registration no greater than 0.5km. This has been identified as requirement RC4 and interpreted in this study to be a 3σ value of 0.5km at nadir, or 14 μr. This is a very demanding requirement, especially when applied to IR channels with IGFOV's of 4 to 8km (112 to 224μr) and when visible to IR co-registration at these levels must be met between different focal planes. The project is not confident of meeting this requirement for any of the imagers proposed under this study. The predicted co-registration performance in microradians is given in Table 9.2.1-1:

TABLE 9.2.1-1

PREDICTED CO-REGISTRATION PERFORMANCE OF THE GOES-N IMAGER

OPTION	REQUIREMENTS (μr)	PREDICTED PERFORMANCE (μr)	INSTRUMENT
GOES-I	28	60	FLIGHT I IMAGER
OPTION I	14	50	IMPROVED IMAGER
OPTION II	14	40	7 BAND IMAGER
OPTION III	14 28	50 **	NEW IMAGER ADDITIONAL IMAGER

** Additional imager performance depends upon approach selected. If an independent small instrument is used, the estimated co-registration performance is 50μr and, if the capability is achieved by speeding up the coverage of the primary imager, the performance would be the that of the selected instrument.

9.2.1.2.1 Imager Co-registration - Options I and II

The Option I and II imagers and the ITT version of the Auxiliary Imager all use beam splitters to send the various channels to different detector arrays and a planet lenses in the IR channels to provide a high optical speed (f# of about 1.0) beam onto the detectors which minimizes the detector size and, thus, its noise. In these systems, co-registration and focusing is accomplished by the physical rotation and translation of beam splitters, lenses, and detectors. This allows the various spectral bands to be optically overlapped and minimizes the impact of the image rotation that occurs with a one mirror scanner. There are generally large physical separations between the visible and IR detectors which are mounted to different structural areas of the instrument. Handling, test and launch vibrations, and the diurnal and seasonal temperature variations that the instruments will experience will all cause the co-registration of the spectral bands to vary during the life of the instrument.

The GOES-I flight I imager has improved thermal isolation of the relay optics that contain the IR beam splitters to reduce the diurnal thermal cycling of this component which will reduce the magnitude of this source of co-registration errors. It does not have any in-chamber or in-flight adjustment of the visible to IR alignment. There are no precision measurements of the co-registration after the instrument is sent to LAS from ITT. The study team has estimated the 3σ co-registration performance of this instrument over its life to be that in the above table.

The Option I, improved imager, will have in-flight visible to IR adjustment capability and perhaps temperature stabilization of the relay optics containing the IR beam splitters. This will lead to the improved performance.

The Option II , 7 band imager, will have 3" optical encoders to improve the pointing accuracy, two new warm focal planes to provide the 0.865μm and 1.65μm bands. There will be in-flight adjustments of the alignment of the warm focal planes, the relay optics will be redesigned to improve its stability, it will be temperature stabilized and some supporting structures may be changed to improve their stability. These changes are estimated to further improve the performance as indicated in the Table 9.2.1-1.

9.2.1.2.2 Advanced Imager Co-registration

The Option III, new or advanced imager, will be an all new design using a GFRP structure, a two mirror scanner, optical encoders and an extended focal plane. The two mirror scanner does not introduce any image plane rotation with scanning so that it is feasible to lay the detectors for the various spectral bands one after another, Figure 9.1.3-1. Because of the wide angular extent (approximately 0.15°) of the set of IR detectors the speed of the optical beam must be slower, typically with an f# of 2 or 3. This increases the detector noise because larger detectors must be used, but the layout allows for TDI techniques by using more detectors along the scan direction for those few spectral bands that require better performance than can be achieved by a set of single detectors. This design also incorporates the spectral defining filters directly over the detectors and does not use any beam splitters. This increases the throughput so that more signal photons fall on the detectors and helps compensate for the performance loss due to detector size. The co-registration alignment then occurs primarily during the fabrication of the focal plane and in control of the telescope focal length and sample timing so that the improved co-registration can be achieved.

There is a problem with an extended focal plane when IMC corrections are applied to the scan. East-west accelerations can be compensated for by dynamically adjusting the sampling rate to maintain co-registration. North-south accelerations will cause mis-registration that can be compensated for by either rotating the image dynamically during the east-west scan, limiting the maximum inclination angle, or resampling the data on the ground. Dynamic rotation compensation introduces many undesirable complications to the design. The approach selected for Option III is to keep the inclination below 0.05 degree. The approach is to correct the inclination error, which grows about 0.002 degree daily, every day when the wheels are being unloaded from the solar pressure effects that occur since the Option III spacecraft does not use a solar sail. Keeping the inclination down to these levels will keep this effect to about 5 μr and allow the performance projected in the table above. To maintain the INR performance it will be necessary to have continuous two station ranging data about every 10 minute with an update of the orbit every few hours. It should be noted that with these small inclinations the required IMC signals to compensate for orbital effects are very low and should present no problems to the pointing system.

9.2.2 Imager Radiometric Performance

Table 9.2.2-1, reproduced from the final study review briefing, shows the spectral bands and spatial resolution under consideration for the new imager. Also shown are the projected performance for each combination as calculated by both ITT and SBRC. There are important differences in the two instrument concepts envisioned by the contractors. The ITT instrument would be an extension of the design of the GOES I-M imager, in which dichroics are used to create spatially registered spectral bands with each band having its own separate optics and focal ratio. The SBRC instrument uses an extension of Thematic Mapper (TM) focal plane architecture, in which all the spectral bands are aligned to a common focal surface and have a common optical path and focal ratio. The ITT approach measures the radiance from a common ground patch simultaneously in all bands but has more aft optics complexity. The SBRC approach measures radiance from a common ground patch as a time sequential event as the scanned image element passes from one spectral band to the next in image space. Band-to-band registration depends on precise control of the scan motion from one IGFOV to the next. The SBRC concept has lower optical complexity.

There are differences in the two predictions. Looking at the 6.75μm and 7.3μm spectral bands at 4km IGFOV both contractors use a nominal F/3 optical ratio, but SBRC projects a detector that is 3 times higher performing than ITT selects. In the 10.7μm and 12μm spectral bands ITT uses an F/1.47 while SBRC uses an F/3.3. However, SBRC projects a detector with 2 times the performance of the ITT detector for this spectral region. In the 13.35μm spectral band the difference is only in the focal ratio; SBRC uses F/3.3 to ITT's F/1.47. The detectors have essentially the same performance for both companies in this spectral band.

It may be dissatisfying to have this diversity of results; however, it is informative. The performance is driven by the selection of design approach. There are certain performance desires that are difficult to achieve and, therefore, higher risk. The 2km/3.9μm band is difficult in both instrument concepts. The 0.5km visible band (0.65μm) does not have acceptable performance. The ITT approach has significant problems in the 4km/6.75μm and 4km/7.3μm bands. No sensitivity requirement has been stated for the 13.35μm band; thus, no comment on the acceptability of the projected performance can be made. It is recommended that all improvements in resolution be deferred at this time to avoid stressing the technology and adding complexity in the cold focal plane by requiring a major increase in the detector count.

TABLE 9.2.2-1
PREDICTED PERFORMANCE VERSUS SPECTRAL BAND

SPECTRAL BAND (μm)	IGFOV (KM)	SNR (0.5% ALB)	NEAT (SBRC) (K @ TEMP)	NEAT (ITT) (K @ TEMP)	NEAT REQ. (K @ TEMP)
0.65 0.65	1.0 0.5	3.5 0.6			
0.865	4.0	15.0			
1.65	4.0	10.0			
3.9 3.9	4.0 2.0		 0.52(300)	0.15(300) 0.60(300)	0.1(300)
6.75 6.75	8.0 4.0		 0.24(240)	0.20(240) 0.80(240)	0.3(240)
7.3	4.0		0.22(240)	1.00(230)	0.5(270)*
10.7	4.0		0.13(300) (WITH 2 TDI)	0.10(300)	0.1(300)
12.0	4.0		0.15(300) (WITH 2 TDI)	0.10(300)	0.1(300)
13.35	4.0		0.80(300)	0.30(270)	0.5(270)*

* Study scientists provided this number

9.3 Sounder Configurations

9.3.1 Option I Sounder Configuration

In keeping with the concept of the Option I spacecraft system as a minimal cost approach to GOES-N, changes to the spacecraft and instruments from the GOES-I configuration are limited to those for cost and/or efficiency improvements and those instrument modifications offering significant performance benefits without significant impact to spacecraft interfaces. The Option I sounder design concept is therefore identical to GOES-M. It is a filter wheel radiometer with eighteen infrared spectral channels arranged in three spectral bands on the filter wheel. Each spectral band has an array of four detector channels, each with a nominal 8.66km diameter IFOV, which receive radiation through common spectral filters sequenced in that particular band of the wheel. One visible spectral channel with four detector channels of 8.66km diameter IGFOV is provided on one separate uncooled focal plane, and eight 1km square IGFOV star sensor detector channels are provided on another.

The detectors' FOV are scanned over the scene in object space by a two-axis gimballed mirror. In order to accomplish the required sounding rate for GOES-I. Each sounding must be completed in 100ms. The scan drive related studies described in Section 9.1.1 which were carried out with negative results for the imager are equally applicable to the sounder, i.e., no "easy fixes" for the difficulties experienced with the GOES-I scanners have been found.

Significant improvement in the sounder NEΔN is limited by the focal plane temperature, which can be significantly lowered within the concept of a low cost, minimal impact system by simply changing the external finish of the Astromast solar sail boom as described in Sections 9.1.1 and 9.5.3.1. A focal plane temperature of 92K should be realizable.

Co-registration of the sounder channels to the stringent requirements of RO25 remains a major problem for GOES-N, as discussed in Section 9.4.1.3. It is recommended that improved means of alignment and co-registration of the sounder channels be developed for all spacecraft options, as discussed there. It is also recommended, as with the Option I imager, that the aft optics be temperature stabilized to avoid the possibility of diurnal drift between channel centroids in the various spectral bands.

Major instrument interface requirements for the Option I sounder are presented in Table 9.3.1-1. As in the imager, approximately 7kg of weight growth in the sounder sensor module relative to GOES I-M has been allocated to accommodate the thermal control and alignment modifications recommended. In all other cases, the specifications are taken from GOES I-M allocations current at the beginning of this study.

9.3.2 High Spectral Resolution Sounder (HSRS)

The highest priority change in instrumentation for GOES-N is the development of a new infrared sounder that has the projected potential to provide 1km vertical resolution in the troposphere with 1K temperature accuracy. The characteristics of this instrument have been defined as needing $0.5cm^{-1}$ spectral resolution in the 15.5μm ($660cm^{-1}$) spectral region with consistent high spectral resolution in the 3.9μm spectral region (nominally --- $2.5cm^{-1}$). The spectral coverage has been enunciated as requiring contiguous spectral information over the entire spectrum. Additional work is required to verify that this last criterion has a good science basis.

Three potential instrumental approaches were considered for the HSRS, a grating spectrometer similar to the AIRS instrument for EOS, a Fabry-Perot Interferometer, and a Michelson Interferometer based on the HIS development proposed by the University of Wisconsin, ITT, and SBRC for retrofit into the GOES I-M program. Principal findings of this study are summarized by Figure 9.3.2-1.

TABLE 9.3.1-1
Option I Sounder Interface

TELESCOPE TYPE	CASSEGRAIN
OPTICAL APERTURE	30cm
SCANNER TYPE	TWO-AXIS SINGLE MIRROR
AFT OPTICS	BEAM SPLIT THROUGH FILTER WHEEL TO 3 IR, 1 VISIBLE FOCAL PLANES
NUMBER DETECTOR CHANNELS @ 8km	4 PER FOCAL PLANE, 16 TOTAL
NUMBER STAR SENSE CHANNELS @1km	8
SENSOR MODULE FOOTPRINT	46cm X 137cm
SENSOR MODULE WEIGHT	99kg
ELECTRONICS DIMENSION	67cm X 38cm X 18.5cm
POWER SUPPLY DIMENSION	20.3cm X 15.7cm X 29cm
ELECTRONICS & P. SUPPLY WEIGHT	34kg
OPERATIONAL/PEAK POWER	105/140 W
TELEMETRY RATE	40 kbps

FIGURE 9.3.2-1
ASSESSMENT OF SOUNDER TECHNOLOGY OPTIONS

GRATING SPECTROMETER

- REQUIRES THOUSANDS OF DETECTORS AT THE FOCAL PLANE
- A "NORMAL" PASSIVE RADIATOR NOT FEASIBLE
- AIRS OPTICS NOT SUITED FOR GEOSYNCHRONOUS ORBIT

THIS APPROACH NOT RECOMMENDED AT THIS TIME

FABRY-PEROT INTERFEROMETER

- EXCELLENT SPECTRAL RESOLUTION OVER SMALL FREE SPECTRAL RANGE (10 TO 20 CM^{-1})
- CAN MEET THE SENSITIVITY REQUIREMENTS, BUT MAY NEED CRYO-REFRIGERATOR
- STRAIGHTFORWARD CALIBRATION OF DATA
- USES COMPLEX AFT OPTICS TO BE ABLE TO COVER NOAA SPECTRAL RANGE REQUIREMENTS (CONTIGUOUS HIGH SPECTRAL RESOLUTION)

FABRY-PEROT CAN BE USED WHEN SELECTED SPECTRAL COVERAGE IS ADEQUATE

FOURIER TRANSFORM INTERFEROMETER (MICHELSON)

- OPTICAL COMPLEXITY SIMILAR TO A FILTER WHEEL SPECTROMETER
- DOES NOT MEET CORE TEMPORAL COVERAGE REQUIREMENT WITH PASSIVE RADIATOR DUE TO LIMITS ON SIZE AND TEMPERATURE OF FOCAL PLANE
- USE OF CRYO-REFRIGERATOR WILL SOUND 3000x3000KM IN 60 MINUTES AT HIGH SPECTRAL RESOLUTION WITH 10KM IGFOV
- MUST USE VERY LINEAR DETECTOR TECHNOLOGY; MAY NOT BE ABLE TO USE HIGHEST SENSITIVITY DETECTOR TECHNOLOGY
- GROUND AND SPACE BASED SIGNAL PROCESSING ARE MORE COMPLEX THAN OTHER APPROACHES

THIS APPROACH OFFERS POTENTIALLY LOWER MECHANICAL COMPLEXITY COMPARED TO OTHER APPROACHES AND PROVIDES COMPLETE SPECTRAL COVERAGE

Based on these assessments, the Michelson approach was selected as the basis for determining size, weight, and power projections for the Advanced Sounder. While there are clearly problems with extension of the AIRS grating technology to geosynchronous orbit, the principal reason for selecting the Michelson over the Fabry-Perot is the requirement for contiguous spectral coverage, which is very difficult to satisfy with Fabry-Perot technology. Should reexamination of NOAA requirements lead to a much more restricted set of narrow spectral bands, which can be defined in advance, the question of the Fabry-Perot vs Michelson approaches should be reconsidered.

In order to offer two levels of risk, an Option II sounder was configured to use a passive radiator with a reduction in its area coverage capability. To help the Option II sounder have better performance, we have increased the aperture to 35cm from 30cm. The Option III sounder uses a cryo-refrigerator to achieve focal plane temperatures in the 60K-65K temperature regime and uses a 30cm (12 inch) aperture. The Option III sounder has a significant performance advantage over the Option II sounder, but is considered to have higher risk due to the lack of a demonstrated refrigerator lifetime in the current time frame.

To enhance the Option II sounder capability the GOES-N spacecraft concept is designed to eliminate the solar sail parasitic into the passive radiator and the spacecraft performs a semi-annual 180 degree yaw maneuver to keep the summer sun off of the cooler. These two factors allow a modest sized cooler to be implemented that operates in the 85K temperature regime.

9.3.3 Option II Sounder Configuration

Section 9.4.2.2 demonstrates the difficulty of achieving simultaneously the sensitivity, spectral resolution, spectral coverage and temporal coverage embodied in the NOAA requirements document. While the requirements for spectral resolution and contiguous spectral coverage drive the instrument configuration to a Michelson interferometer approach, as discussed in Section 9.3.2, the requirements for sensitivity and temporal coverage drive the spacecraft and instrument designs to achieve lower focal plane temperatures. The 65K focal plane temperature, which is required to approach the overall instrument performance of requirements, is probably only attainable with mechanical refrigerators, but, at this time, such devices are considered to be too developmental for an operational program such as GOES. While it can be expected that considerable advances will be made in that technology over the next few years because of the commitment being made in the NASA EOS program, it is too early to commit GOES-N to that approach. The study team therefore decided to model both approaches, a passive radiator cooler for Option II and a mechanical refrigerator for Option III.

As discussed in Section 9.1.2, the principal initiative undertaken in the Option II system relative to Option I is the provision for a HSRS. The system design features which are incorporated in addition to the instrument approach are largely directed at achieving lower focal plane temperatures for the sounder and benefit the imager as well as the sounder. They are described in other portions of this report, as outlined in Section 9.1.2.

Figure 9.3.3-1 shows the general instrument configuration modeled for the Option II sounder. It is a single mirror, two axis scanner with a Cassegrain telescope (extended FOV of ±2 mr) collecting light for analysis in the Michelson interferometer aft optics. The focal plane temperature modeled is 85K, leaving quite a gap in performance against NOAA objectives. A 35.6cm (14 inch) optical aperture is incorporated to provide some compensation for the relatively poor performance. Increasing the collecting area is an expensive method of improving performance, due to the rapidly increasing weight penalty and the need to maintain optical quality and scan efficiency of larger optics and scan mirror. Further increases in the optical aperture are not recommended, because they would severely stress the technology for this instrument approach. A cooler for the aft optics is shown schematically in the same location as the filter wheel cooler for the Option I (GOES-I) sounder.

Detailed analysis for this cooler was not carried out, but operating temperatures below 200K will be required if the instrument performance is to remain detector noise limited. The instrument weight and volume increases relative to Option I are driven mainly by the increased optical aperture.

Figure 9.3.3-2 is an optical schematic for the interferometer design, taken from "High-Resolution Interferometer Modification of the GOES-I/M sounder: Feasibility Study" (September 1988). The Cassegrain collecting optics is directly scaled up from the Option I sounder. A dichroic beamsplitter at instrument ambient temperature separates the IR and visible components and another beamsplitter separates the visible spectrum to provide the light to separate focal planes optimized for imaging and star sensing.

This study has not addressed alternatives to the foreoptics design presented here. There are potential advantages to an off-axis, three mirror type foreoptic which may far outweigh the larger volume which would be required relative to the Cassegrain (Appendix D.5). The principal advantage is that direct illumination by sunlight of the secondary mirror suspended on a high thermal impedance spider is avoided, significantly easing the thermal design problem for three-axis stabilized spacecraft. Secondly, the extended FOV of such designs is potentially considerably better than that for Cassegrain or Gregorian systems, easing constraints placed on focal plane technology. Thirdly, the unobscured optics will result in less diffraction for a given optical aperture than for the obscured Cassegrain. Further study should be carried out to select a preliminary design for the three mirror foreoptic and to determine the relative advantages of these two approaches.

The depiction of the Michelson interferometer optics in Figure 9.3.3-2 is highly schematic. A more detailed description can be found in Section 2 of the referenced report. The proposed instrument retains three spectral bands for optimization of detector responsivity vs. wavelength. It is important to note that, unlike the GOES I-M sounder, a common field stop (aperture plate) for all spectral wavelengths has been placed at the first focus of the Cassegrain telescope. The ray bundles exiting the field stop are processed through the interferometer in parallel and, finally, are re-imaged through an array of fast condensing lenses onto individual detectors much like the GOES I-M arrangement. This approach assures that the final data will be spatially registered band-to-band at the expense of what may be a difficult problem of registering the condensing lens array to the field stop. This particular aspect of the design should be analyzed more closely because of the possibility that vignetting could render the information from one or more focal planes useless.

Moreover, the in-flight band-to-band adjustment mechanisms, recommended in any case, become mandatory with this approach.

As discussed in Section 9.4.1.3, the requirement for band-to-band co-registration has been reexamined in response to concerns of the study team, with the result that such co-registration may not be an overriding concern. Thus, an alternative approach similar to that used on GOES-I, but with in-flight adjust mechanisms and thermal control of the aft optics to improve band-to-band co-registration, may be preferable.

The study has shown that in order to approach the combined requirements for the GOES-N sounder, not only must colder focal planes be attained, but more detector channels must be processed simultaneously. Whereas the GOES-I sounder spatially multiplexes four detector channels, GOES-N requirements can only be approached by spatially multiplexing sixteen. When various possible arrangements of these channels in object space are considered, it becomes apparent that the focal plane arrays become considerably larger. Image rotation and extended FOV requirements become as significant as they are with the imager. In order to avoid serious problems with image rotation without resorting to a two mirror scanner as recommended for the Advanced Imager, the field stops are arranged as a 2 x 8 array of 8.66km IGFOV's on 30km centers east-west by 20km north-south, with the short axis of the array oriented east-west, as shown in Figure 9.3.3-3. The visible channel focal plane array, equivalent to 30 x 160 detectors with effective 1km IGFOV is synthesized from a conventional CCD with perhaps one fourth that IGFOV size. Large detector arrays (1024 X 1024) are available at the present time with detector sizes of about 25μm. Assumption of an effective focal length of about 3.56m (f/no = 12) results in the smaller IGFOV. The visible mosaic overlays the IR focal plane in object space and provides the high-resolution daytime cloud clearing function requested (RO18). Since the visible array is oversized relative to the IR, the very accurately co-registered visible data requested (RO25, 14μr 3σ) can be synthesized.

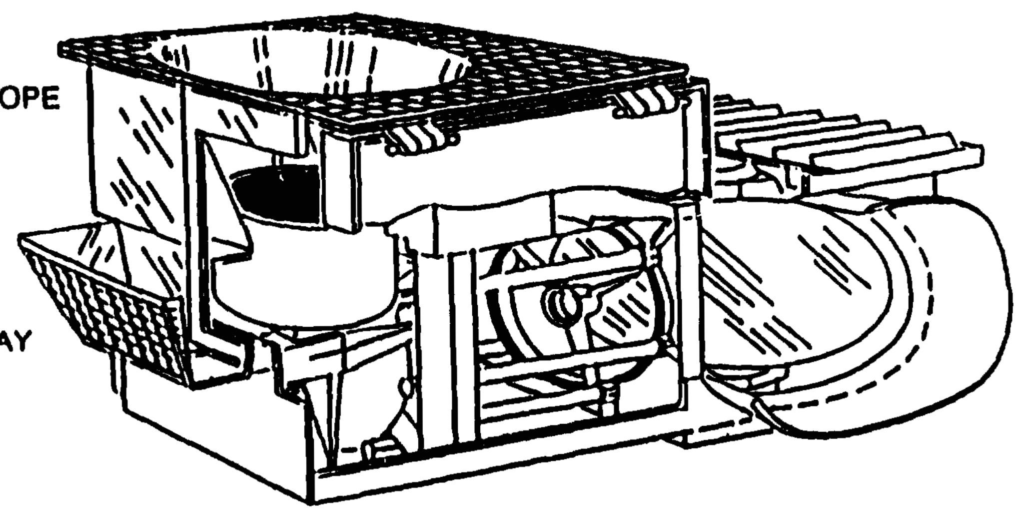
The larger visible detector array is incorporated to allow a sparse IR sampling mode with full visible data available for cloud clearing, thereby greatly increasing the spatial coverage rate. With the focal plane array of Figure 9.3.3-3, for instance, a "vertical venetian blind" coverage for IR pixels can be obtained by stepping the array in object space by three IGFOVs to the east or west, rather than the single IGFOV used for contiguous coverage. IR spatial fill factor of 33.3% will be generated, but the contiguous 1km IFOV visible data necessary for cloud clearing will be available in the background. Other possibilities are clearly available, depending on what combinations of sparse sampling modes are desired.

No provision is made in the Option II sounder for the 2km contemporaneous IR cloud clearing data requested (RO18-night). Even a single linear array covering the 160km north-south dimension of the focal plane array would require an additional 80 cooled detectors, an unacceptable thermal load for the passive radiation cooler.

Two foreoptics considerations, which were discussed in the context of the Advanced Imager, are also of concern to the sounder, and should be considered in Phase-B. As discussed above, the effects of image rotation place constraints on focal plane technology and result in unavoidable scan irregularities in object space, even with the arrays selected for this model. The elimination of image rotation by the two mirror scanner may well be as desirable for the sounder as for the imager. Further, the size of the focal plane array stresses the capability of the Cassegrain design selected. Use of the Ritchey-Chretian design selected for the imager or the three mirror telescope recommended for consideration there may provide some welcome margin for performance in the case of the sounder as well.

FIGURE 9.3.3-1

OPTION II SOUNDER



APERTURE:	14 INCHES
SCANNER:	SINGLE MIRROR
FORE OPTICS:	CASSEGRAIN TELESCOPE
FIELD OF VIEW:	± 2 MILLIRADIAN
SPECTRAL BANDS:	IR 2 x 8 ARRAY VISIBLE 30 x 160 ARRAY
FOOTPRINT CM (IN):	71 x 127 (28 x 50)
ENVELOPE CM (IN):	171 x 90 x 92 (67.5 x 35.6 x 36.3)
WEIGHT KG (LB):	SENSOR 131 (288) ELECTRONICS AND POWER SUPPLY 50 (110)
POWER AVERAGE (W):	150

Figure 9.3.3–2

OPTION II SOU''DER OPTICAL SCHEMATIC
(Passive Radiator Configuration)

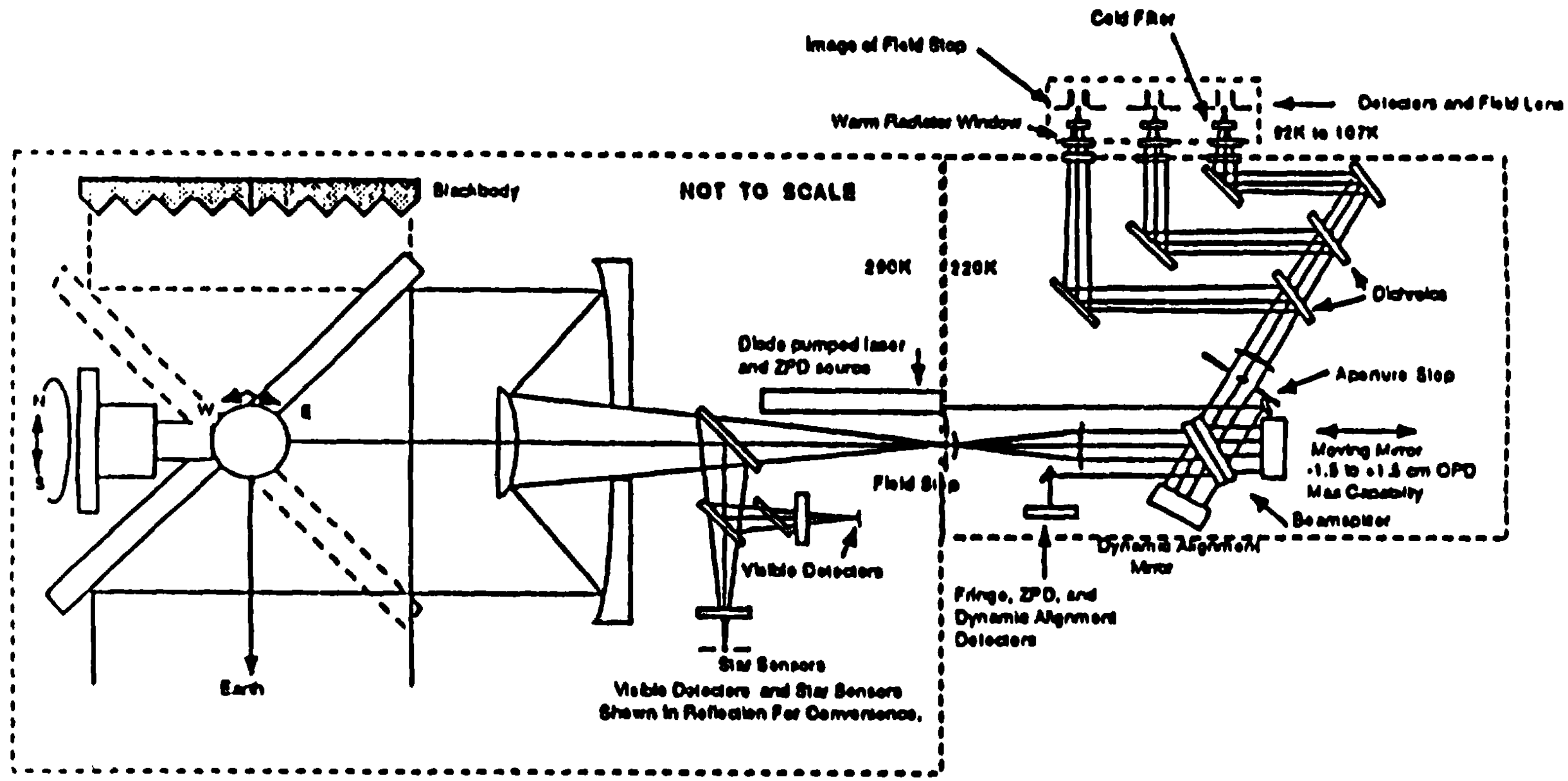
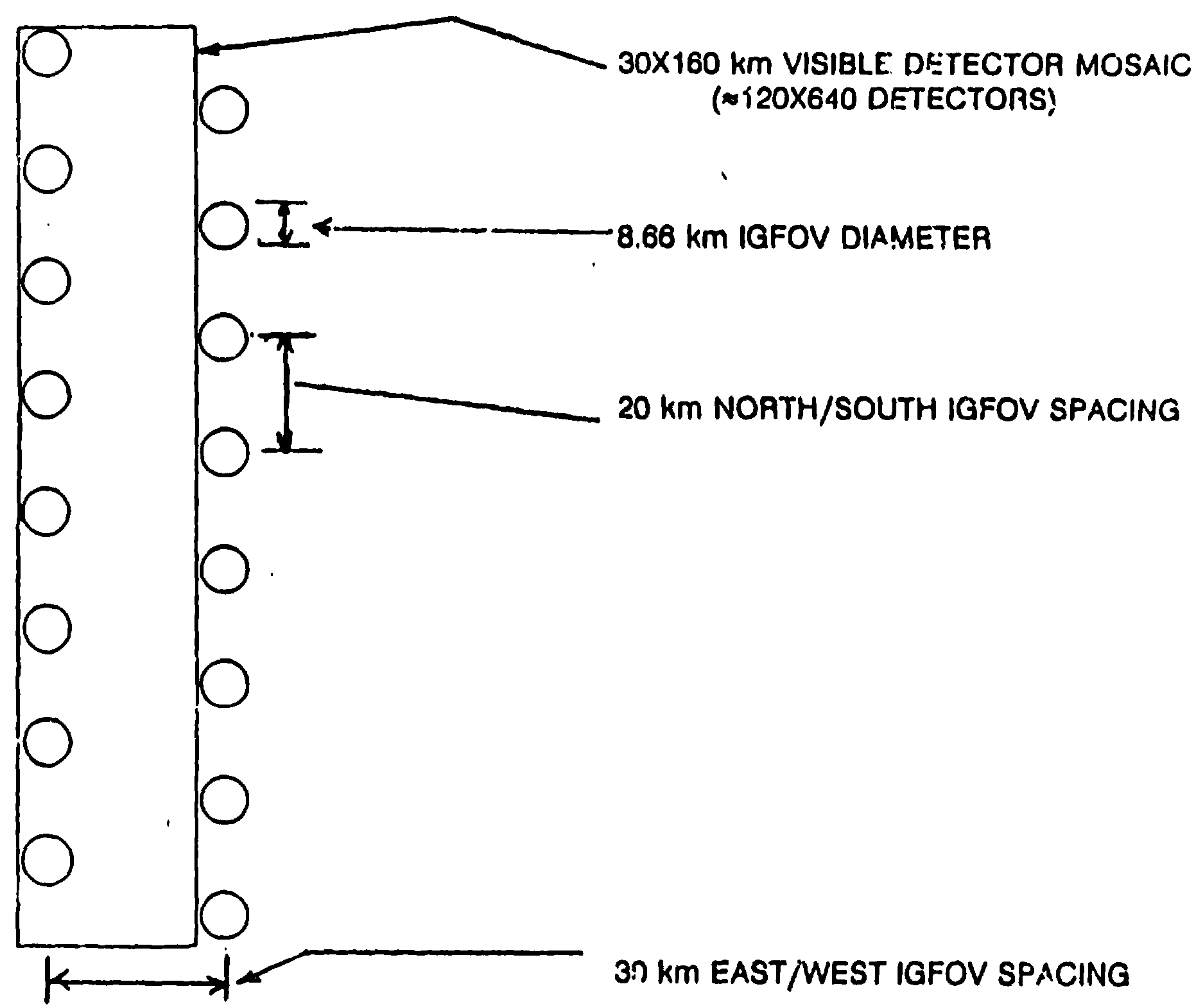


Figure 9.3.3–3

OPTION II FOCAL PLANE ARRAY



The baseline signal processing approach is to send the digitized interferogram to the ground without performing any in-orbit signal processing such as the Fast Fourier Transform. Section 11 shows that the communication subsystem can accommodate the required data rate within the existing spectrum allocation, albeit at some increase in power requirements. It is the study team position that unless there is overriding need to put this processor in the satellite, better reliability will be realized by ground processing.

9.3.4 Option III Sounder Configuration

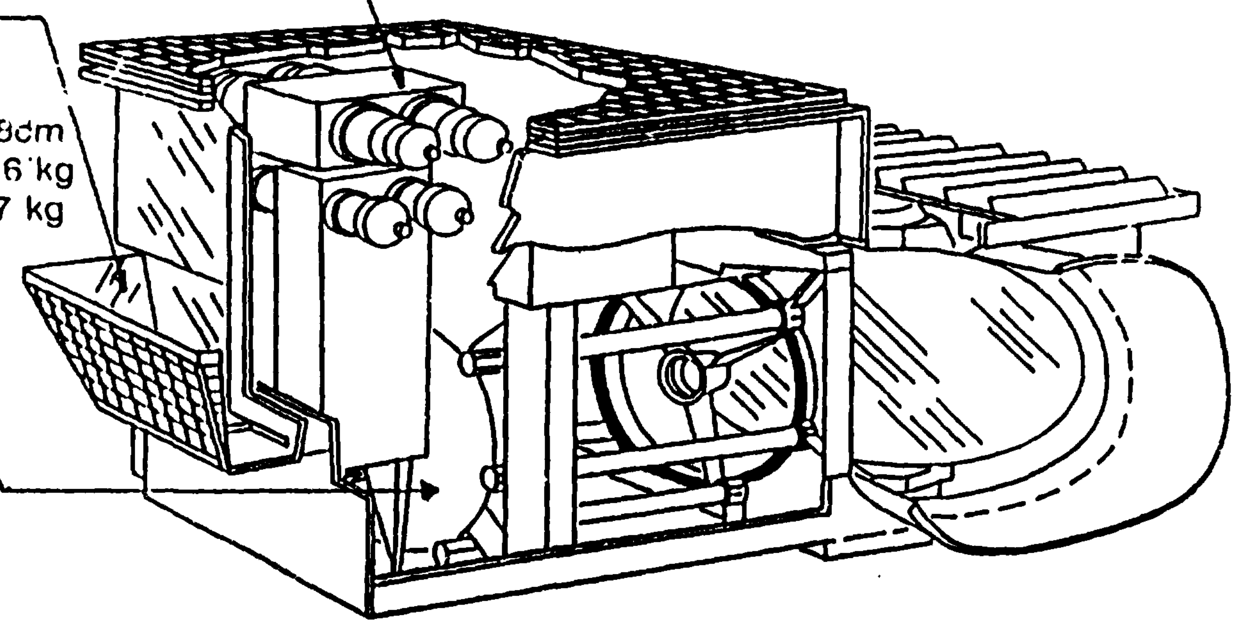
Figure 9.3.4-1 shows the configuration of the Option III sounder. Mechanically, it differs from the Option II sounder in that a Stirling Cycle cooler has replaced the passive radiator cooler and the optical aperture has been reduced back to the 30cm of GOES I-M It should be noted that the mass of the two approaches is very similar since we can use the smaller optics aperture with the refrigerator and still obtain much better radiometric performance. The refrigerator weight is offset by the lighter optics weight. The power requirement is of course higher for the Option III instrument concept because of the refrigerator.

The Stirling Cycle cooler is modeled after the plans for the AIRS instrument on EOS. Four compressors are mounted at the top of the figure to an external bulkhead which has the same orientation as the passive radiator cooler of Option II, but now rejects the heat from the compressor operation. Four cooler displacers are mounted to the aft optics below the compressors, and with their "cold fingers" in thermal contact with the cooled focal plane. Each compressor is connected to its corresponding displacer by a single line carrying the working fluid. The units are operated in opposing pairs to minimize the mechanical excitation of the aft optics of the instrument. The schematic is intended to indicate mechanical isolation insofar as possible between the compressor units and the and aft optics of the instrument. Two such pairs are provided for redundancy, with only one pair operating at any time. No thermal switches are used in the AIRS concept, so that the "OFF" pair of displacers presents a parasitic heat load to the "ON" pair.

Use of mechanical refrigerators in long-life spaceborne applications is in a developmental stage, and flight proven hardware does not exist at the present time. However, NASA is making a major investment in space technology in this area through the EOS program, which is relying on mechanical refrigerators for several major instruments. It is likely that by the "design freeze" for GOES-N, these devices will be available nearly "off the shelf". It would not be prudent to rule out the use of mechanical refrigerators so early in the GOES-N development cycle, since this technology appears to be a prerequisite to satisfaction of NOAA's sounding needs in the GOES-N era. Instead, the work already in process should be supported with the view of incorporating it with confidence in the GOES-N spacecraft when that decision point is reached.

FIGURE 9.3.4-1

OPTION III SOUNDER



Use of the mechanical refrigerator makes possible the incorporation of contemporaneous IR detectors for nighttime cloud-clearing (RO18). Figure 9.3.4-2 shows the modification to the aft optics required to implement this capability. Upstream of the interferometer, an achromatic beamsplitter with ~ 90% transmission steals a small amount of energy from the beam and reflects it to a fourth port on the vacuum housing of the cooler. A relatively slow field lens (f/no ~ 3) images the scene on a linear array of 80 indium antimonide (InSb) or mercury cadmium tellurium (HgCdTe) detectors at roughly 50μm pitch. Figure 9.3.4-3 shows the superposition of the contemporaneous IR channels on the IR focal plane in object space. For the optical arrangement of Figure 9.3.4-2, a slit aperture in the field stop at the telescope prime focus is required to match the imaged linear array. However, the same concerns expressed in Section 9.3.3 with this optical design are applicable to Option III. It is noteworthy that elimination of the field stop at the telescope prime focus would allow the consideration of a staring area array for the contemporaneous IR cloud clearing channels, with a corresponding improvement in sensitivity. The visible cloud clearing array is identical to the Option II sounder.

9.4 Sounder Performance

9.4.1 Sounder Spatial Performance

9.4.1.1 Sounders Spatial Weighting Functions (SWF)/Encircled Energy

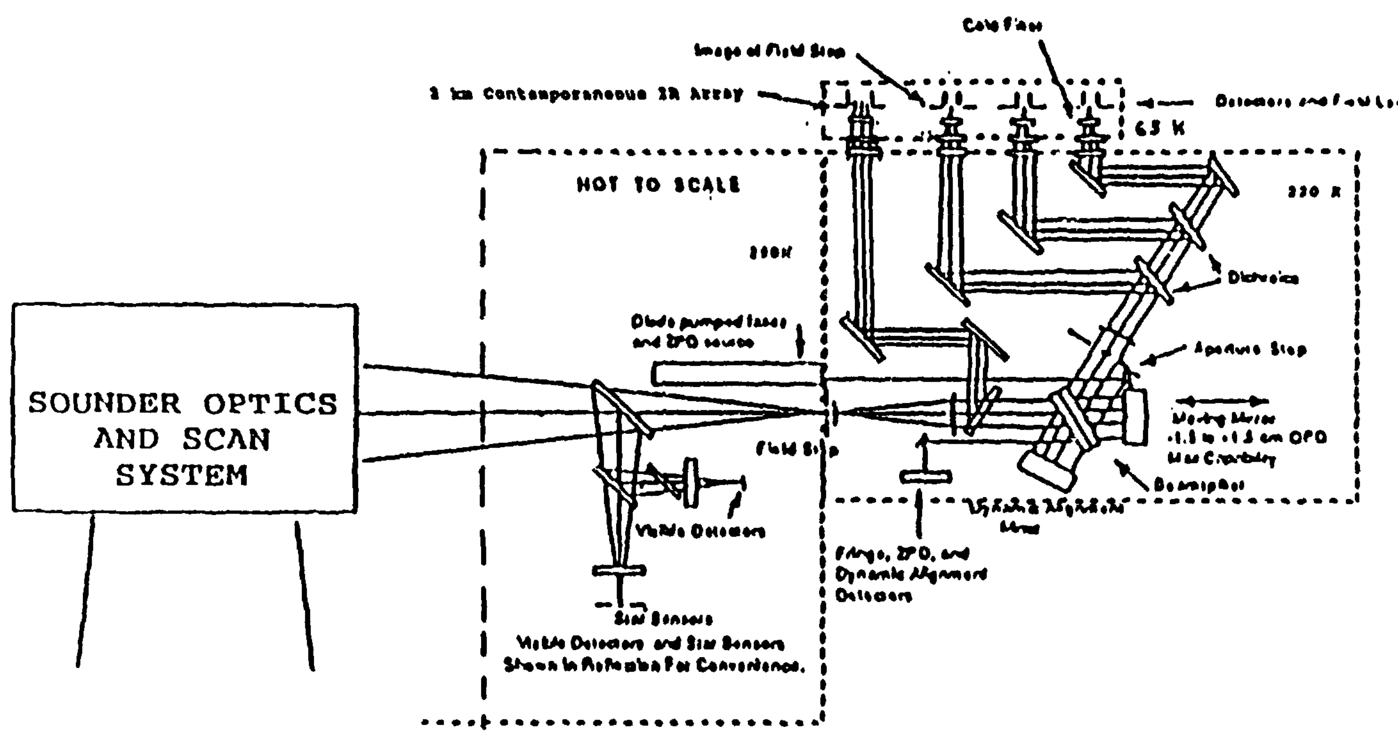
The relative response of a radiometric sensor to radiation arriving from a given direction with respect to some arbitrary origin fixed in the scene is called the SWF. The system output at any time is the integral of the product of the SWF and the scene brightness in the appropriate spectral band. The SWF is primarily a function of the channel IGFOV in object space, i.e., the IGFOV is the result of mapping the channel field stop backward through a diffraction-free optical system to its resulting configuration in the scene. For a multi-channel instrument, (i.e., one that has multiple channels sampling either spatially or spectrally diverse portions of the scene) each channel's SWF is in general different. For GOES-N, the co-registration requirements for the imager and sounder channels place stringent constraints on the SWFs of the various spectral channels. Likewise, the specifications placed on matching channel spectral response centroids and widths for the sounder attempt to maintain uniform spatial distribution of the scene contribution to the measured radiance as a function of wavelength. The optical system unfortunately alters the SWF in a wavelength dependent manner through the effects of diffraction, so that the "footprint" in the scene may be quite different for two spectral channels which have identical IGFOVs. For a scanning instrument such as the imager, the SWF is a function of time, as the IGFOV is moved over the scene under control of the scan mechanism. For such a dynamic situation, the SWF is further modified by the electronic bandwidth of the observing system.

For the GOES-N sounder, the SWF is given by the two dimensional convolution of the channel IGFOV with the (on-axis) optical point spread function. Since the scanner operates in a "step-and-settle" manner and any residual scene scanning due to the spacecraft ephemeris is removed by the IMC subsystem, the SWF for a given sounding column is not a function of time. The SWF is three dimensional, as it specifies the relative response versus two scan axis coordinates,

Figure 9.3.4–2

OPTION III SOUNDER OPTICAL SCHEMATIC

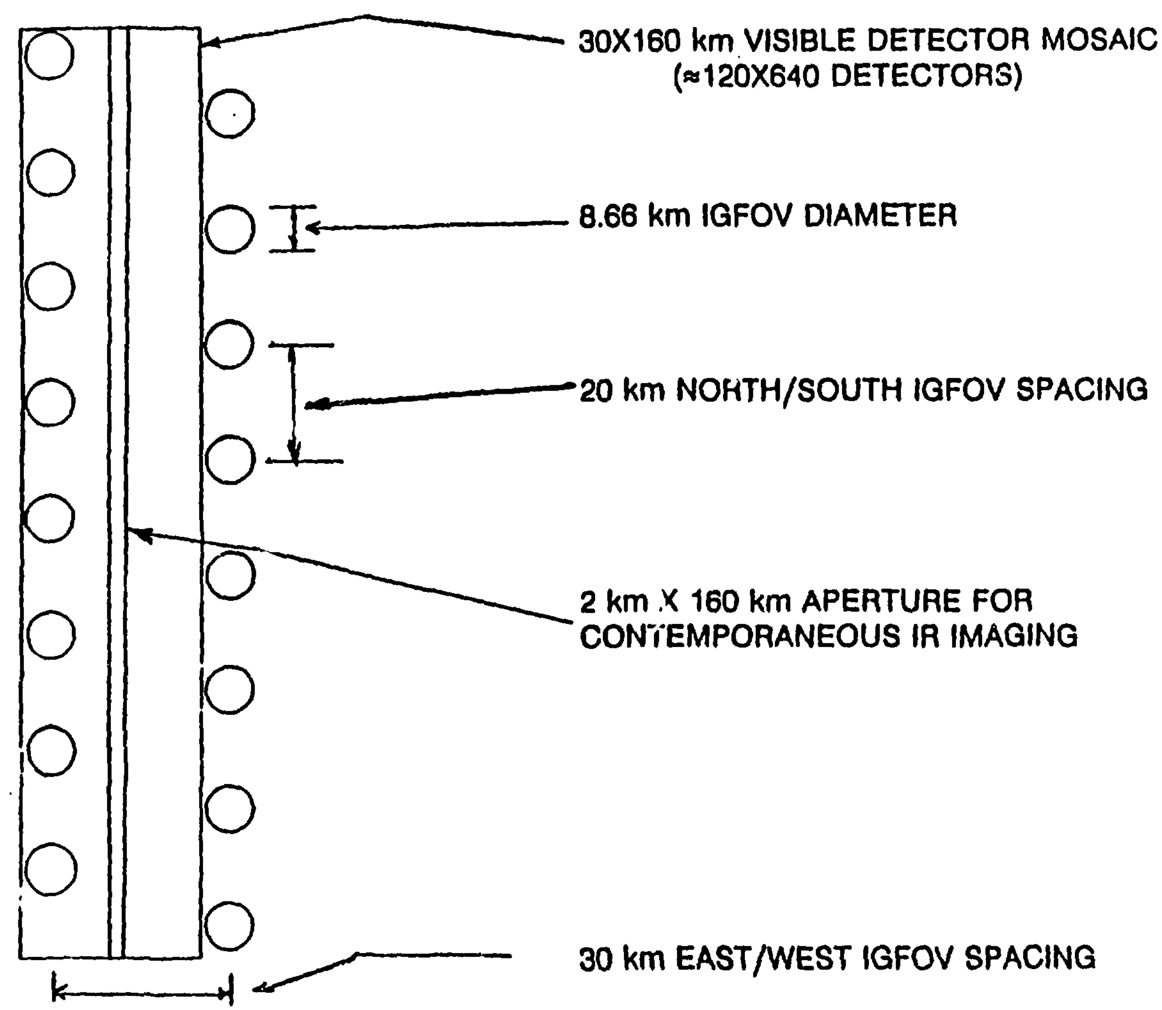
(MECHANICAL REFRIGERATOR CONFIGURATION)



Main components of the interferometer

Figure 9.3.4–3

OPTION III FOCAL PLANE ARRAY



but since for an ideal optical system it is radially symmetric with respect to the channel centroid, one may cross section the SWF through its center and display it in two dimensions. Figure 9.4.1-1 shows the spatial weighting function of the two wavelength extremes of the GOES I-M sounder, as if they were perfectly co-registered in object space. The diffraction induced effects in the SWF are clearly significant for the 30cm optical aperture and 242.6μr IGFOV applicable to the instrument model. Figure 9.4.1-1 in fact does not properly show the possible impact for scene irradiance from far outside the IFOV because the GENII software used is not accurate for SWF below about 1 per cent. Further, a log scale would be more appropriate for the ordinate because the dynamic range inherent in the scene is so wide that a large out-of-field high contrast area in the scene may couple quite strongly into the spectral channel at even low values of SWF.

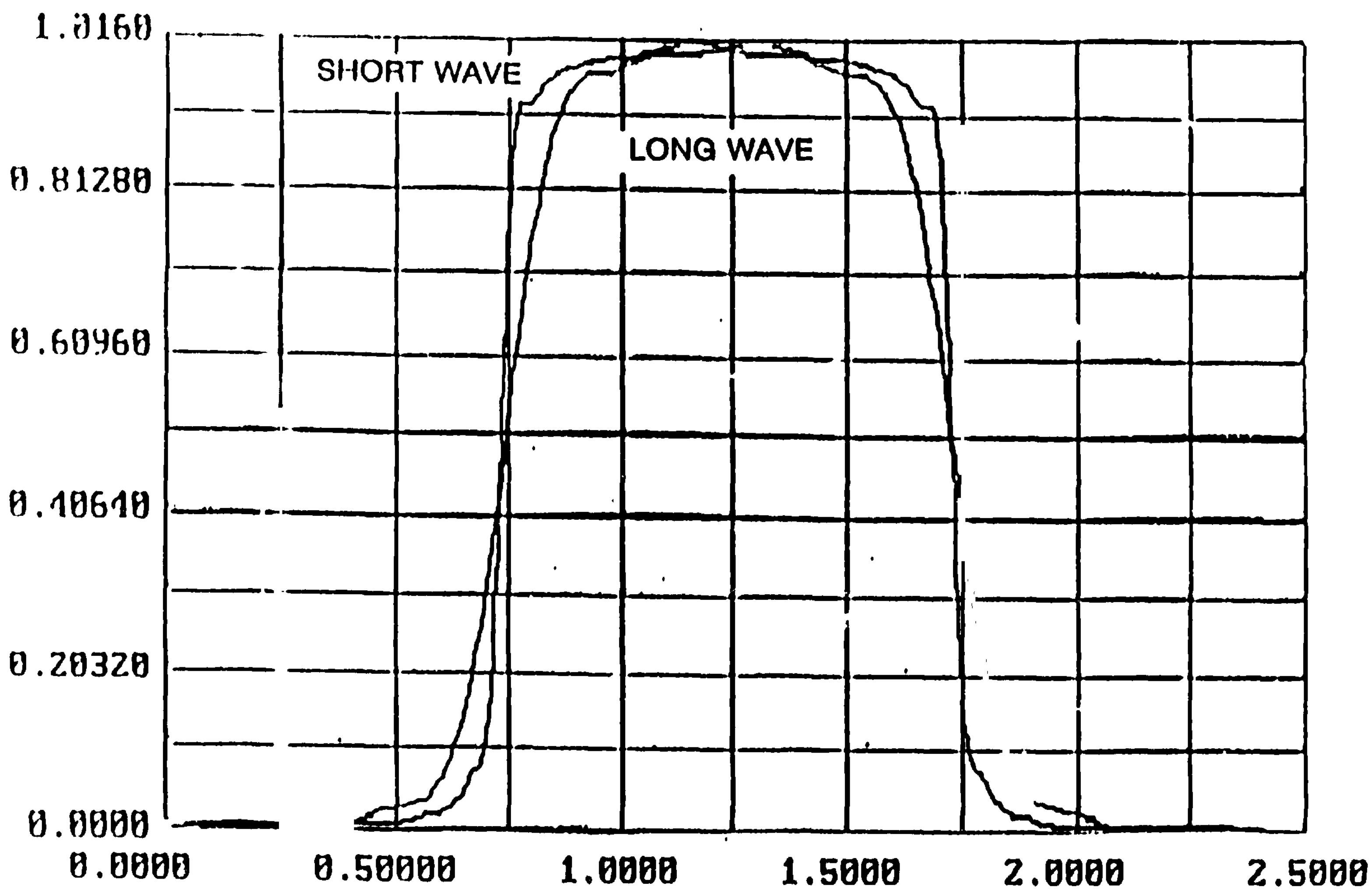
Diffraction effects limit the encircled energy performance of the sounder, particularly at the longer wavelengths. The encircled energy requirement RC28 (paraphrased) specifies that the two dimensional integral of the normalized SWF over a circle about its centroid shall be > 0.7 for a radius of 1/2 IGFOV, and > 0.83 for a circle of radius 0.625 IGFOV. Figure 9.4.1-2, taken from the GOES-I Critical Design Review (CDR) material, shows the calculated encircled energy performance for the longwave channel as a function of primary to secondary mirror despace, the most significant variable for that performance parameter. It can be seen that encircled energy of ~ 0.83 is the best achievable.

Since that level is principally due to diffraction, a requirement of 0.83 leaves essentially no margin for error for a 30cm optical system. For that reason, the encircled energy performance requirement for GOES I-M was relaxed from a spectrally flat 0.85 at 1.25 IGFOV to be wavelength dependent with a longwave value of 0.73. Achieving the requested 0.83 or better at all wavelengths implies optimal system performance for a 30cm aperture and essentially zero despace tolerance. This performance level can be obtained with margin given the larger aperture (35cm) and suitably athermal instrument design contemplated for the Option II sounder. For the Option III sounder, even with an athermal design, there is no margin for error due to its 30cm aperture. Consideration should be given to either relaxing the requirement for encircled energy to approximately 0.80 at 1.25 IGFOV, or encouraging the use of a larger aperture for the sounder.

9.4.1.2 Single Pixel Sounding

This topic is addressed only because the requirement document states that single pixel sounding should not be precluded. What follows is an attempt to address an engineering type statement to these words. NWS has not responded with any clarification of the intent of the words at the time of the writing of this report.

The ability of the sounder to retrieve vertical profiles of temperature and moisture in broken (i.e., partly cloudy or highly structured) scenes is intrinsically related to the encircled energy performance of the instrument. This study has not addressed an error analysis for the retrieval process nor selection of optimal cloud clearing algorithms for control of those errors. Thus, there has been considerable discussion as to the correct interpretation of requirements RC28, which requires a sounding for a 60 x 60km area using 9 "clear" IFOVs, and RO28 which requires



SOUNDER SPATIAL WEIGHTING FUNCTIONS

FIGURE 9.4.1-1

SOUNDER LONGWAVE CHANNEL
ENCIRCLED ENERGY VS PRI-SEC DESPACE

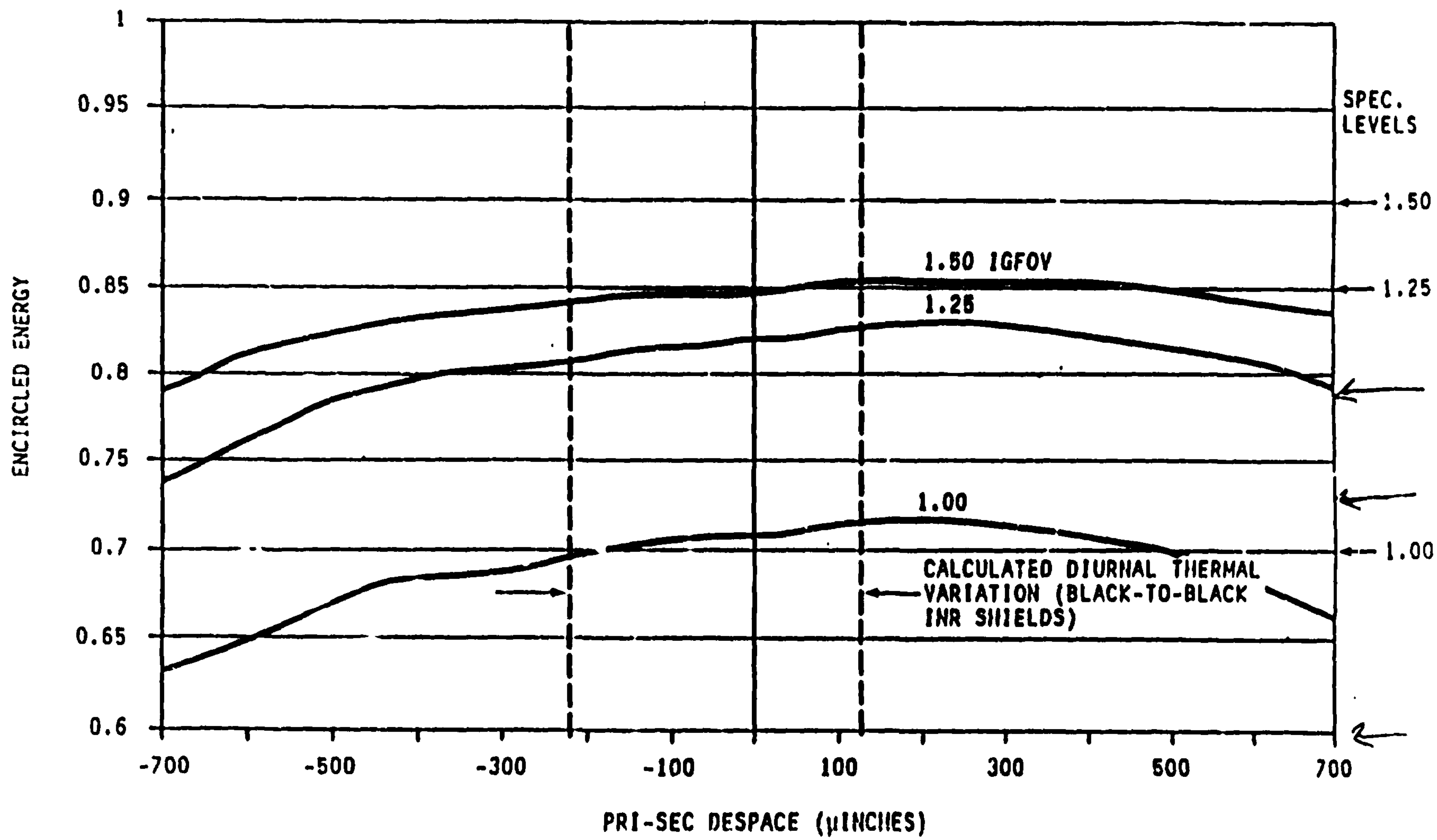


FIGURE 9.4.1-2

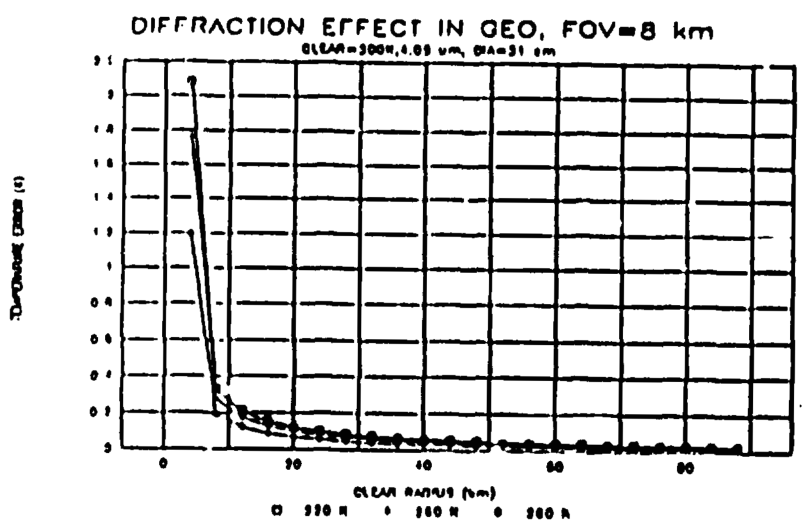
AEROSPACE/OPTICAL DIVISION ITT

SOUNDER ENCIRCLED ENERGY

REQUIREMENT: 70% OF ENERGY WITHIN 8 KM IGFOV FROM 8 km AREA AND 83% FROM 10 km AREA. PROVIDE THE POTENTIAL FOR SOUNDINGS OF INDIVIDUAL FOVs.

ISSUES:

- o CURRENT SOUNDER SHOULD ACHIEVE THE ENCIRCLED ENERGY REQUIREMENT. HOWEVER, THIS PERFORMANCE IS <u>NOT</u> ADEQUATE FOR "SINGLE PIXEL" SOUNDING AT LONG WAVELENGTHS.
- o IF A 10 km HOLE IN A 220 K CLOUD SURROUNDS AN 8 km, 300 K SCENE, THE TRUE RADIANCE IS CONTAMINATED, LEADING TO OVER 8K ERROR IN EFFECTIVE BLACKBODY TEMPERATURE.
- o EVEN WHEN THE HOLE DIAMETER IS INCREASED TO 40 km, THE ERROR IS STILL 1.0 K.
- o PERFORMANCE AT SHORT WAVELENGTHS IS CONSIDERABLY IMPROVED (SEE CHART).



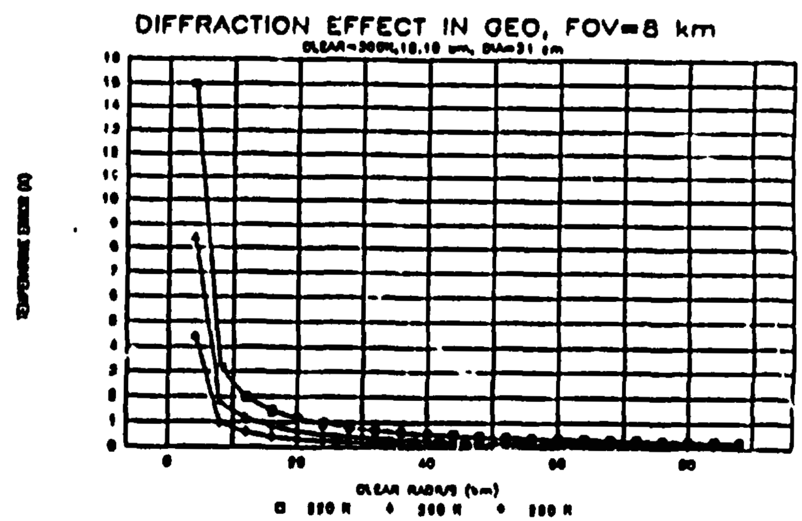


FIGURE 9.4.1-3

"single" IFOV sounding. The crux of the problem is the extremely large dynamic range of scene radiance mentioned in Section 9.4.1.1 which results from the T^4 dependency of that radiance. Extended clouds from well outside the IFOV can cause significant errors in the brightness temperature associated with the scene. Figure 9.4.1-3 shows the magnitude of this effect for sounding at both short and long wavelengths through a hole in an otherwise overcast scene. Two striking conclusions can be drawn. First, the spatial resolution achievable for sounding at short wavelengths is dramatically better than at long wavelengths. Second, sounding broken scenes at long wavelengths is limited to situations where relatively large clear areas are available. Just how large can only be determined by an error analysis for the retrieval process, including the effects of the cloud clearing algorithm to be used. Figure 9.4.1-4, defines the criteria for single pixel sounding in terms of a yet to be determined allowable error in inferred brightness temperature.

FIGURE 9.4.1-4
SINGLE PIXEL SOUNDING
SUGGESTED CRITERIA

- **A CLOUD FREE AREA IS ASSUMED IN WHICH A SENSITIVITY IS ACHIEVED EQUIVALENT TO 0.2K NEAT AT A SCENE TEMPERATURE OF 260K[1]**
- **SECOND, THE REQUIRED EXTENT OF THE CLOUD FREE AREA IS WAVELENGTH DEPENDENT AND IS DEFINED AS THAT EXTENT NECESSARY TO MAINTAIN THE ERROR IN INFERRED TEMPERATURE FROM A MAXIMUM CONTRAST CLOUD AT LESS THAT TBD K**
- **THIS ALLOWS AS FEW AS ONE GOOD SOUNDING PER 60KM X 60KM SOUNDING AREA TO MEET THE REQUIREMENTS FOR INVERSION OF RADIANCE DATA TO VERTICAL TEMPERATURE AND MOISTURE PROFILES**

(1) Recommended by W. Smith of University of Wisconsin

The NWS is currently planning to average the results of 9 separate "clear" soundings within a 60 x 60km cell to achieve the accuracy for their retrievals. If NWS desires to be able to work from a single clear sounding in the cell, then the following criteria may be the correct statement of the requirement to achieve a single pixel sounding:

Using a nominal scene condition of 260K with an atmospheric emissivity of 1.0, then the required sensor noise equivalent change in temperature must be less than 0.2K in every spectral interval. In addition a clear hole in the clouds must be twice the diameter of the IGFOV (i.e., for an 8km IGFOV, the hole in the cloud should be 16km). This is defined to account for the radiance contamination of the clouds causing a different effective temperature to be measured. Other criteria could be developed for distance for the edge of a cloud in which the sounding column was along only one edge.

9.4.1.3 Sounder Co-registration Requirements

The sounder channel-to-channel or co-registration requirements, identified as RC25 for this study, were defined by NOAA as a core requirement to have the centroids of the SWFs for the various spectral channels matched to 2% of total IFOV width (1σ) and the half-power SWF channel widths matched within 1% (1σ). The initial assessment of unmet NOAA requirements versus spacecraft options that was presented at the GOES-N Study Final Review presented a predicted centroid matching to 10μr performance for all 3 options versus the 2% or 4.5μr requirement and a half-power IFOV of 20μr for all three options versus the 1% or 2.2μr requirement.

The study team's assessment was that these requirements could not be met because:

- Diffraction limits the similarity of spatial weighting function,
- Fabrication and calibration techniques limit accuracy of matching centroids,
- Thermal and lifetime stability of beam splitter optics limits stability of co-registration across the 3 spectral bands of all 3 sounder options, and the
- Step & settle performance of the Option I sounder causes co-registration errors between channels in the same spectral region.

A memo from Paul Menzel and Hank Revercomb of the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin titled "Further Clarification of Some of the GOES-N Specifications Causing Difficulty" provided some potential clarification of these requirements. The appropriate section of this memo reads as follows:

Sounder Channel to Channel Registration (Core):

This can be rewritten so that the window channel in each band (long, middle and short wavelength) is the reference of registration. Thus, "the channel to channel registration for each channel within each band with respect to the window channel in that band must be such that the radiometric response centroids shall be within ± 2% of the total FOV width and that the half power FOV channel widths shall match each other to within the diffraction limit."

This is a significant modification of the requirement and, if accepted by NOAA, should make it feasible to match the centroids to the 2% required on the Option II and Option III sounders. Problems in making measurements of the width of the 1/2 power points of the FOV will preclude validation of performance to 1%. Brief discussion of how these requirements are approached in the Sounder design are presented in the following sections.

An Option requirement to co-register cloud detection visible and IR data within 14μr (3σ) and to have all IFOV's matched to within 2% (1σ) was identified as RO25 for this study.
(c.f., Section 9.4.3) Which discusses the cloud-clearing channels for the sounders and indicates that this requirement can be met.

9.4.1.3.1 Option I Sounder Co-registration.

The GOES I-M sounder can be modified to improve the co-registration performance without major changes to the sensor.

One modification would be to slow down the filter wheel by about 10% and increase the time allowed for the scan mirror to step and settle from 28ms to 38ms. This could reduce the motion of the line of sight during the time soundings are being measured from about 10μr to less than 7μr which causes misregistration of the sounding channels relative to the window channel. This would keep the signal to noise ratio of the sounding channels unchanged but will increase the time required to cover a given area by 10%. This will also simplify the fabrication of the sounder by allowing some reduction in the required performance of the east-west servo of the sounder.

Another modification would be to temperature stabilize the aft optics beam splitting assembly to minimize diurnal and seasonal temperature variations which cause the 3 spectral bands to change their relative alignments. The modification in the co-registration requirements identified in the CIMSS memo cited above, if accepted, could eliminate the need for this modification.

9.4.1.3.2 Options II & III Sounder Co-registration

The Option II and III sounders will require beam splitting systems to direct the signal to different detector arrays in the 3 spectral regions and thus would have similar co-registration problems as the GOES I-M sounder if the changes in the requirements identified in the CIMSS memo are not accepted. The large arrays proposed for the Option II & III sounders lead to long dwell times and, thus, the step and settle time and performance of the scan mirror should not be a significant factor in the co-registration of these instruments. The beam splitting systems will be designed considering the thermal variations to be seen on orbit and may include in-flight adjustments if required.

The edge of the moon can be observed in the visible and sounding channels and used to verify the co-registration in orbit. The moon has an albedo of about 0.07 to 0.1 and thus would be directly compatible with the visible and star sensor detectors. The sunlit portions of the moon reach temperatures of about 400K and thus for the IR sounding channels it will be necessary to incorporate a system to reduce the gain and thus avoid saturation when observing the moon. With these design features incorporated it should be possible to check the co-registration of the sounder in flight.

9.4.2 Sounder Radiometric Performance

9.4.2.1 Requirements

Three different technologies were considered for the high spectral resolution sounder: Fourier Transform Spectrometer (FTS), grating spectrometer, and Fabry-Perot interferometer. Rather than develop separate models specific to each approach, an existing Lotus 123 spreadsheet was modified to do a generic analysis.

The spreadsheet model does not attempt to simulate complex atmospheric profiles. Instead, it is assumed that the atmosphere is a 260K blackbody radiator. A complete description of the analysis is presented in Appendix E entitled "Advanced Sounder Studies."

The analysis shows that if all spatial, spectral and temporal requirements are to be met simultaneously, then the NEΔT requirement of 0.2K cannot be attained. The overriding limitation on NEΔT performance is detector noise. Actively cooling the focal plane substantially reduces detector noise, but still does not achieve the desired NEΔT performance.

Because detector noise dominates all other noise sources, the following courses of action will be of great benefit in improving NEΔT performance:

- Cooler fore optics
- Cooler aft optics
- Increased Analog-to-Digital (A/D) resolution

9.4.2.2 Performance Tradeoff

From the radiometric analysis, it is clear that in order to meet the NEΔT requirement of 0.2 K, performance trades must be made. Such alternate performance considerations could include any combination of the following:

1. Colder focal plane (to reduce detector noise)
2. Larger IGFOV
3. Smaller frame area
4. Larger optics
5. Wider spectral bandwidths
6. More detectors in the focal plane
7. Increased frame time
8. Using a skip scan

This list is ordered in decreasing relative importance; that is, the first several items on the list produce the most pronounced improvement in NEΔT without compromising area coverage.

Figure 9.4.2-1 compares the expected NEΔT for an actively cooled focal plane to that of a passive cooler (i.e., 65K vs. 85K focal plane).

The effects of changing the IGFOV are illustrated in Figure 9.4.2-2.

Numerous additional plots are presented in Appendix E. The plots show projected NEΔT performance for a fairly wide range of spatial and temporal conditions. The conclusion to be reached is that essential satisfaction of the sounding system requirements advanced by NOAA for GOES-N can only be attained by multiplexing many more data channels (i.e., using larger numbers of detectors) and at the same time achieving much colder focal plane temperatures than

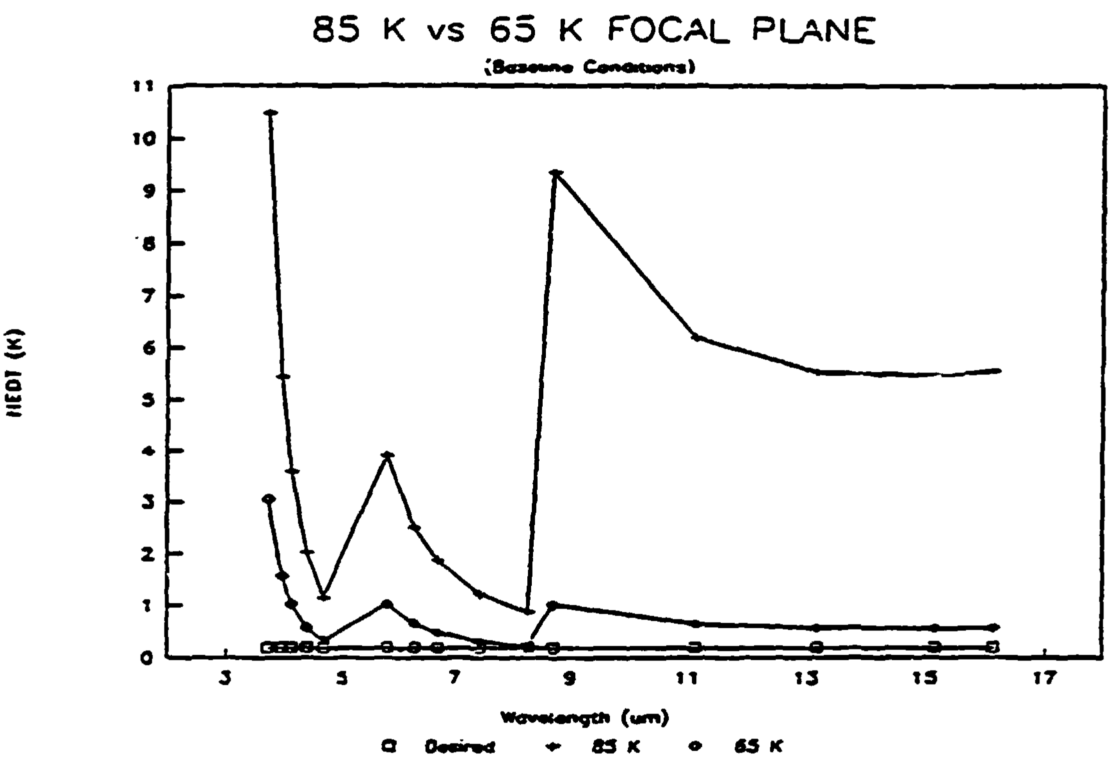


FIGURE 9.4.2-1

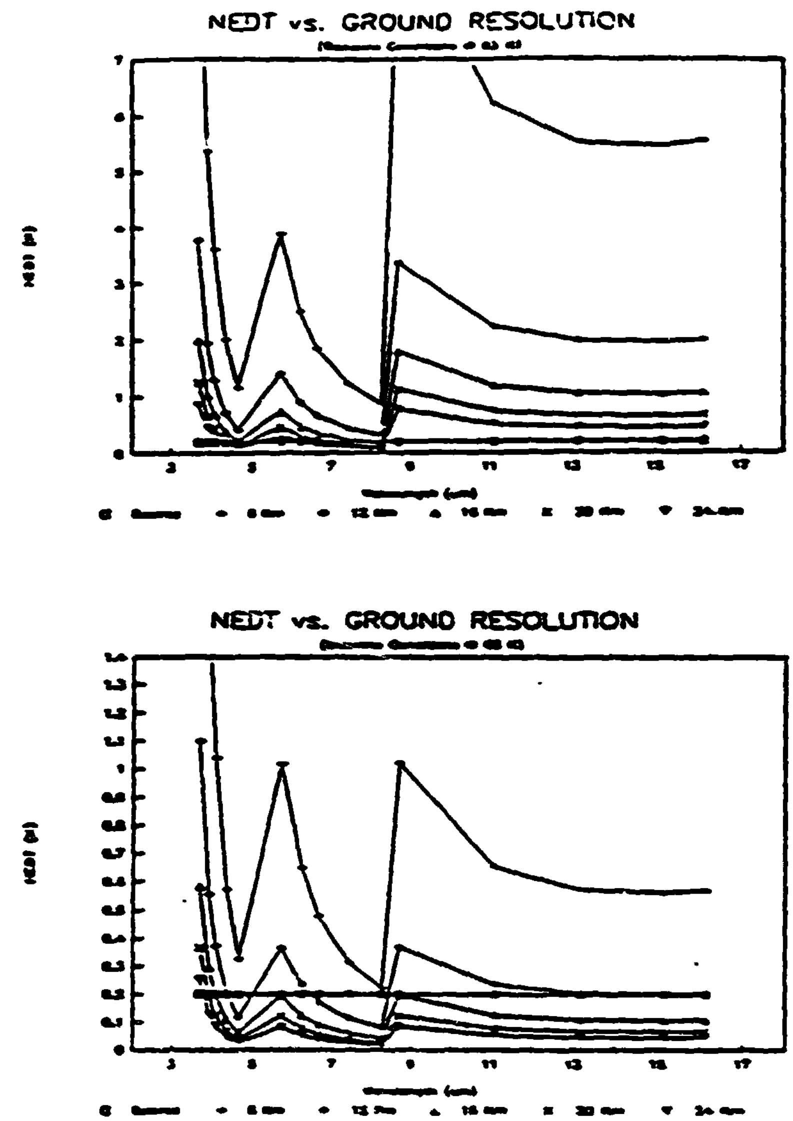


FIGURE 9.4.2-2

is the case for GOES-I. While the indication is that a cryo-refrigerator is required and should be pursued, more study should be also be devoted to extending the passive cooler approach to lower temperatures as an option, should the advance in reliability of the mechanical approach be less than hoped for.

9.4.3 Sounder Performance - Cloud Clearing

NOAA's requirement for contemporaneous visible imagery for sounder cloud detection at a 1km resolution (IGFOV) was identified as Option requirement R018 in this study and was also interpreted by NASA as indicating a desire to see clouds at night using a 2km IGFOV in the 3.8μm IR band.

Option I Sounder - 1km Visible for Cloud Clearing

The GOES I-M sounder could be modified to provide cloud detection with 1km IGFOV visible detectors. This could be accomplished using linear or area arrays of silicon detectors. A linear array of 10 detectors in a vertical line each 1 x 1km could be readout during the time the scan mirror is stepping to the new position. This could provide good sensitivity, greater than 3 to 1 south-north at a signal to noise ratio of 0.5% albedo, but would have co-registration uncertainties because of uncertainties in the precise position of the scan mirror while stepping. Image rotation effects on this data would match the rotation of the sounding detectors but would make the generation of a contemporaneous cloud images more difficult.

The preferred approach is to use an area array of detectors, probably a CCD to detect the clouds. The focal length of the sounder telescope is about 3.56 meters which would require detectors 100μm on a side to provide a 1km IGFOV.

This is a large detector for a CCD array. Most CCD have detectors between 10 and 25μm on a side with a large number of detectors in rectangular arrays. It would be reasonable to use any space qualified array, such as those used in CCD star trackers for the cloud detection. The signal from the detectors would be summed in the spacecraft to synthesize a 10 x 10 array of 1km IGFOV "detectors" and the data sent to the ground in the wideband data. This array would integrate the signal from the scene for part of the dwell time (say 50ms) to minimize jitter due to the step and settle of the scan mirror. This array would be very sensitive and could provide good cloud detection at very low light levels.

Co-registration of the visible data to the IR arrays could be done to better than 1/4 of a km (7μr) by controlling the timing of the readout and, thus, could be adjusted in the TV chamber or in flight. The readout of this array could be controlled so as to compensate for the image rotation so that good cloud images could be generated, but the co-registration with the IR would degrade slightly.

Either of these two approaches would increase the data rate from the GOES I-M sounder because 100 x 4 visible channels must be telemetered versus the 4 channels in the present design. The minimum increase in the data rate would be about 40,000bps.

This same array could be used for star sensing if a spectral region could be identified that would provide for both star sensing and cloud detection. This would remove some optical complexity from the present design. The star sensor performance could be better than that of the present sounder because it would be feasible to electrically back scan the data in the array to track the 73 μr/S motion of the stars as seen by the detectors. This would allow for a few seconds of integration time versus the 0.3sec. currently used in the Operation Ground Equipment (OGE) which would improve the south-north by perhaps a factor of 2. A single readout of the array would be done after the signals are integrated and sent to the OGE which would locate the star in the FOV. In this mode it would be preferred to readout at the pixel resolution of about 1/4 km so that the star could be located to better than 7μr.

Option II and III Sounders - 1km Visible for Cloud Clearing

A similar approach could be used to provide 1km IGFOV visible for cloud clearing for the HSRS used in Option II or III. The CCD array must accommodate the specific focal length of the telescope and IR array size used in the HSRS. Assuming the focal plane array of Figure 9.3.3-3 is used, then an array to synthesize a set of 30 by 160 1km cloud detection detectors would be used as a minimum. Assuming that each physical detector has a 1/4km IGFOV, this is still a small array of 120 by 640 detectors. These same detectors could probably be used for star sensing as described for the Option I sounder. The final array size and processing are flexible and should probably be selected to provide desirable sparse IR sampling modes for improved spatial coverage.

Option I and II Sounders - 2km IR for Cloud Clearing at Night

The Option I and II sounders use passive radiative coolers. These coolers do not provide a large enough cooling capacity at a sufficiently low temperature to make inclusion of this capability feasible.

Option III Sounder - 2km IR for Cloud Clearing at Night

The Option III sounder uses mechanical refrigerators to provide the cooling of the IR focal planes. The refrigerators proposed for the Option III sounder have sufficient capacity at a low enough temperature to make technically feasible the inclusion of an IR array to provide a 2km IGFOV IR detection system operating in the 3.8μm spectral region. This IR array must steal a little light from the short wave spectral region of the sounder and be imaged on an IR detector array as shown in Figure 9.3.4-2.

The IR array may be implemented as a linear or area array using an approach similar to that proposed for the visible cloud clearing detector arrays. The scan rate of the GOES-I imager is 350,000μr/s while the rate of motion of the sounder scan mirror while stepping is under 20,000μr/s. This indicates that there will be sufficient energy to operate in this mode even if less than 10% of the light is diverted from the sounding beams. For the proposed array of sounding channel IGFOVS, a linear array of 80 IR detectors is required. This contemporaneous IR data would have a small impact on the data rate of the HSRS.

While the Option III sounder model uses the linear array, less light would be required and better performance could be achieved if an area array of IR detectors were used. Arrays of InSb and Platinum Silicon (PtSi) detectors have been developed that may be able to be used at the proposed focal plane temperatures with appropriate optics and electronics to process the signals. Sensitivity calculations are required for confirmation of this approach. Use of an area array would require moving the contemporaneous IR beam splitter before the field stop in the telescope focal plane.

While it is technically feasible to incorporate 2km IR detectors for cloud detection at night in the Option III HSRS, it will have a significant cost impact. The Phase-B study of this instrument should include this capability as an option and the real cost difference established. A concurrent study activity should be conducted by NOAA to establish the importance of this contemporaneous IR data to the performance of the sounder and the impact of the difference in the data on their products and forecasts.

9.5 Technology Issues

9.5.1 Technology Issues Nighttime Operations

9.5.1.1 Thermal Modeling of Sunshade Effects

An analysis was performed to determine the thermal gradients in the sunshield and the heat inputs into the scan mirror as the length of the sunshield is increased. The length of the sunshield required to shade the scan mirror from direct sunlight as a function of orbit position or local time and as a function of sun angle relative to the equatorial plane or time of year is shown in Appendix D.3. At periods around the equinoxes, there are times that the sun cannot be shaded regardless of the length of the shield. The current design of the GOES-I,J,K scanners utilizes a sunshield approximately eight inches long which shades the scan mirror from direct sunlight for periods up to two hours after 6:00 P.M. and before 6:00 A.M. The shield does not shade the scan mirror between 8:00 P.M. and 4:00 A.M. A shield of four feet was selected as the maximum practical length to be considered in this analysis.

The sounder sunshield was modeled as shown in Figure 9.5.1-1 as a rectangular cone four feet deep with a rectangular patch at the base to represent the scan mirror aperture. The cone walls were divided into 112 zones to enable prediction of temperature gradients as a function of time of day. The earth viewing face of the spacecraft was modeled as a plate, and a second cone was modeled as shown in Figures 9.5.1-2 and 9.5.1-3 to approximate a similar sunshield on the imager. The earth viewing face of the spacecraft was assumed to be covered with multi-layer insulation (MLI), faced with aluminized Kapton, Kapton side out (α=0.45, ε=0.78); the interior surfaces of the cones were assumed to be painted black (α=0.96, ε=0.87); and the external surfaces of the cones were assumed to be painted white, with or without an MLI blanket (α=0.01, ε=0.03; or α=0.25, ε=0.85).

The scan mirror, scan optics and the radiation shields behind the scan mirror were not modeled because of the complexity and cost of the analysis that would be required. Instead, the patch was assumed to be black (α=0.99, ε=0.99) and decoupled radiatively and conductively from the rear. Two conditions were analyzed: (1) the patch temperature was allowed to come to equilibrium; and

(2) the patch was held constant at 20 degree C and the power required to maintain that temperature was computed. Steady state solutions were obtained for an equinox orbit at positions every 10 degree between 6:00 P.M.(90 degree) and midnight (180 degree). These solutions also apply in reverse order for positions between midnight and 6:00 A.M. because of symmetry.

The results for the four foot sunshield are shown in Table 9.5.1-1. Temperatures are provided for three positions on each cone wall. The specific locations are nodes 8, 11, and 14 on the south wall, 36, 39, and 42 on the west wall, 64, 67, and 70 on the south wall, and 92, 95, and 98 on the east wall. The patch column in the second of the two conditions lists the power required to maintain the patch at 20 degree C. At the 90 degree orbit position, the sunlight does not enter the cone and the cone and patch temperatures are cold. At the 100 degree position, the sunlight illuminates the top nodes of the east wall of the sunshield. At the orbit position of about 155 degree the sunlight illuminates the east wall down to the patch and portions of the north and south walls. At the 170 degree orbit position the patch is fully illuminated by sunlight, and at approximately 1 degree later the spacecraft enters the earth's shadow. Table 9.5.1-2 shows the effect of removing the insulation from the external surfaces of the sunshield and painting these surfaces white. These temperatures are substantially cooler than those in Table 9.5.1-1.

To compare the results from the four foot sunshield with a sunshield comparable to that used on GOES-I,J,K, the model was modified by retaining the nodes adjacent to the patch and removing the outer six layers of nodes. The results are shown in Tables 9.5.1-3 and -4 for comparison with Tables 9.5.1-1 and -2. The configuration comparable to GOES-I,J,K is shown in Table 9.5.1-3. The temperatures of the smaller sunshield are cooler.

Table 9.5.1-5 shows the results for two sunshields of intermediate lengths: (1) three layers of nodes long and (2) five layers of nodes long. Only the patch temperature floating condition was computed for these two sunshield lengths.

It is difficult to draw conclusions from these results without knowledge of the thermal performance of the GOES-I,J,K scanner. However, this analysis does show that the "earth patch" stays cold longer than the short earth shield and, thus, provides a more benign environment.

The scan mirror is highly polished. Part of the sunlight incident on this mirror is absorbed and the rest is reflected into the scan cavity. There, much of the energy is absorbed by thermal shields which are thermally isolated from the cavity walls. The north wall is not shielded and its temperature is regulated by thermal control louvers. The temperatures of the scan mirror and the thermal shields rise sharply as the sunlight strikes the scan mirror and begin to cool when the scan mirror becomes shaded from the sun. The thermal responses vary depending on the thermal mass of each element and on the time intervals that each is exposed to direct or reflected sunlight. The critical factor is the thermal distortion introduced by temperature gradients in the scan mirror. These gradients are increased when the mirror heats up. In addition the front to back gradients reverse during the cool down phase. A detailed model of the scan mirror and the elements in the scan cavity is needed to assess the effects of changes in the length of the sunshield and in its external surface properties.

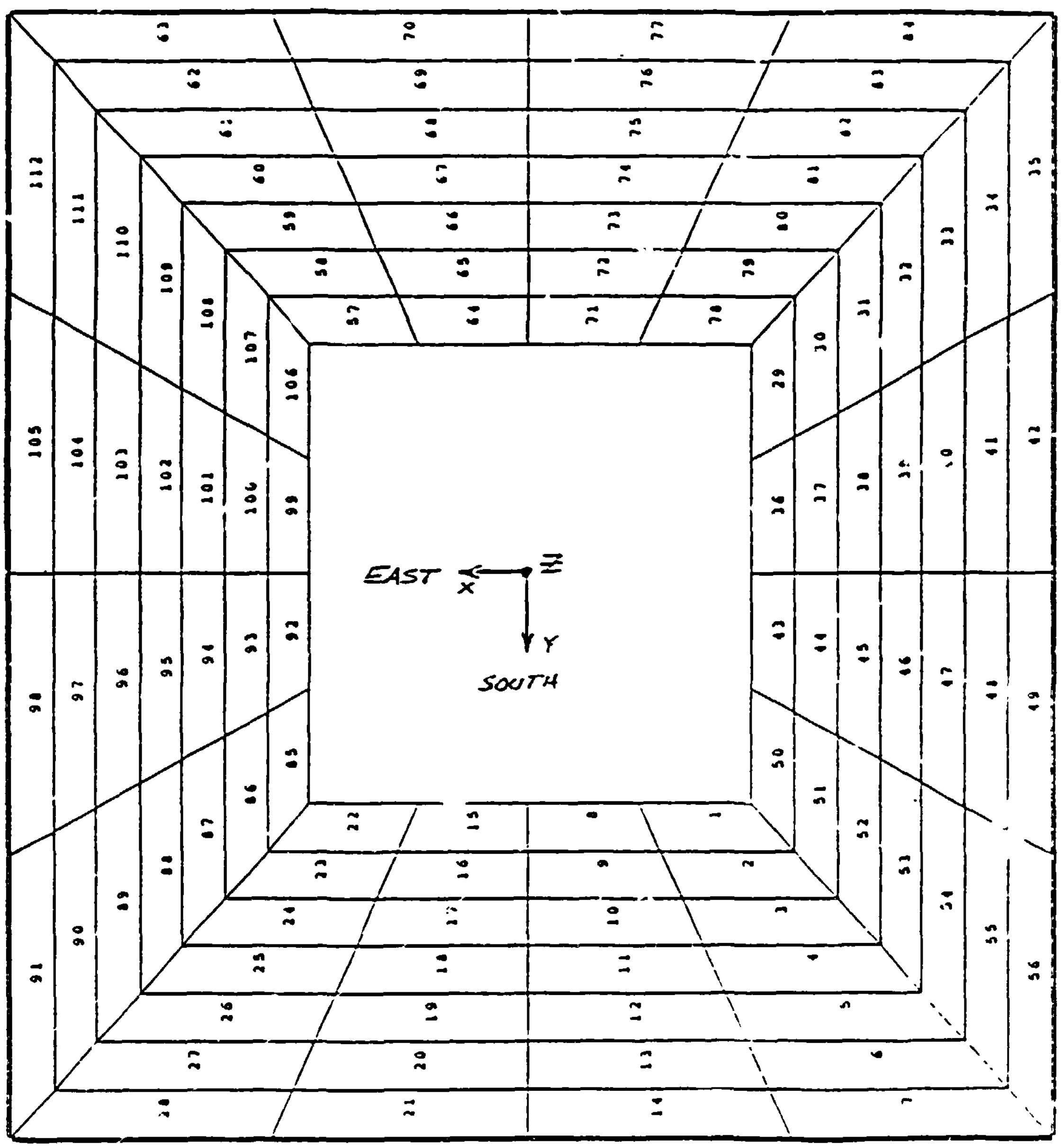


FIGURE 9.5.1-1 Four Foot Sunshield, earth View

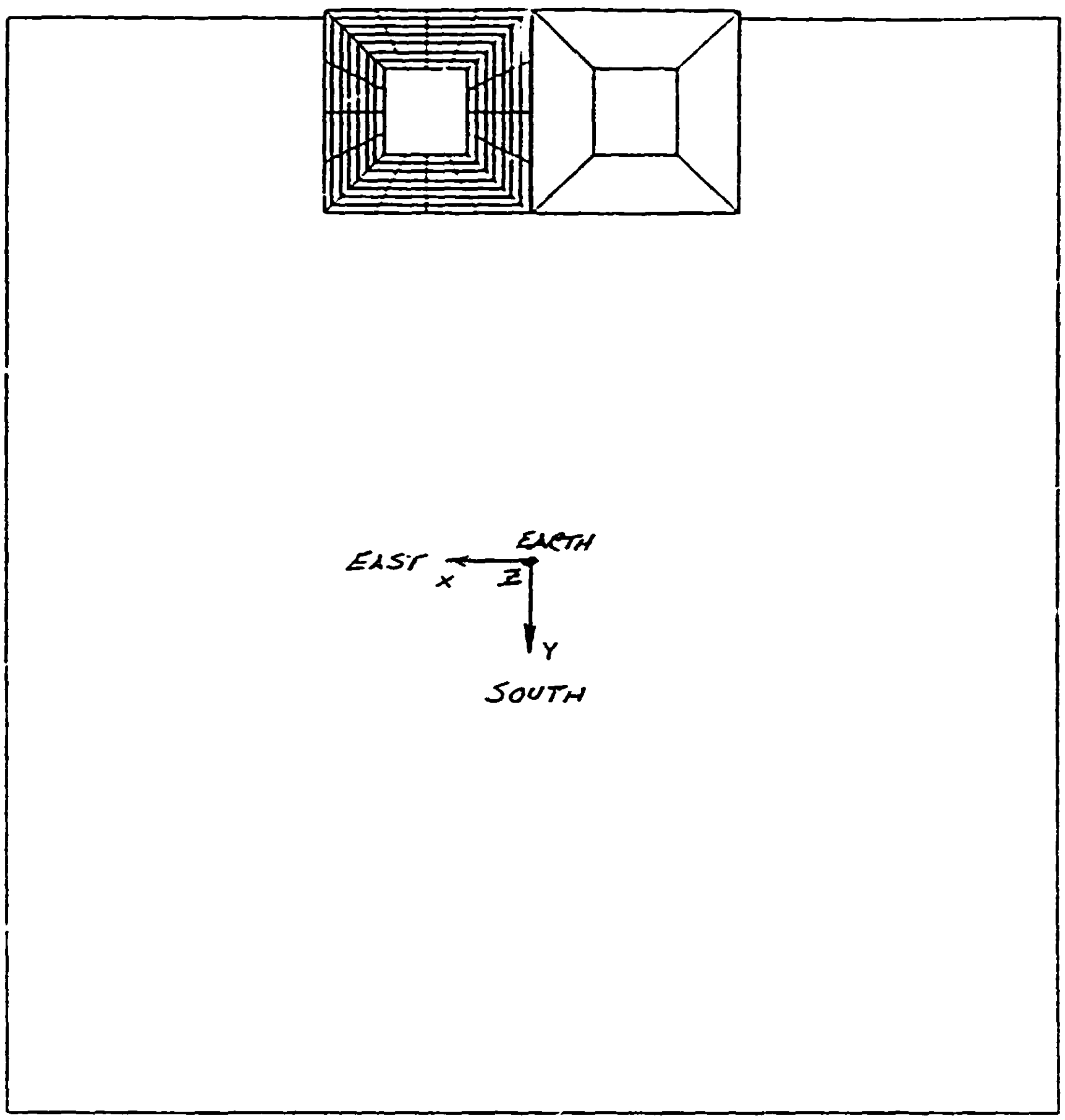


FIGURE 9.5.1-2 GOES, Earth Viewing Face

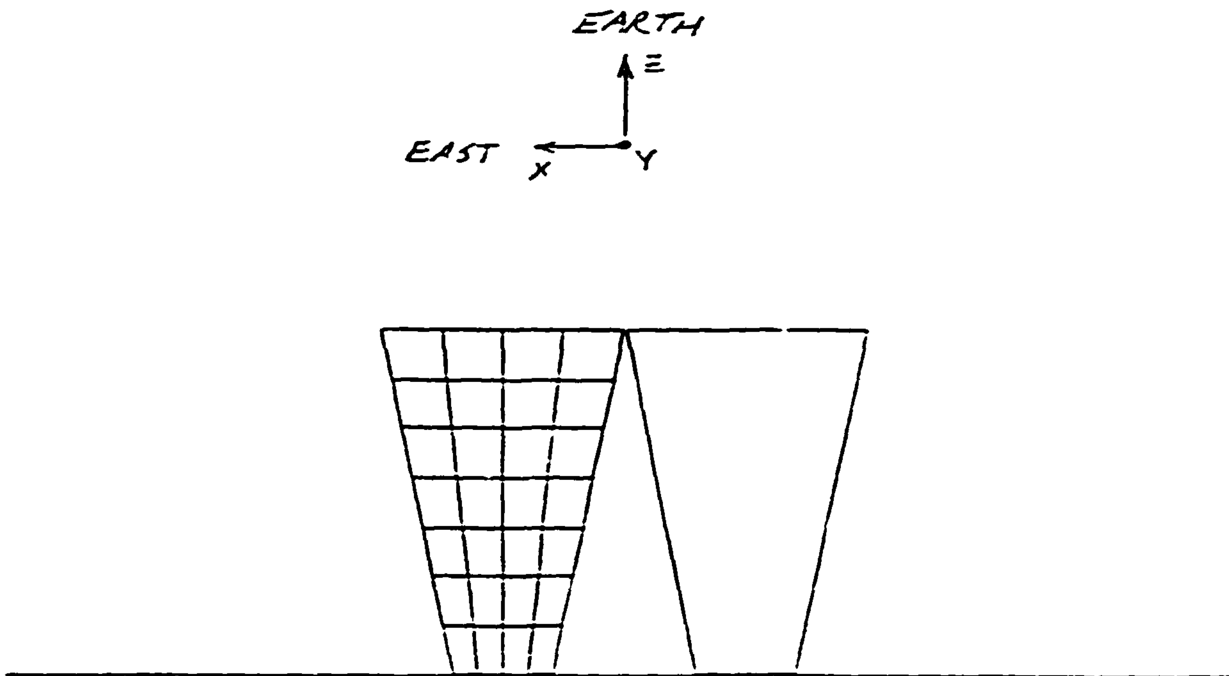


FIGURE 9.5.1-3 GOES, View of Four Foot Sunshields from South

TABLE 9.5.1-1
FOUR FOOT SUNSHIELD WITH EXTERNAL INSULATION
TEMPERATURE, °C

1. Patch Temperature Floats

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	-114	-131	-157	-101	-115	-130	-115	-132	-157	-113	-130	-156	-114
100°	-62	-56	-56	-57	-45	-50	-62	-58	-37	-6[illegible]	-65	99	-57
110°	-31	-14	-9	-28	-2	-12	-31	-14	11	-31	-26	140	-28
120°	-4	19	25	-2	30	13	-4	21	40	-3	4	140	-1
130°	30	53	45	33	64	29	29	60	56	30	123	138	32
140°	72	81	57	78	89	38	73	94	65	76	154	132	71
150°	109	105	63	115	107	42	111	124	70	116	156	123	105
160°	168	124	67	162	116	41	170	133	73	184	153	109	177
170°	190	130	66	179	116	36	192	133	70	199	142	88	207
180°	-154	-171	-187	-154	-171	-190	-154	-171	-187	-155	-171	-10	-150

2. Patch Temperature Set at 20°C; Patch Column is in Watts.

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	-21	-85	-135	-17	-78	-116	-21	-86	-135	-20	-85	-134	33
100°	-13	-42	-53	-9	-32	-47	-13	-44	-34	-12	-49	100	25
110°	-3	-7	-8	0	4	-11	-3	-7	12	-2	-19	140	18
120°	8	21	26	9	33	13	7	23	40	8	7	141	9
130°	24	51	44	27	63	29	23	59	55	24	122	138	-6
140°	50	76	56	78	84	37	51	89	64	55	152	132	-32
150°	76	97	61	84	99	39	78	117	68	84	151	121	-63
160°	[illegible]	107	61	96	97	33	111	116	67	130	139	104	-163
170°	116	106	57	96	89	24	119	110	62	130	120	81	-222
180°	-25	-96	-147	-24	-95	-147	-25	-96	-147	-24	-95	-147	35

TABLE 9.5.1-2
FOUR FOOT SUNSHIELD WITH NO EXTERNAL INSULATION
TEMPERATURE, °C

1. Patch Temperature Floats

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	−90	−98	−123	−18	−23	−28	−92	−98	−113	−88	−100	−125	−71
100°	−53	−66	−81	−3	−9	−15	−52	−61	−56	−57	−81	49	−43
110°	−30	−43	−49	7	4	[illegible]	−28	−35	−20	−37	−66	84	−28
120°	−13	−25	−23	16	14	4	−10	−14	3	−22	−53	82	−15
130°	1	−9	−9	23	24	8	5	6	18	−10	53	77	−2
140°	14	6	0	31	30	8	19	27	27	8	77	69	12
150°	26	20	6	38	33	6	31	48	33	26	69	57	25
160°	63	35	9	57	32	0	68	53	37	77	58	41	111
170°	[illegible]	41	9	66	28	−7	[illegible]	53	38	86	42	20	147
180°	−179	−190	−198	−179	−188	−197	−178	−187	−191	−180	−197	−206	−163

2. Patch Temperature Set at 20°C; Patch Column is in Watts.

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	−60	−92	−121	−5	−21	−27	−62	−91	−109	−59	−94	−123	37
100°	−37	−63	−80	6	−7	−14	−37	−58	−55	−41	−78	49	29
110°	−20	−41	−41	14	5	−4	−18	−33	−20	−26	−64	84	24
120°	-7	−24	−23	21	15	4	−4	−13	4	−15	−52	82	19
130°	5	−8	−9	27	24	8	8	7	18	−5	54	77	13
140°	16	6	1	32	30	8	20	27	27	10	77	69	5
150°	25	20	6	37	33	6	30	48	33	25	69	57	−3
160°	46	32	8	39	22	−1	52	50	36	61	56	40	−91
170°	55	36	7	36	22	−9	60	48	35	61	37	18	−151
180°	−86	−153	−181	−85	−152	−179	−85	−148	−166	−85	−155	−186	46

TABLE 9.5.1-3
SMALL SUNSHIELD WITH EXTERNAL INSULATION
TEMPERATURE, °C

1. Patch Temperature Floats

Angle	South	West	North	East	Earth
90°	-161	-134	-163	-163	-154
100°	-59	-56	-42	67	-59
110°	-11	-22	11	118	-14
120°	30	3	51	141	36
130°	59	19	70	144	76
140°	80	32	86	143	106
150°	91	41	96	140	128
160°	98	54	102	132	138
170°	105	87	106	122	145
180°	-178	-178	-178	-179	-167

2. Patch Temperature Set at 20°C; Patch Column is in Watts.

Angle	South	West	North	East	Earth
90°	-74	-67	-74	-74	48
100°	-36	-34	-23	74	35
110°	-3	-14	17	121	19
120°	27	-1	48	140	-12
130°	48	2	61	138	-49
140°	63	5	70	134	-88
150°	70	6	76	126	-123
160°	75	18	80	114	-141
170°	81	59	83	101	-154
180°	-75	-75	-75	-75	48

TABLE 9.5.1-4
SMALL SUNSHIELD WITH NO EXTERNAL INSULATION
TEMPERATURE, °C

1. Patch Temperature Floats

Angle	South	West	North	East	Earth
90°	-140	-34	-149	-145	-126
100°	-66	-15	-62	25	-69
110°	-25	-1	-17	71	-29
120°	8	11	18	92	23
130°	33	20	37	95	66
140°	52	27	52	96	98
150°	63	31	63	94	121
160°	70	39	70	89	131
170°	75	62	74	80	138
180°	-182	-181	-183	-184	-168

2. Patch Temperature Set at 20°C; Patch Column is in Watts.

Angle	South	West	North	East	Earth
90°	-97	-23	-101	-99	47
100°	-53	-8	-49	30	39
110°	-20	3	-12	73	26
120°	8	10	18	92	-2
130°	28	14	33	92	-40
140°	43	16	44	90	-79
150°	51	16	51	85	-114
160°	57	22	57	78	-133
170°	61	45	60	67	-145
180°	-108	-108	-108	-108	50

TABLE 9.5.1-5
OTHER SHIELD SIZES WITH NO EXTERNAL INSULATION
TEMPERATURE, °C

1. Patch Temperature Floats; 3-Layer Sunshield

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	−101	−106	−118	−23	−25	−27	−106	−113	−124	−102	−111	−123	−85
100°	−56	−60	−67	−5	−6	−10	−53	−62	−64	−64	−79	34	−48
110°	−29	−33	−35	10	8	3	−29	−32	−28	−41	−4	72	−28
120°	−8	−13	−10	21	19	13	−7	−8	−2	−23	58	82	−9
130°	9	6	8	32	28	19	13	18	12	49	77	79	11
140°	27	24	21	42	34	22	35	35	22	78	81	72	47
150°	46	44	30	52	38	24	62	47	30	91	76	64	94
160°	67	52	35	59	40	23	73	53	34	89	68	52	130
170°	77	55	38	61	39	20	78	56	36	82	56	35	149
180°	−181	−186	−192	−180	−186	−190	−179	−186	−191	−182	−193	−202	−164

2. Patch Temperature Floats; 5-Layer Sunshield

Orbit Angle	South			West			North			East			Earth Patch
	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	Bot	Mid	Top	
90°	−93	−100	−119	−20	−24	−27	−97	−105	−120	−93	−103	−123	−76
100°	−54	−63	−73	−4	−8	−12	−55	−64	−62	−59	−81	49	−45
110°	−30	−38	−41	8	6	0	−29	−37	−27	−38	−56	83	−29
120°	−12	−19	−16	17	17	9	−11	−16	−2	−22	−33	82	−14
130°	4	−4	0	27	26	14	6	7	10	−8	58	78	2
140°	19	13	10	36	32	16	23	26	19	40	78	70	23
150°	32	32	17	45	34	15	40	43	25	86	70	60	45
160°	64	43	22	59	35	12	69	49	29	89	60	45	117
170°	79	47	23	65	32	7	82	50	30	85	46	26	149
180°	−179	−189	−195	−179	−188	−193	−179	−189	−193	−181	−197	−203	−163

9.5.1.2 Night Visible Operation

An assessment was made of the possibility of using a visible spectral band to observe moon illuminated clouds down to 1/4 moon conditions. It was determined that this capability cannot be incorporated into any scanning imager design. A separate sensor is required that operates in a staring mode.

If a scene condition is assumed to be 1/4 moon illumination of a cloud with 80% reflectance, then the following performance can be achieved. The target radiance was calculated and is listed below.

SPECTRAL BAND	IRRADIANCE (W/m2-sr)		
	FULL MOON	1/2 MOON	1/4 MOON
0.55 -0.75μm	$4X10^{-14}$	$5X10^{-15}$	$1X10^{-15}$
0.55 - 0.90μm	$7X10^{-14}$	$9X10^{-15}$	$2X10^{-15}$

The sensor is conceived to use a 1000 x 1000 pixel solid-state imaging device with an F/3 optic (6cm aperture). The IGFOV of each element is 2km. The following signal-to-noise performance can be provided:

DWELL TIME (SECONDS)	PIXEL AGGREGATION	SIGNAL-TO-NOISE (1/4 MOON, 80% ALBEDO)
5	1X1	2.3
5	2X2	5.0
10	2X2	7.2

This sensor would be smaller than the LMS and has better resolution. It may be possible to modify the LMS to provide this capability through a separate focal plane using the same optics. However, the present configuration places the bandpass filter for the lightning event detection in front of the optics to be able to achieve and maintain the narrow spectral bandpass. If the filter remains in this position, then modification of the LMS is not recommended, and a separate sensor should be developed. The technology risk is low.

To truly proceed with this capability some basic data requirements must be stated before design can commence. A night visible sensor with 3km IGFOV's would cover a 3000 x 3000km area.

9.5.2 Technology Issues – In-Flight Co-Registration Mechanisms

The stringent requirements imposed on the imager and sounder for INR performance result in derived requirements for mechanical stability of the system with life, vibration, and thermal environment which exceed the capability of conventional mechanical system design. The susceptibility to these effects may vary somewhat with the particular design concept, but these effects must be dealt with for any system in which ultimate pointing stability and accuracy of a few arcsec is required. (The RO2 navigation requirement for the imager of 2km 3σ at 45 degree latitude corresponds to a pointing knowledge of 33μr or 7 arcsec at nadir). Indeed, the thermal modeling of the instrument and spacecraft together shows that thermal effects give rise to diurnal pointing dislocations of the order of 1000μr peak-to-peak, necessitating the assumption of day-to-day repeatability to enable image motion compensation for that effect as well as the effect of orbit inclination. Thus the effect on pointing of a single IFOV in the GOES I-M system is quite large. The GOES I-M system assumes that the thermal distortion effects are identical for the multiple IFOVs incorporated in both instruments, an assumption which is certainly true for spacecraft effects which result in rotations of the entire instrument frame-of-reference. It is also approximately true for those instrument thermal distortions that only affect the alignment of the primary and secondary mirrors. In the aft optics, however, to the extent that the optical systems become differentiated for the various spectral bands and detector channels, the opportunity for mechanically and thermally induced differential distortions between IFOVs arises. As the aft optics design becomes more complex, the problems of obtaining and maintaining optical alignment become more difficult. In this situation, depending on the susceptibility of a particular design and the requirements for co-registration of the multiple IFOVs, consideration must be given to the use of in-flight control mechanisms to compensate for the effects of the launch vibration environment and possible gravity release misalignments. Further, for differentiated optical systems, it may be necessary to employ precise thermal control to avoid diurnal or seasonally driven pointing errors between IFOVs.

These considerations have been the primary motivation in the selection of the design approach for the Advanced Imager, in which only one beamsplitter is employed to separate the warm and cold focal planes. Within a given focal plane, since all IFOVs are affected equally by purely boresight optical shifts, the co-registration accuracy is primarily governed by the manufacturing precision with which the field stops can be assembled and by the system optical speed, which should be as slow as possible to maintain high tolerance for dislocations in the focal plane. In general, however, sensitivity requirements drive the system to high optical speed, so that a compromise is necessary. For the Option III imager, the suggested focal ratio of 3 results in a plate scale (spatial displacement in the focal plane resulting from a given angular displacement in object space) of 0.89μm per μr. Thus a 14μm displacement of one IFOV with respect to another in object space (the maximum allowed by RC4) would result from a displacement in the focal plane of 12.5μm. According to SBRC, the precision with which detectors of different bulk material can be assembled in a common focal plane is 2.9μm rms, or about 9μm 3σ. Thus there is very little tolerance remaining for alignment and stability of the beamsplitter which separates the warm and cold focal planes. It is therefore recommended that an alignment mechanism be incorporated to provide for in-flight registration of the focal planes, and that the aft optics be thermally stabilized to prevent diurnal and seasonal misregistration effects. Note that obtaining 14μr co-registration with optics faster than F/3 will be even more difficult since manufacturing tolerances become more significant. Conversely, the sensitivity discussion of Section 9.2.2 shows that NEΔT performance would suffer relative to guideline requirements for much higher focal ratio.

This discussion can be generalized to a recommendation that in-flight adjustment mechanisms and thermal stabilization be considered for any instance of multiple focal planes, such as that required for the HSRS, where the stated requirements for co-registration of the spectral channels are even more restrictive and probably not physically realizable, as was pointed out in the course of the study. It has been suggested that, for the sounder, the individual focal planes associated with each spectral region might be separately co-registered to a window channel within that individual spectral region. This compromise, if accepted by NOAA, could mitigate the requirement for in-flight adjustment. However, the utility of the high-resolution cloud clearing array on the warm focal plane would be somewhat reduced, requiring individual co-registration for each cold focal plane to the warm focal plane. The data from the array could become useless if the various focal planes were subject to diurnal temperature driven dislocations. Thus, it is likely that temperature stabilization will still be required.

Specific approaches for co-registration of the focal planes have not been addressed in the Phase-A study since detailed optical system designs have not been performed for the developmental instruments. However, several approaches might be employed. For simple adjustment of the lines of sight, a tilt control of reflective optics such as a fold mirror in a particular optical path could be used, as was done in the TM design. Lateral shifts of such elements can also be used to obtain a single degree of freedom in image location. Lateral shifts of optical elements with optical power, such as a relay lens, present another possibility, although the optical design is considerably more complex. Much more difficult would be a lateral shift of the focal planes themselves, particularly where cooled detectors are involved. Mechanisms for implementation of the adjustments include "inch-worms", as used in TM, and motorized micrometers, as used in the enhanced TM. Further study of the application of such mechanisms to the developmental instruments for GOES-N is recommended for Phase-B.

9.5.3 Technical Issues - Cooler Capacity

9.5.3.1 Passive Radiation Coolers

An analysis was performed to study ways of enhancing the performance of the ITT radiative cooler design for GOES-I,J,K to enable a similar design to operate at substantially lower temperatures. The initial approach was to study the heat balance data for the GOES-I,J,K imager and sounder coolers as provided in Reference 1 for three conditions:

1. Equinox
2. Summer solstice (SS), beginning of life properties (BOL)
3. Summer solstice (SS), end of life properties (EOL)

The temperatures and heat inputs of the GOES-I,J,K imager and sounder coolers are shown in Tables 9.5.3-1 and -2. The worst case condition is summer solstice, end of life. Of the three cases, the most favorable condition is equinox. The absence of sunlight on the second surface mirror radiator and into the rectangular cone of the shield leads to the coolest temperatures of the shield and the radiator. If the summer solstice condition can be avoided by flipping the spacecraft at each equinox, then the equinox would become the worst case and the control temperature could be lowered to about 95 degree K. Another major source of heat inputs to the patch is the astromast and solar sail, which if eliminated would result in further reduction of the patch temperature.

In order to predict the effects of modifications to the coolers, a System Improved Numerical Differencing Analyzer (SINDA) model of the imager cooler was derived from the data in Table 9.5.3-1. The model, for the equinox orbit environment, consists of:

1. Diffusion nodes for the patch, radiator and shield;
2. Boundary nodes for space and for the instrument interface with the cooler;
3. Heat inputs for joule heating, control power, solar heating, astromast and solar sail heat loads, and a fixed input for the ports;
4. Conductive and radiative couplings derived from the data in Table 9.5.3-1.

The latter were assumed to be constants and were selected from the values derived for each of the three orbit environments. For the port inputs the best fit with the data was developed by trial and error assuming a fixed input plus a radiative coupling. The model was checked by re-computing the three orbit conditions in Table 9.5.3-1. The results are shown in Table 4, where the Table 9.5.3-1 temperatures are shown in parentheses. The agreement for the patch temperatures is within 0.2 degree K and within 2 degree K for the radiator and the shield.

The patch temperature for the equinox orbit environment without control power is 88 degree K (Run 4 of Table 9.5.3-4). If the input from the astromast and the solar sail is removed from the equinox case, the patch temperature drops to 70 degree K (Run 5 of Table 9.5.3-4). The final run simulates the effect of removing the cone from the cooler. The resulting patch temperature is 68 degree K. If a 7 degree K margin is added for control power, a passive cooler at about 75 degree K appears to be feasible for GOES-N using the GOES-I,J,K cooler design if the spacecraft can be oriented to keep sunlight from impinging on the shield radiator and cone and if the astromast and solar sail can be removed from the FOV of the patch and radiator.

TABLE 9.5.3-1
IMAGER COOLER HEAT INPUTS

ORBIT ENVIRONMENT	EQUINOX	SS, BOL	SS, EOL
PATCH TEMPERATURE, DEGREE K	105.0	105.0	105.0
RADIATOR TEMPERATURE, DEGREE K	114.8	143.7	151.1
SHIELD TEMPERATURE, DEGREE K	147.5	227.4	248.6
PATCH INPUTS, mW			
CONDUCTIVE	3.0	11.9	14.1
INSULATION	1.2	7.2	9.4
SHIELD WALL	4.4	33.3	47.0
OPTICAL PORT	1.0	2.4	3.0
ASTROMAST & SOLAR SAIL	62.6	66.3	66.3
JOULE HEAT	17.8	17.8	16.8
CONTROL POWER	103.0	54.1	35.4
TOTAL	193.0	193.0	193.0
RADIATOR INPUTS, mW			
CONDUCTIVE	65.6	159.7	181.6
INSULATION	17.7	127.7	180.1
SHIELD WALL	2.4	19.0	27.0
OPTICAL PORT	30.1	39.2	43.7
ASTROMAST & SOLAR SAIL	43.5	46.2	46.2
TOTAL	159.3	391.8	478.6
SHIELD/HOUSING INPUTS, W			
CONDUCTIVE	3.370	1.365	0.883
INSULATION	1.519	0.947	0.680
SUN	0.000	25.306	37.882
TOTAL	4.889	27.618	39.444

TABLE 9.5.3-2
SOUNDER COOLER HEAT INPUTS

ORBIT ENVIRONMENT	EQUINOX	SS, BOL	SS, EOL
PATCH TEMPERATURE, DEGREE K	102.0	102.0	102.0
RADIATOR TEMPERATURE, DEGREE K	107.6	145.5	154.7
SHIELD TEMPERATURE, DEGREE K	136.0	226.0	247.9
PATCH INPUTS, mW			
CONDUCTIVE	1.7	113.2	16.0
INSULATION	0.7	9.0	12.4
SHIELD WALL	2.9	32.0	46.2
OPTICAL PORT	1.7	4.2	3.1
ASTROMAST & SOLAR SAIL	62.6	66.3	66.3
JOULE HEAT	12.0	12.0	12.0
CONTROL POWER	90.2	35.1	13.6
TOTAL	171.8	171.8	171.8
RADIATOR INPUTS, mW			
CONDUCTIVE	54.9	148.0	168.1
INSULATION	12.9	128.5	184.9
SHIELD WALL	1.7	17.9	26.0
OPTICAL PORT	9.9	70.6	100.3
ASTROMAST & SOLAR SAIL	43.5	46.2	46.2
TOTAL	122.9	411.2	525.5
SHIELD/HOUSING INPUTS, W			
CONDUCTIVE	2.444	0.953	0.615
INSULATION	1.086	0.684	0.492
SUN	0.000	25.306	37.882
TOTAL	3.530	26.943	38.989

TABLE 9.5.3-3
SUMMARY OF RESULTS

RUN #	CONDITIONS	TEMPERATURES, DEGREE K		
		PATCH	RADIATOR	SHIELD
1	SUMMER SOLSTICE, BOL	104.8 (105.0)*	141.8 (143.7)*	226.9 (227.4)*
2	SUMMER SOLSTICE, EOL	104.8 (105.0)*	149.8 (151.1)*	248.1 (248.6)*
3	EQUINOX	104.9 (105.0)*	113.2 (114.8)*	145.9 (147.5)*
4	EQUINOX - NO CONTROL POWER	88.3	112.3	145.9
5	EQUINOX - NO CONTROL POWER, NO ASTROMAST	69.9	105.5	145.8
6	EQUINOX - NO CONTROL POWER, NO ASTROMAST, NO COOLER CONE	67.5	105.0	145.9

* (GOES-I,J,K results)

A modified GOES-I,J,K cooler was proposed by R. Annable[2] for the GOES-N advanced sounder which can operate at 80 degree K with 20% increase in detector heat loads. The major modifications were:

1. Reduction of the thermal loads from the astromast and solar sail to the patch from 66.3mw to 12.4mw by changing the astromast surface finish from diffuse fiberglass (a=0.80) to a specular reflector (a=0.15);
2. Reduction of the input from the shield walls to the patch by lowering the shield temperature (by removing the sun load on the cooler cone and the second surface mirror radiator on the shield/housing) to the values obtained at equinox for the GOES-I,J,K cooler.

The combination of (1) and (2) above reduces the uncontrolled patch temperature to 72.5 degree K, which allows controlled operation at 80 degree K. The uncontrolled patch temperature is warmer than the results from Run #5, Table 9.5.3-3 because the patch heat inputs are 12.4mw higher than the values in Run #5.

To eliminate the sun load on the shield, Annable proposed yawing the spacecraft by 180 degree every six months, but he rejected this solution as undesirable for reasons other than thermal. Instead, he proposed a partial sunshield rotating at one revolution per day. The shield/housing radiator was divided into a fixed part to cool the region behind the patch and radiator and a rotating part to cool the rotating shield. The cooler fixed radiators (patch radiator and vacuum housing) were increased to support a 20% increase in detector load and were configured within a 16 inch diameter circle. For a controlled patch temperature of 80K the radiator and shield temperatures were sized to operate at 108K and 153K, respectively.

From the results of this analysis and the work of Annable discussed above, the current GOES-I,J,K radiative cooler design should be capable of operating at a controlled patch temperature of about 75 degree K without modification if the astromast is removed from the FOV of the cooler cone and if the spacecraft is flipped at equinoxes to prevent sunlight from impinging on the shield/housing radiator and into the cooler cone. From the work of Annable, an increase in the joule heating from added detectors can be accommodated by increasing the size of radiators by a comparable amount. One may also want to consider the circular configuration of the radiators as proposed by Annable but without the rotating sunshield. Temperatures lower than 75 degree K may be feasible, but further study is required to consider methods to reduce the heat inputs by conduction and radiation to the rear of the patch, radiator, and shield/housing.

9.5.3.2 Mechanical Refrigerators

The issue of the technical risk of cryogenic refrigerator technology in the GOES program can only be addressed by observing the progress of the technology over the next several years. The NASA Earth Observing Program is committing significant resources to develop refrigerators with 5 year life. This activity should benefit NOAA instrumentation at some time in the future. In addition, a British instrument will fly a cryo-refrigerator with a multi-year life within the next two years.

Without positive results from these activities NOAA should not plan on using refrigerators in the operational environment. However, if the mission requirement drives the need for focal plane temperatures below 80K, then this technology will have to be considered. It may be possible to design an interface that allows a passive radiator to be used initially while later units use a refrigerator to improve performance.

REFERENCES:

1. ITT, Aerospace/Optical Division, GOES Critical Design Review (Mechanical/Structural/Thermal), May 24, 1988
2. R. Annable, *80K Radiant Cooler for the Advanced Sounder*, ITT DEFENSE, Aerospace/Optical Division, Memo dated February, 28 1990

9.6 Lightning Mapper Sensor (LMS)

9.6.1 Lightning Mapper Sensor (LMS) Normal Mode of Operation

The LMS is the first payload specifically designed to detect lightning from a geosynchronous satellite and to locate it with respect to terrestrial coordinates. Its spectral, spatial, and temporal resolution have been optimized to observe lightning, and its FOV has been selected so that nearly full-disk coverage can be achieved. It has the capability to analyze and output lightning data in real time.

The LMS observes lightning flashes in the atomic oxygen spectral line at 777.4nm or the atomic nitrogen band at 868.3nm. Because of multiple scattering in clouds, lightning flashes observed from space are typically several hundred microseconds in duration, and cover the full spatial extent of a cloud. The LMS frame rate of 1000 Hertz and the LMS spatial resolution of 10 x 10km (at nadir) are matched to these temporal and spatial characteristics of lightning.

The LMS is a staring sensor with a two-dimensional CCD focal plane array covering a 10.4 degree x 10.4 degree FOV. The eastern satellite, at 75 degree W longitude, covers all of the continental United States except California. The western satellite, at 135 degree W longitude, covers the western 2/3 of the continental United States and Hawaii. Each satellite has its LMS boresight angle tilted 2 degree northward from nadir, producing a boresight at 11.34 degree N latitude.

The LMS has a very high CCD readout rate of 10^{10} bits per second due to the large number of pixels in the CCD arrays and the 1000Hz frame rate at which they are read out. On-board processing is used to extract the relevant parameters while yielding a much lower data rate of $2x10^{5}$bps for the sensor. Sequential frame subtraction is used to subtract background from the images.

In addition to its normal mode of operation, the LMS has an imaging mode with a duration of 1.6sec which can be activated by command. Cloud-free areas would be selected for imaging. During severe storm tracking, this mode may be activated as often as every 10 minutes. During the imaging mode, data requirements are reduced by sectorizing and never exceed 64kbps. (including lightning).

City lights are used for night landmark identification to determine the precise attitude of the LMS, refining the registration of lightning observations to terrestrial coordinates. The relevant parameters, lightning time, intensity, and location, are extracted from the raw data in real time, permitting the LMS to support many applications which require a real-time warning capability.

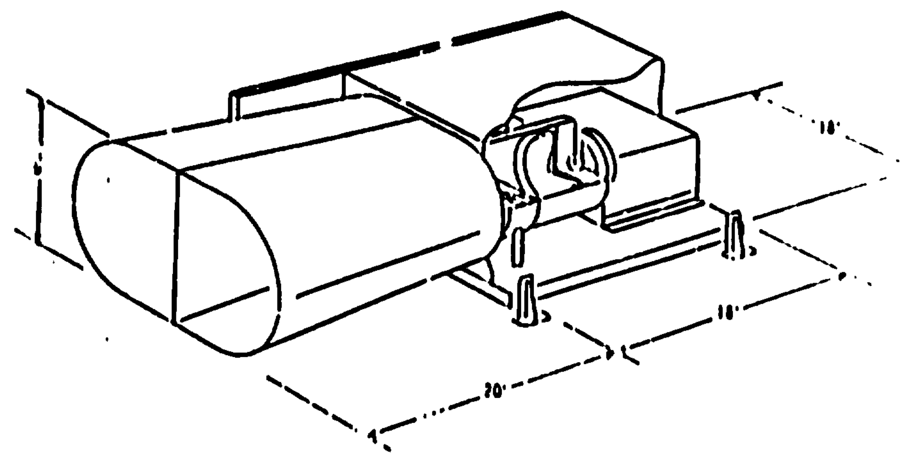
The LMS is a staring sensor with no mechanical motion during its normal modes of operation. At present, the preferred design uses two separate, co-boresighted apertures to achieve the dual-wavelength capability. The preliminary estimates of size, weight, and power are presented along with a conceptual drawing in Figure 9.6.1-1

Phase I Accomplishments

Repackaged LMS is Smaller, Better Integrated

Original LMS

- Size: 46w x 23h x 97 cm
- Weight: 19.7 Kg
- Power: 38.2 W
- Heat pipe/radiator thermal control



New LMS

- Size: 51w x 27h x 53 cm
- Weight: 19.8 Kg
- Power: 62.5 W
- Heater/radiator thermal control

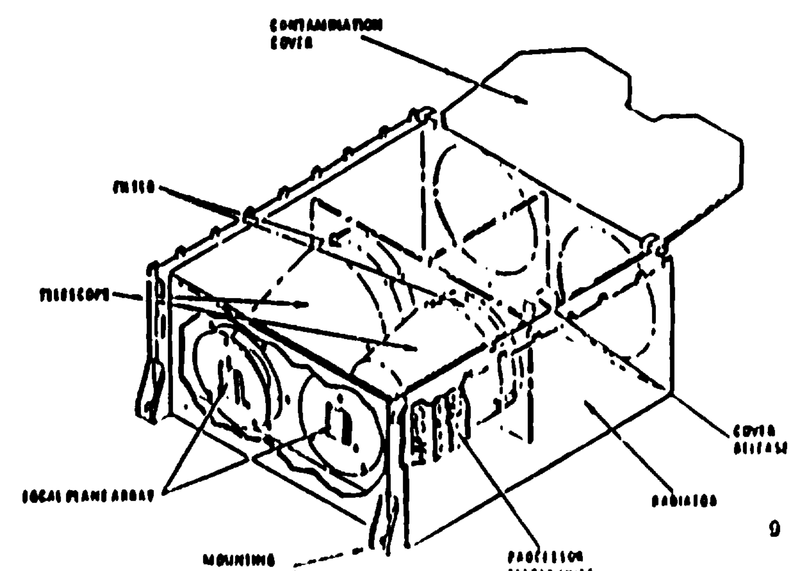


FIGURE 9.6.1-1

9/20/90

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9.6.2 Alternative Use of Lightning Mapper Sensor (LMS) as a Nighttime Imager

The suggestion has been made that the LMS be used as a low-light-level imager to provide cloud images at night whenever the lunar illumination level is quarter-moon or greater. This mode of operation could possibly be implemented in either of two ways: extension of the integration time or expansion of the spectral passband. Extension of the integration time would require minor electronic modifications but should not impact the optical or mechanical aspects of the sensor. The possibility of cloud imaging in such a narrow spectral band (possibly detuned into the continuum outside the atomic resonance) has not been examined. Expansion of the spectral passband would require removal of the narrow-band optical filter. This function could also be straightforward to implement if it were practical to locate this filter on a wheel in the aft optics. However, we have understood from the development contractor that the impact to the design of the GOES-L/M LMS, which has the filter on the object space side of the system, is excessive. For that reason, it is our recommendation that a separate staring sensor be developed, as described in Section 9.5.1.3, if nighttime visible data is to be provided.

9.6.3 Status of Lightning Mapper Sensor (LMS)

An LMS development program to build a prototype instrument intended for flight on the GOES I-M series has been under way for some time with NASA funding and management by MSFC. A competitive procurement led to the selection of TRW as the development contractor. Phase-B has been completed, but the Phase-C/D development has been on hold pending finalization of a NASA/NOAA agreement to fly the instrument late in the GOES I-M program. A preliminary accommodation study for the LMS was completed by the spacecraft contractor, but at the time, very little hard instrument information was available. The current plan is to update the accommodation study using the Phase-B instrument information and, barring unforeseen difficulties, to proceed with implementation of the LMS.

It has been our understanding that the development of the LMS for GOES-L/M has been severely constrained by the perceived power and weight limitations associated with the GOES I-M bus and launch vehicle. This situation should be reviewed in the process of determining detailed requirements for the LMS for GOES-N. If substantial performance penalties have been taken, significant non-recurring engineering effort may be indicated for GOES-N, in which case it is recommended that the instrument be developed under separate contract and provided as Government Furnished Equipment (GFE) to the spacecraft contractor.

9.7 Observations and Recommendations

(NOTE: instrument sensor recommendations are also included in Section 8.4)

9.7.1 Observations

The imager requirements (core, options, and enhancements) tend to indicate a desire to evolve the design of the imager being built for the GOES I-M spacecraft. However, those requirements which add spectral bands to the cold focal plane lead to major optical, mechanical, and electronic design modifications that could warrant the development of a new imager. It is recognized at this time that the GOES I-M imager has major optical-mechanical design deficiencies that limit INR performance. Any redesign to correct these deficiencies will result in significant non-recurring costs. Careful assessment is required to determine the direction for the development of the GOES-N imager. Should it really evolve from the current design, or should it be a new approach? The evolutionary approach, which corrects current deficiencies and adds new spectral bands, may incur as large a non-recurring expense as going with a new approach. The advantage of evolution is the reduced risk of working with a contractor who by the year 2000 will have had substantial experience in 3-axis GOES navigation technology and in manufacturing procedures for the operational imager. If this contractor continues to have delivery problems, then a new imager is mandated.

The sounder for the GOES-N time frame will be a new development activity. The Michelson design approach is the strongest candidate for the sounder. If a reduced set of spectral bands is responsive to the NWS needs, then a Fabry-Perot approach is a competitor. There are certain aspects of the signal processing impacts of the Michelson approach that have not been investigated. The experience with the aircraft instrument is inadequate to document the true characteristics in an operational environment. Because of the substantial difference in extracting radiance data from an interferogram and the concomitant increased focal plane performance requirements in the areas of linearity and dynamic range for the Michelson, careful engineering and management decisions are needed to fully understand the areas of risk associated with selecting this new technology for an operational system.

9.7.2 Recommendations

9.7.2.1 System Configuration Recommendations

The benefits of flying spacecraft in a constellation that has 3 elements should be assessed (e.g., an imager bus, east and west, and a single sounder bus). Navigation will improve for the imager spacecraft. The sounder spacecraft can reduce the risks/impacts of bringing the new sounder on-line. The sounder spacecraft may even carry the Auxiliary Imager for full disk data support. In this scenario, the spacecraft can now remain within the Delta envelope and yet carry instruments that have grown physically to provide enhanced capabilities. This system may cost more, but there is a robustness that may warrant the expense.

9.7.2.2 High Spectral Resolution Sounder Recommendations

With regard to the new sounder, the most prudent path into the future is to immediately begin design and breadboard of the critical components. In addition, a detailed assessment of data processing requirements and impacts should be initiated. It is probably desirable to have an independent entity take the proposed retrieval algorithm and verify the accuracy of the technique. If no algorithm exists, development should begin. Contemporaneous visible data at 1km IGFOV can be included in the sounder, but contemporaneous IR is not recommended for an instrument using a passive radiator.

As discussed in Section 9.3.3, further analysis is required before committing to the aft optics design based on the GOES I/M High-Resolution Sounder feasibility study. The performance of an alternate design replacing the common field stop with individual field stops in each focal plane, but retaining the in-flight adjust mechanisms and thermal control of the aft optics, should be evaluated in light of the reduced emphasis likely to be placed on band-to-band co-registration. This evaluation should include an optical layout to demonstrate that the adjust mechanisms recommended in any case can be physically incorporated within a reasonable aft optics volume.

9.7.2.3 Advanced Imager Recommendations

The addition of IR bands to the imager will be a significant impact to cooler design. A detailed study is needed to quantify the required changes to add the additional infrared bands. The study probably should address the performance with the solar sail still in the FOV as well as the performance with the Option III spacecraft attitude control system. These studies are also crucial for improvement of the Option II sounder, where much colder focal planes are required to approach the desired overall performance.

Improving operations around local midnight probably should be addressed by major changes in the design and materials selection used in the imager and sounder, as has been recommended for both advanced instruments. There have been estimates that total thermal distortion within the GOES-I imager could be reduced by an order of magnitude through this change, but they have not been verified by detailed analysis. To ensure that RFP performance levels are realizable, an analytical structural model of the Advanced Imager must be constructed and its thermal/structural stability evaluated. Another improvement, extending the sunshade, does limit direct exposure to the sun, but more work is required to develop an engineering design that keeps the sunshade itself from being a major heat load into the aperture cavity.

As discussed in Section 9.1.3, implementation of the Advanced Imager depends on maintaining low orbit inclination and/or ground resampling of the data for satisfactory performance. The corresponding study tasks were not performed as part of the study. The study cannot be considered complete in this respect until the system impacts of those requirements are evaluated.

9.7.2.4 Night Visible Recommendations

Night visible can be implemented in a low risk technology using solid-state imaging arrays in a separate sensor designed for this purpose. Modification of the LMS is not recommended due to the impact to its implementation.

9.7.2.5 Auxiliary Imager Recommendations

The Auxiliary Imager can be an upgrade of the GVHRR on the INSAT, but major design changes are needed to incorporate the INR capabilities that are now part of the GOES. These changes would be low risk but incur moderate non-recurring expense.

10.0 TASK 3. CONTROL SYSTEM AND IMAGE NAVIGATION AND REGISTRATION (INR) DESIGN CONSIDERATIONS

10.1 Introduction

10.1.1 Background

10.1.1.1 Objective, Scope, and Guidelines

The objective of the GOES-N controls study was to investigate and develop viable design alternatives to meet NOAA INR performance requirements. In order for the resulting design to approach the stringent INR requirements, it was necessary that the scope of the effort treat the spacecraft control subsystem and the instrument servo as an integrated design. This integration is reflected in the proposed design for Options II and III and, to a lesser extent, in Option I. That is, the resulting proposed designs use signals derived from the control subsystem to provide end-to-end fine pointing control for the instrument mirrors; and for Options II and III, the instrument structures and materials were selected to provide improved servo response performance and minimize thermal effects, respectively.

To minimize the design risk associated with achieving the INR requirements, the use of proven technology for each element of the design was used as a guideline. As a result, even though the proposed design has never been implemented for a geosynchronous earth pointing spacecraft, the recommended star trackers, reaction wheels, etc., and the design concepts all have been proven on other spacecraft.

Since the Option I spacecraft was defined to be an evolution of the GOES I-M series (which falls considerably short of achieving NOAA's Option and Enhanced INR requirements), it was decided that the Option II and III control subsystem designs were not to be constrained (except for the use of flight proven elements). Also, in order to be able to complete the study within the allocated resources, only a 2-axis gimbal system (as used on the current GOES-I instruments) was studied. A dual mirror servo system will need to be investigated if selected based on instrument considerations; however, this is not expected to change the overall pointing performance.

10.1.1.2 GOES-N Pointing

The NOAA INR requirements for the GOES system impose very stringent spacecraft control and instrument pointing requirements. One way to understand the requirements is to relate them to other missions:

- For a geosynchronous spacecraft to achieve the same pointing stability consistent with the instrument resolution of a low earth orbiting (LEO) spacecraft, the accuracy and stability must be about 40 times better.
- Fine pointing control systems on other spacecraft with the same accuracy/stability requirements as GOES-N (e.g., IUE, SMM and HST) all stare at their targets, and can use the target itself or another reference that is fixed in location relative to the target as a means of deriving an error signal to precisely control the pointing. In contrast, the GOES

spacecraft have scanning instruments, which do not readily allow for using a fixed reference from which a precise error signal can be generated.

- The sounder requires a non-spinning platform to achieve the signal-to-noise needed; the non-spinning spacecraft (i.e., one with a specific side always earth pointing) will experience diurnal thermal variations which significantly affect the pointing control.

10.1.1.3 NOAA Performance Requirements

System performance requirements for the GOES program have been defined by NOAA in terms of long term and short term deviations of pixels within images. These end-to-end image performance specifications are the INR requirements; these INR requirements are defined as:

- Navigation: knowledge of the location of each pixel in earth coordinates
- Within-frame registration: the variation in separation of any 2 pixels containing specific scene information within the same image
- Frame-to-frame registration: the variation in separation of a given pixel in two images of the same earth scene

NOAA specified two sets of INR requirements for GOES-N: Core and Option. The 3σ INR Core and Option requirements are provided in Table 10.1.1-1, along with the GOES I-M requirements. The Core requirements for navigation and within-frame registration are the same as the GOES I-M requirements. However, the frame-frame registration requirement is halved to 42μr. It should be noted that the INR core requirement for navigation, unlike the other core requirements, does not reflect the NOAA 1983 stringent requirement for navigation of 56μr (2km) at nadir.

TABLE 10.1.1-1

INR PERFORMANCE REQUIREMENTS

(All Requirements 3σ)

	GOES I-M μr (ARCSEC)		GOES-N μr (ARCSEC)
		CORE	OPTION
NAVIGATION	112 (23)	112 (23)	33 (6.8)
WITHIN FRAME REGISTRATION	42 (8.7)	42 (8.7)	14 (2.9)
FRAME-TO-FRAME REGISTRATION	84 (17)	42 (8.7)	14 (2.9)

The Option requirements, which reflect NOAA 1989 requirements, are a significant improvement over the existing GOES I-M navigation and registration specifications. Navigation performance is requested to be 2km at 45 degree latitude, which equates to 33μr at nadir. Within-frame and frame-frame registrations are both reduced to 14μr.

10.1.1.4 Issues/Concerns

The major GOES-N study issue, which is considered the significant study shortfall, is the lack of GOES-I flight performance data to substantiate the INR performance concept. Without GOES-I performance data to substantiate the LAS derived INR performance budgets, the GOES-N Option I performance budgets are unproven. In contrast, the Options II and III designs are on somewhat firmer ground due to the experience gleaned from the IUE, SMM, and HST spacecraft and UIT/Astro Observatory. Table 10.1.1-2 delineates the specific areas of concern discussed below.

TABLE 10.1.1-2 GOES-N STUDY SHORTFALL
LACK OF GOES-I FLIGHT PERFORMANCE DATA

- **SERVO PERFORMANCE**
- **ORBIT/ATTITUDE DETERMINATION & CONTROL**
  - SYSTEMATIC ERRORS
  - NOISE
  - MMC ESTIMATION
- **THERMAL EFFECTS**
  - INSTRUMENTS
  - SPACECRAFT
  - EARTH SENSOR (ES)
  - SNAPPING
- **DYNAMIC INTERACTIONS**

Achieving the stringent instrument servo performance in a zero gravity, thermal environment is a major concern because of the control, thermal, and structural dynamics problems encountered in the GOES-I instrument design and testing to date. Clearly, if the instrument servo design and implementation do not perform to expectations, the INR concept cannot perform as expected, since it requires repeatable and accurate instrument pointing.

Orbit/attitude determination and control concerns are in the three areas of (1) systematic errors, (2) noise and (3) the estimation of the MMC required. Increased systematic errors (e.g., solar pressure) and increased ES noise will result in larger errors than predicted; however, the inability to estimate MMC to the required tolerance or an error in the computation of the spacecraft dynamics used for modeling the MMC will result in very degraded imagery. More importantly, poor MMC estimation will result in degraded star location performance, which directly affects orbit/attitude determination and the corresponding IMC performance.

With no GOES-I data to substantiate the INR performance budget, the thermal performance of the instruments, spacecraft, and earth sensor also may result in larger errors than budgeted. These errors, along with the systematic errors associated with O/A determination, can be contained to some extent with the use of Short Span Attitude Adjustment (SSAA), which is discussed in Appendix C.2 and Section 10.3.1.1. Thermal snapping, if present, will result in very degraded performance during those time periods following a thermal snap.

Finally, dynamic interactions could cause modal frequencies to be excited (i.e., non rigid body effects). The result could be an inability to accurately estimate the diurnal variations in instrument pointing that is central to the INR concept. This concern has been mitigated to some extent by the dynamic interaction spacecraft testing performed by LAS.

10.1.2 Overview of Options I, II, and III

The INR performance allocations of the GOES I-M spacecraft series and the three options studied are described in Appendix C. A brief overview of the performance of the three options is given below. Detailed system descriptions are given in Subsections 10.3, 10.4 and 10.5, which address the individual options.

The GOES-I and Option I system performances are nearly identical. As shown in Appendix C, the primary difference in performance between the two systems is due to the improved earth sensor in the Option I system. Options II and III provide significant performance improvements as a result of the design changes delineated in Table 10.1.1-3. Note that all of the design changes for Option II are incorporated into Option III along with the noted additional instrument redesign.

10.1.3 Organization of The Control System/Image Navigation and Registration (INR) Design Section

The remainder of Section 10 contains a discussion of Task 2: GOES I-M Improved Efficiency/Cost Effectiveness in Section 10.2 and descriptions and discussions of Options I, II, and III in Sections 10.3, 10.4, and 10.5, respectively. Section 10.6 contains the Recommended Additional Studies/Investigations to complete the Phase-A INR study effort, and Section 10.7 discusses the recommended research to further improve the current navigation and registration performances predicted for Option III.

TABLE 10.1.1-3
CONTROL SYSTEM FEATURES

AREA	OPTIONS I	OPTIONS II	OPTIONS III
SPACECRAFT			
• CONTROL SYSTEM	MOMENTUM BIAS WITH EARTH SENSOR	ZERO MOMENTUM WITH GYRO/STAR TRACKERS	ZERO MOMENTUM WITH GYRO/STAR TRACKERS
• SOLAR TORQUE BALANCING	SOLAR SAIL/TRIM TAB	THRUSTER FIRINGS	THRUSTER FIRINGS
• OPTICAL BENCH	NO	YES	YES
• SEMI-ANNUAL 180° YAW FLIP	NO	YES	NO
INSTRUMENTS			
• SERVO CONTROLLER	ANALOG & DIGITAL WITH INDUCTOSYN	DIGITAL WITH 3 IN OPTICAL ENCODER SOUNDER FEEDFORWARD	DIGITAL WITH 5 IN OPTICAL ENCODER SOUNDER FEEDFORWARD
• MOTION COMPENSATION	IMC: 24 HOUR CORRECTION MMC: RT SPACECRAFT MOTION ESTIMATION & MIRROR CORRECTION	IMC: 24 HOUR CORRECTION SMC: RT SPACECRAFT JITTER DETECTION AND MIRROR CORRECTION	IMC: 24 HOUR CORRECTION SMC: RT SPACECRAFT JITTER DETECTION AND MIRROR CORRECTION
• STRUCTURE (THERMAL/ MODAL FREQUENCY)	-----	NEW SOUNDER DESIGN WITH GFRP MATERIAL	NEW INSTRUMENT DESIGN WITH GFRP MATERIAL
INR			
• ATTITUDE DETERMINATION • ORBIT DETERMINATION • THERMAL ESTIMATION	EARTH SENSOR/INSTRUMENTS 1 STATION RANGING & INST. LANDMARKS/STARS	GYRO/STAR TRACKERS MULTI STATION RANGING INST. LANDMARKS/STARS	GYRO/STAR TRACKERS MULTI STATION RANGING INST. LANDMARKS/STARS

10.2 Task 2: GOES I-M Improved Efficiency/Cost Effectiveness

10.2.1 Study Areas

The two studies performed in support of Task 2 were the elimination of north-south stationkeeping by modifying the spacecraft to operate at large inclination angles, and an examination of the utility of providing an alternate back-up for the L-Mode wheel configuration to maintain INR performance if one of the V-Mode momentum wheels fails.

10.2.2 Study Results

10.2.2.1 Elimination of North-South Stationkeeping

Operation of the spacecraft at inclinations up to 3.1 degrees as a means of eliminating the requirement for north-south stationkeeping has the advantages of:

- Extending mission life to 7 years
- Eliminating the periodic interruptions associated with north-south stationkeeping
- Saving (about) 100kg of fuel which could be used as additional payload mass

Unfortunately, there are a number of disadvantages associated with operating the GOES I-M spacecraft at large inclination angles. The study details are provided in Appendix A.1 and the results are summarized below.

- Ground antennas will require modification to provide continuous spacecraft tracking
- Continuous image and communications coverage to ± 60 degree latitudes is not possible at higher inclinations (i.e., each day latitudes above 60 degree are not visible for a period of time and latitudes below -60 degree are not visible during a period of time that is 12 hours later)
- The present instrument servo is not capable of tracking the increased IMC rates/accelerations required by the higher inclinations to maintain a fixed grid
- The only viable approach for providing a fixed grid may be re-sampling on the ground, since a redesign of the servo may not achieve the rates/accelerations necessary to support IMC. Also, the increased mass associated with the redesign will offset some of the fuel mass savings.
- All the sun pointing instrument FOVs are impacted and would require redesigns
- The coolers will need to be redesigned

In considering the above, the system impacts appear to far outweight any of the derived benefits. As a result, the use of higher inclinations as a means of eliminating north-south stationkeeping is not recommended.

10.2.2.2 Elimination of Control System Backup L-Mode Operation

This task was undertaken because the initial analysis presented at the INR CDR showed that the backup L-Mode of operation did not meet the INR jitter requirements. By providing on alternate back-up instead of the L-Mode wheel configuration, the spacecraft could still meet its INR performance with one wheel failed.

As a replacement to the L-Mode, two alternate wheel configurations were investigated: (1) two redundant momentum wheels (a 4 momentum wheel configuration) and (2) a tilt mechanism and one extra momentum wheel which would be positioned to replace the failed wheel. Both of these configurations were found to require an increase in mass of about 10kg over the L-Mode.

In mid February 1990, LAS prepared a memorandum showing that the INR CDR results were in error and that the L-Mode control system did meet the INR budget allocations. Since the alternate solutions being considered had a substantial mass impact, the study efforts were discontinued.

10.3 Option I

10.3.1 Overview of GOES I-M and Option I

10.3.1.1 GOES I-M and Option I System Descriptions

The GOES I-M and Option I system are identical except for the performance of the earth sensors, minor improvements to the imager servo, and a tightening of the momentum wheel tachometer noise specification. The system functional block diagram is given in Figure 10.3.1-1 and shows the command and data flow. Figure 10.3.1-2 is the spacecraft control system conceptual block diagram, and Figure 10.3.1-3 illustrates the Option I spacecraft configuration.

In this system, an earth sensor maintains the spacecraft pointing towards the earth. Earth sensor detected attitude errors in roll or pitch are sent to the momentum bias control system. The control system then causes changes in the momentum wheel speed to compensate for the sensed change in attitude.

The orbit and attitude are determined by a ground computer from (1) landmark and star measurements made using the instrument and (2) single station ranging data. The measurements (observations) for a 24 hour period are compared against the predicted locations for the landmarks and stars to determine the residual errors. These residual errors along with the ranging information are then used to update orbit/attitude information for the next 24 hour period.

Based on the calculated orbit/attitude, a set of IMC coefficients are generated and uploaded to the spacecraft AOCE computer. These IMC coefficients are then used to repoint the mirrors in the instruments to correct for diurnal variations in the orbit/attitude due to inclination and thermal effects. The IMC concept relies on diurnal variations being essentially the same on successive days. That is, the expected daily changes due to the position of the sun, normal orbit maintenance, etc. are within limits that permit the specified INR requirements to be met based on orbit/attitude predictions using the information from the previous 24 hours.

The dynamic interaction effect of instrument mirror motion producing a spacecraft nutation also is accounted for by repointing the mirrors. This is referred to as MMC. The repointing to correct for dynamic interaction is based on a simulation model of the spacecraft dynamics and in-orbit calibration of the model coefficients. The actual repointing determination is performed in real time by the AOCE computer using uniform time samples of the mirror positions received from both the imager and sounder.

In order to account for the effects of clouds and radiance gradients, and any other non-repeatable errors, SSAA will be used. SSAA (which impact the earth sensor) uses the residual errors from landmark and star measurements from a 2 or 3 hour period to determine if there is any trend in the mispointing. If the average value (mean) of the trend exceeds a preset threshold (e.g., 10μr), the zero order IMC coefficients for roll, pitch and/or yaw are corrected. The result is to maintain the non-repeatable error within acceptable limits.

10.3.1.2 Controller Hardware Description

As described previously, the Option I spacecraft control system hardware is nearly identical to the GOES I-M spacecraft control system. Figure 10.3.1-1 depicts a block diagram layout of the Option I control system hardware. In the on-orbit mode, a redundant set of horizon scanning earth sensors are used to provide pitch and roll attitude information to the AOCE. The earth sensors, developed by Lockheed in Sunnyvale, California, sense the earth limb through a pair of bolometers. The bolometer sky-earth transition data is fed into analog electronics circuitry and then through some complex adaptive threshold logic circuitry, which minimizes cold cloud and radiance gradient effects, to generate the roll and pitch data. The sensor is expected to operate to relative earth diameters of up to 40 degrees. It provides data at 4Hz with a bit quantization of 0.00125 degree (22μrad). The noise of the sensor is quite high as compared to the expected spacecraft end-to-end performance. The 3-sigma noise is 0.025 degree (436μrad) for pitch signal and 0.017 degree (296μrad) for roll. The primary modification to the earth sensor for Option I is to improve sensor noise. These modifications are expected to improve the noise characteristics by a factor of 1.4.

The Option I spacecraft will retain the basic three-axis, momentum bias configuration of GOES I-M. Two large momentum capacity wheels arranged in a V-shaped configuration provide gyroscopic stiffness and primary control torque capability along the spacecraft pitch and yaw axes. The momentum wheels each can store up to 50ft-lb-sec of momentum and provide 12in-oz of control torque. For redundancy, a smaller, 2ft-lb-sec reaction wheel is mounted along the spacecraft yaw axis to replace the yaw component of either of the momentum wheels. The GOES I-M wheels are provided by Teldix of Heidelberg, West Germany. The wheel system weights approximately 60lb.

The Option I AOCE is based on four 2901 bit slice microprocessor elements. The AOCE operates at a clock speed of 1MHz and sends out torque commands at a rate of 4Hz. Other control hardware included on the Option I spacecraft include 5lb thrusters for stationkeeping and a solar sail, trim tab and 100amp-turn-m^2 torquer bars for momentum management. In addition, coarse and fine sun sensors as well as rate integrating gyros are used to provide attitude information during acquisition and stationkeeping. For more detailed information of the Option I attitude control system, see the GOES I-M satellite operations handbook.

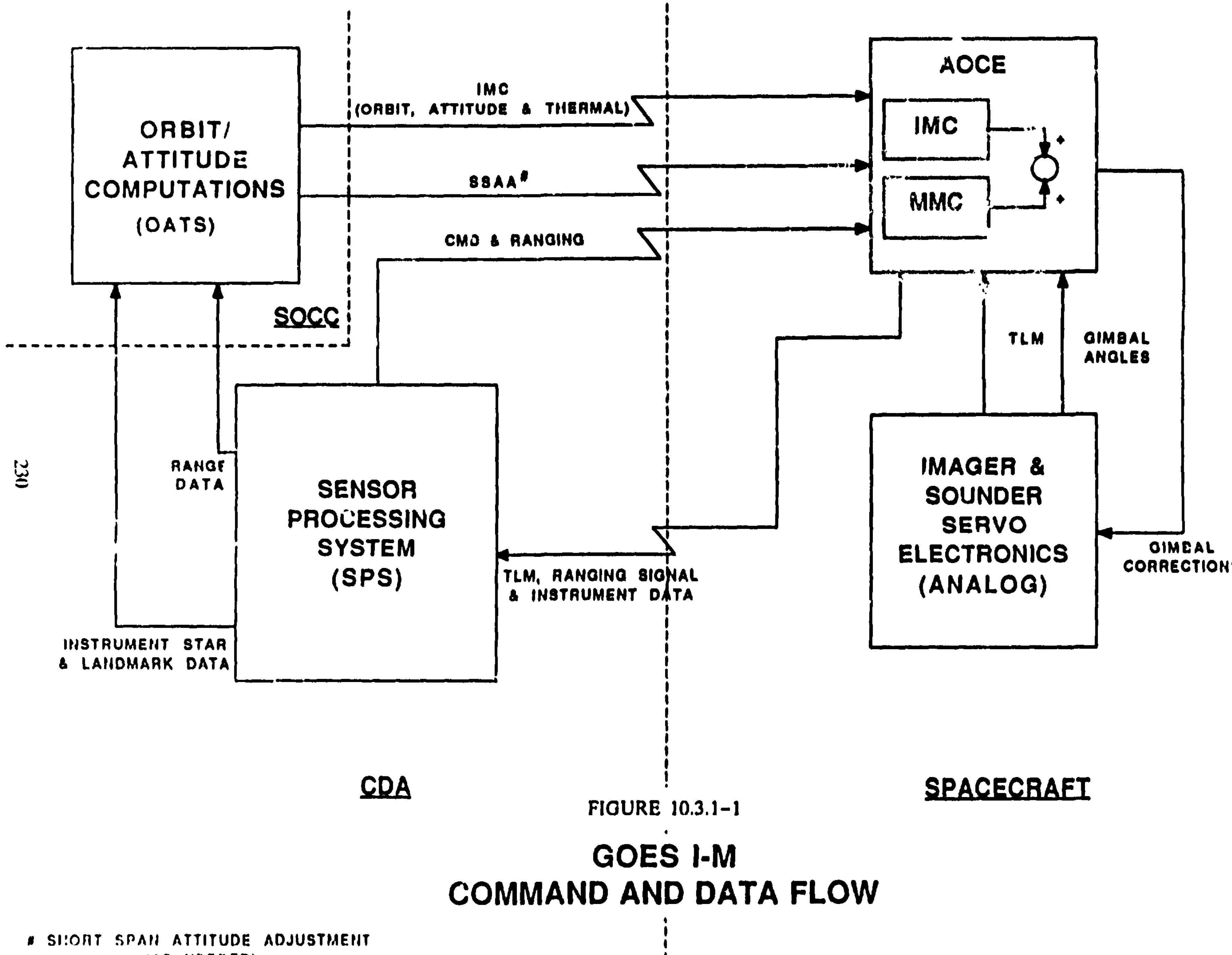


FIGURE 10.3.1-1

GOES I-M
COMMAND AND DATA FLOW

SHORT SPAN ATTITUDE ADJUSTMENT
(AS NEEDED)

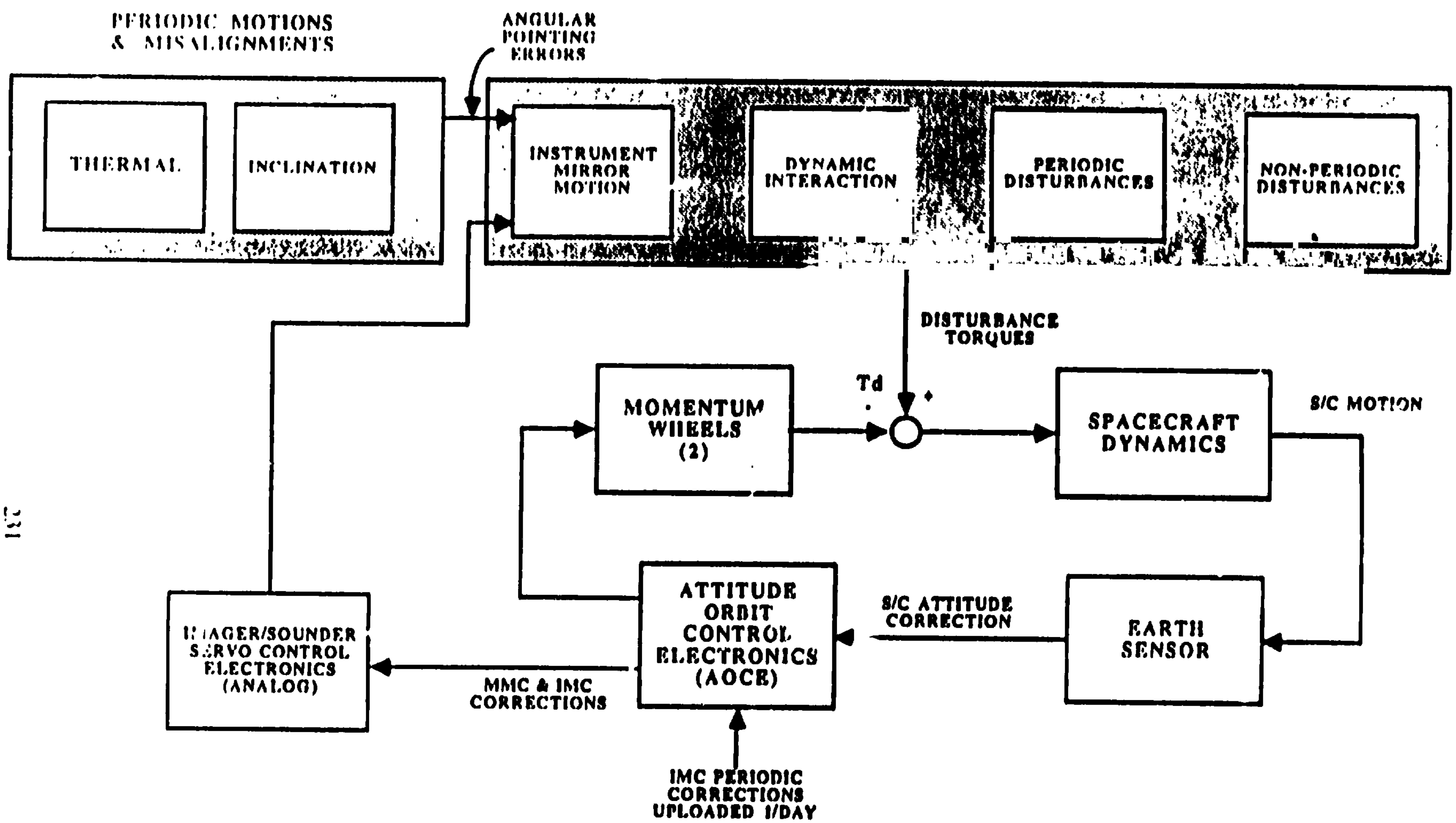
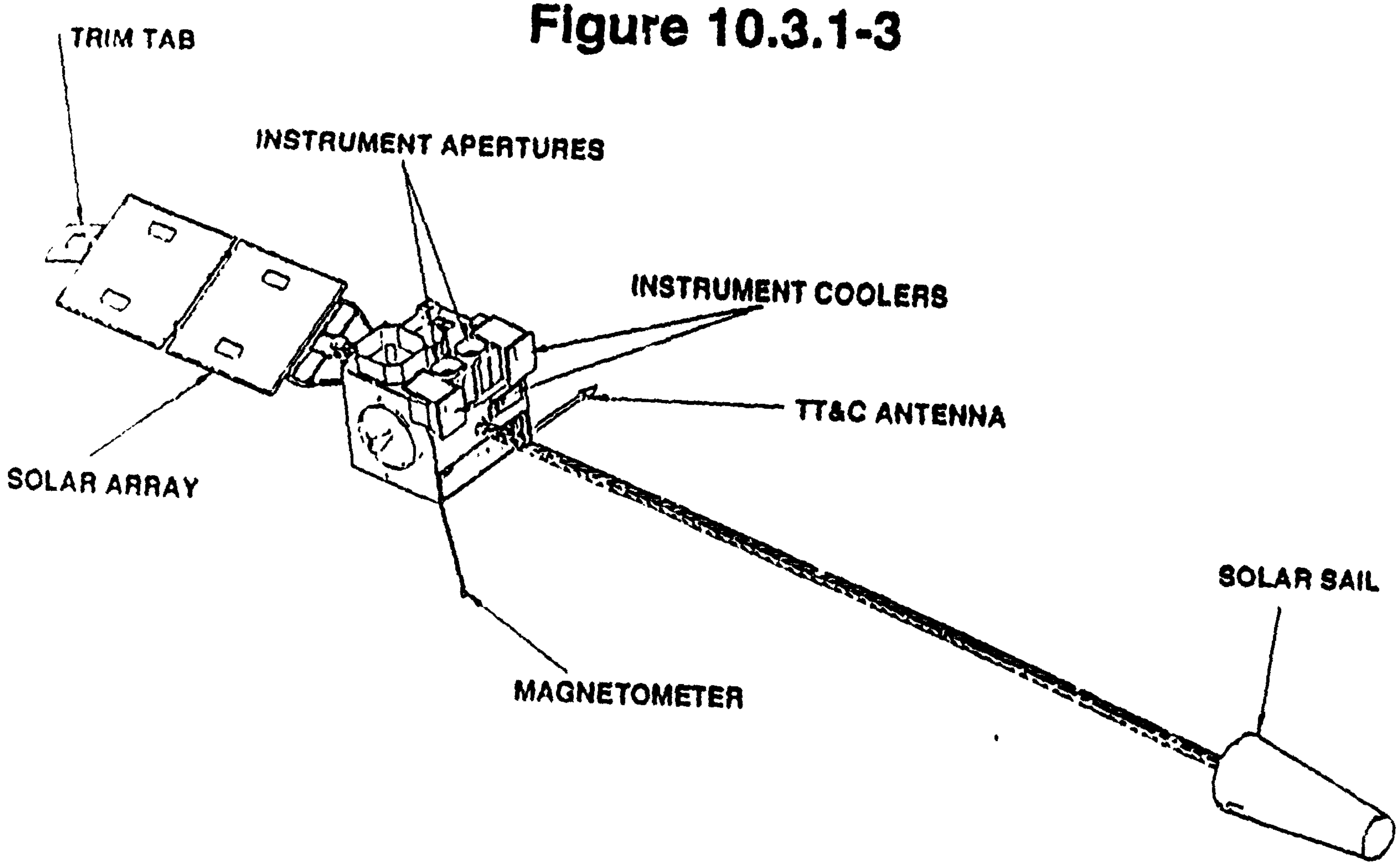


FIGURE 10.3.1-2

GOES I & GOES N OPTION I SPACECRAFT CONTROL SYSTEM CONCEPTUAL BLOCK DIAGRAM

GOES–N OPTION I (ORBIT CONFIGURATION)

Figure 10.3.1-3



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10.3.2 Summary of Predicted Performance

10.3.2.1 Budget Allocation Description

A full description of the allocation budget entries is provided in Appendix C. Tables 10.3.2-1 and 10.3.2-5 summarize the predicted INR performance of the GOES I-M and Option I systems. In Tables 10.3.2-2 through 10.3.2-8, the error is grouped into seven major categories which combine to form the total error:

1. Attitude stability (line 9),
2. Mirror motion compensation (MMC, line 19),
3. Short term image motion compensation (IMC, line 20),
4. Imager pointing (line 22),
5. AOCE interface (line 34),
6. Long term IMC errors with a perfect attitude model (line 41),
7. Long term IMC error from imperfections in the attitude model and error non-repeatability (line 44).

TABLE 10.3.2-1
COMPARISON AND SUMMARY GOES I-M

	NAVIGATION (μr)	WITHIN FRAME REGISTRATION (μr)	90 MINUTE FRAME-FRAME (μr)
ATTITUDE STABILITY	22.0	31.0	31.0
MCC COMPUTATION ERROR	7.0	9.9	9.9
IMC COMPUTATION ERROR	5.0	7.0	7.0
IMAGER POINTING	15.9	22.5	10.5
AOCE INTERFACE	4.9	6.9	6.9
PERFECT O/A DETERMINATION	26.0	26.0	26.0
NONRPTL. ERROR W/SSAA	18.7	11.6	12.6
COMBINED ERROR	43.1	49.7	45.9
COMBINED ERROR WITH 50% MARGIN	64.7	74.6	68.8

Spec - GOES-N Req't		112 uR
File Name NAV-REV		GOES I-M
Imager Navigation		
COMBINED SHORT&LONG TERM		43.1
SHORT TERM		28.9
ATT. STAB.		22.0
ES/IRU NOISE	20.0	
DYN. INTER.	9.1	
RIGID BODY	6.4	
SA STEPPING	4.0	
MIRR.MOTION	5.0	
OTHER	0.0	
MW IMBALANCE	5.0	
NONRIGD.BODY	4.0	
MMC COMP.ERR		7.0
IMC COMP.ERR		5.0
IMGR.POINT		15.9
IMC SERVO ERROR	4.0	
IMC PROC.ERR	7.0	
INTER.TORQ	2.1	
CKT.DRIFT	0.4	
QUAD.ERRORS	0.0	
LINEARITY	3.5	
LINEARITY BIAS	12.0	
NOISE/JITTER	2.0	
STEP/SETTLE	1.0	
DET.ROTATION	4.2	
VIDEO DELAY	2.0	
AOCE INTERFC		4.9
LINE NOISE	4.0	
LPFILTER LAG	2.0	
DAC ERROR	2.0	
LONG TERM ORBIT/ATTITUDE		32.0
PERFECT O/A DETERMIN		26.0
(From INR Simulator)		
NONRPTL.& O/A MOD. W/		18.7
ORBIT/ATTITUDE MODEL		30.0
THERM(IM&SC)	30.0	
MODEL PARMTR	0.0	
NONRPTBL.ERR		81.9
CLOUD/RADGRD	70.0	
HEATER OPS.	30.0	
S/C YAW	30.0	

Spec - GOES-N Req't File Name INFR-REV Imager Navigation		42 uR GOES I-M
COMBINED SHORT&LONG TERM		49.7
SHORT TERM		40.8
ATT. STAB.*1.41		31.0
ES/IRU NOISE	20.0	
DYN. INTER.	9.1	
RIGID BODY	6.4	
SA STEPPING	4.0	
MIRR.MOTION	5.0	
OTHER	0.0	
MW IMBALANCE	5.0	
NONRIGD.BODY	4.0	
MMC COMP.ERR*1.41		9.9
IMC COMP.ERR*1.41		7.0
IMGR.POINT * 1.41		22.5
IMC SERVO ERROR	4.0	
IMC PROC.ERR	7.0	
INTER.TORQ	2.1	
CKT.DRIFT	0.4	
QUAD.ERRORS	0.0	
LINEARITY	3.5	
LINEARITY BIAS	12.0	
NOISE/JITTER	2.0	
STEP/SETTLE	1.0	
DET.ROTATION	4.2	
VIDEO DELAY	2.0	
AOCE INTERFC*1.41		6.9
LINE NOISE	4.0	
LPFILTER LAG	2.0	
DAC ERROR	2.0	
LONG TERM ORBIT/ATTITUDE		28.5
PERFECT O/A DETERMIN (From INR Simulator)		26.0
NONRPTL.& O/A MOD. W/		11.6
ORBIT/ATTITUDE MODEL		8.0
THERM(IM&SC)	8.0	
MODEL PARMTR	0.0	
NONRPTBL.ERR		14.1
CLOUD/RADGRD	6.0	
HEATER OPS.	8.0	
S/C YAW	10.0	

ALLOCATION

TABLE 10.3.2-4

REGISTRATION, 25-Oct-90

Spec - GOES-N Req't	84/105 uR	
File Name REG-REV	GOES I-M	
Imager Navigation		
COMBINED SHORT&LONG TERM		45.9
SHORT TERM		35.6
ATT. STAB.*1.41		31.0
ES/IRU NOISE	20.0	
DYN. INTER.	9.1	
RIGID BODY	6.4	
SA STEPPING	4.0	
MIRR.MOTION	5.0	
OTHER	0.0	
MW IMBALANCE	5.0	
NONRIGD.BODY	4.0	
MMC COMP.ERR*1.41		9.9
IMC COMP.ERR*1.41		7.0
IMGR.POINT		10.5
IMC SERVO ERROR	4.0	
IMC PROC.ERR	7.0	
INTER.TORQ	2.1	
CKT.DRIFT	0.6	
QUAD.ERRORS	0.0	
LINEARITY	4.9	
LINEARITY BIAS	0.0	
NOISE/JITTER	2.8	
STEP/SETTLE	0.0	
DET.ROTATION	0.0	
VIDEO DELAY	2.8	
AOCE INTERFC*1.41		6.9
LINE NOISE	4.0	
LPFILTER LAG	2.0	
DAC ERROR	2.0	
LONG TERM ORBIT/ATTITUDE		28.9
PERFECT O/A DETERMIN		26.0
(From INR Simulator)		
NONRPTL.& O/A MOD. W/		12.6
ORBIT/ATTITUDE MODEL		12.0
THERM(IM&SC)	12.0	
MODEL PARMTR	0.0	
NONRPTBL.ERR		22.8
CLOUD/RADGRD	14.0	
HEATER OPS.	10.0	
S/C YAW	15.0	

TABLE 10.3.2-5
COMPARISON AND SUMMARY GOES-N

	OPTION I		
	NAVIGATION (μr)	WITHIN FRAME REGISTRATION (μr)	90 MINUTE FRAME-FRAME (μr)
ATT. STAB.	17.5	24.8	24.8
MMC COMP. ERR	7.0	9.9	9.9
IMC COMP. ERR	5.0	7.0	7.0
IMGR. POINT	15.9	22.5	10.5
AOCE INTERFC	4.9	6.9	6.9
PERFECT O/A DETERMINATION	26.0	26.0	26.0
NONRPLT. ERR W/SSAA	18.7	11.6	12.6
COMBINED ERROR	41.0	46.1	41.9
COMBINED ERROR W/50% MARGIN	61.6	69.1	62.8

Items (1) through (5) are considered short term sources of error, because they vary more rapidly than the nutation period of the spacecraft (approximately 3 minutes).

Items (6) (line 41) and (7) (line 44) characterize long term errors in the IMC signal. In both the GOES I-M and GOES-N systems, star and landmark measurements are used to make observations of pointing error throughout each orbit. The observed error is then used to generate an IMC correction to be applied the following day. This scheme is designed to remove slowly varying errors from the system. Item (6) refers to the residual orbit/attitude error from one day to the next. Even if the IMC could repeat exactly the next orbit, and even if the spacecraft could follow the correction perfectly, there will still be pointing error due to instrument noise.

Item (7) includes the errors which occur because the system may only be capable of following an approximation of the calculated correction, and because the correction applied today based on yesterday's error will not be entirely correct due to non-repeatability of the error sources (e.g., change in the sun angle).

The INR performance budget allocation errors were important to understand during the initial study efforts, because they provided insight into how to provide significant improvements in Options II/III and some level of improvements in Option I. Table 10.3.2-9 lists the errors by

Spec - GOES-N Req't		112 uR
File Name NAV-REV1		OPTION 1
Imager Navigation		
COMBINED SHORT&LONG TERM		41.0
SHORT TERM		25.6
ATT. STAB.		17.5
ES/TACH	15.0	
DYN. INTER.	9.1	
RIGID BODY	6.4	
SA STEPPING	4.0	
MIRR.MOTION	5.0	
OTHER	0.0	
MW IMBALANCE	5.0	
NONRIGD.BODY	4.0	
MMC COMP.ERR		7.0
IMC COMP.ERR		5.0
IMGR.POINT		15.9
IMC SERVO ERROR	4.0	
IMC PROC.ERR	7.0	
INTER.TORQ	2.1	
CKT.DRIFT	0.4	
QUAD.ERRORS	0.0	
LINEARITY	3.5	
LINEARITY BIAS	12.0	
NOISE/JITTER	2.0	
STEP/SETTLE	1.0	
DET.ROTATION	4.2	
VIDEO DELAY	2.0	
AOCE INTERFC		4.9
LINE NOISE	4.0	
LPFILTER LAG	2.0	
DAC ERROR	2.0	
LONG TERM ORBIT/ATTITUDE		32.0
PERFECT O/A DETERMIN (From INR Simulator)		26.0
NONRPTL.& O/A MOD. W/		18.7
ORBIT/ATTITUDE MODEL		30.0
THERM(IM&SC)	30.0	
MODEL PARMTR	0.0	
NONRPTBL.ERR		81.9
CLOUD/RADGRD	70.0	
HEATER OPS.	30.0	
S/C YAW	30.0	

TABLE 10.3.2-7 :

ALLOCATION IN-FRAME REG., 25-Oct-90

Spec - GOES-N Req't		42 uR
File Name INFR-RE1		OPTION 1
Imager Navigation		
COMBINED SHORT&LONG TERM		46.1
SHORT TERM		36.2
ATT. STAB.*1.41		24.8
ES/TACH	15.0	
DYN. INTER.	9.1	
RIGID BODY	6.4	
SA STEPPING	4.0	
MIRR.MOTION	5.0	
OTHER	0.0	
MW IMBALANCE	5.0	
NONRIGD.BODY	4.0	
MMC COMP.ERR*1.41		9.9
IMC COMP.ERR*1.41		7.0
IMGR.POINT * 1.41		22.5
IMC SERVO ERROR	4.0	
IMC PROC.ERR	7.0	
INTER.TORQ	2.1	
CKT.DRIFT	0.4	
QUAD.ERRORS	0.0	
LINEARITY	3.5	
LINEARITY BIAS	12.0	
NOISE/JITTER	2.0	
STEP/SETTLE	1.0	
DET.ROTATION	4.2	
VIDEO DELAY	2.0	
AOCE INTERFC*1.41		6.9
LINE NOISE	4.0	
LPFILTER LAG	2.0	
DAC ERROR	2.0	
LONG TERM ORBIT/ATTITUDE		28.5
PERFECT O/A DETERMIN (From INR Simulator)		26.0
NONRPTL.& O/A MOD. W/		11.6
ORBIT/ATTITUDE MODEL		8.0
THERM(IM&SC)	8.0	
MODEL PARMTR	0.0	
NONRPTBL.ERR		14.1
CLOUD/RADGRD	6.0	
HEATER OPS.	8.0	
S/C YAW	10.0	

1	Spec - GOES-N Req't		42 uR
2	File Name REG-REV1		OPTION 1
3	Imager Navigation		
4			
5	COMBINED SHORT&LONG TERM		41.9
6			
7	SHORT TERM		30.3
8			
9	ATT. STAB.*1.41		24.8
10	ES/TACH	15.0	
11	DYN. INTER.	9.1	
12	RIGID BODY	6.4	
13	SA STEPPING	4.0	
14	MIRR.MOTION	5.0	
15	OTHER	0.0	
16	MW IMBALANCE	5.0	
17	NONRIGD.BODY	4.0	
18			
19	MMC COMP.ERR*1.41		9.9
20	IMC COMP.ERR*1.41		7.0
21			
22	IMGR.POINT		10.5
23	[illegible]C SERVO ERROR	4.0	
24	[illegible] PROC.ERR	7.0	
25	IN[illegible]R.TORQ	2.1	
26	CKT.DRIFT	0.6	
27	QUAD.ERRORS	0.0	
28	LINEARITY	4.9	
29	LINEARITY BIAS	0.0	
30	NOISE/JITTER	2.8	
31	STEP/SETTLE	0.0	
32	DET.ROTATION	0.0	
33	VIDEO DELAY	2.8	
34	AOCE INTERFC*1.41		6.9
35	LINE NOISE	4.0	
36	LPFILTER LAG	2.0	
37	DAC ERROR	2.0	
38			
39	LONG TERM ORBIT/ATTITUDE		28.9
40			
41	PERFECT O/A DETERMIN		26.0
42	(From INR Simulator)		
43			
44	NONRPTL.& O/A MOD. W/		12.6
45	ORBIT/ATTITUDE MODEL		12.0
46	THERM(IM&SC)	12.0	
47	MODEL PARMTR	0.0	
48	NONRPTBL.ERR		22.8
49	CLOUD/RADGRD	14.0	
50	HEATER OPS.	10.0	
51	S/C YAW	15.0	

TABLE 10.3.2-9
GOES I-M/OPTION I MAJOR PERFORMANCE DRIVERS
(IN ORDER OF IMPACT)

NAVIGATION	IN-FRAME REGISTRATION	FRAME-FRAME REGISTRATION
LONG TERM ORBIT/ATTITUDE • THERMAL DEFORMATION • SPACECRAFT YAW	ATTITUDE STABILITY/ES NOISE	ATTITUDE STABILITY/ES NOISE
INDUCTOSYN LINEARITY	INDUCTOSYN LINEARITY	NON-REPEATABLE ERRORS • CLOUDS/RADIANCE GRADIENTS • HEATER OPERATIONS
ATTITUDE STABILITY/ES NOISE	IMAGER POINTING	LONG TERM ORBIT/ATTITUDE • THERMAL DEFORMATION • SPACECRAFT YAW
NON-REPEATABLE ERRORS • CLOUDS/RADIANCE GRADIENTS • HEATER OPERATIONS	LONG TERM ORBIT/ATTITUDE • THERMAL DEFORMATION • SPACECRAFT YAW	------------
------------	NON-REPEATABLE ERRORS • CLOUDS/RADIANCE GRADIENTS • HEATER OPERATIONS	------------

their relative importance for navigation and in-frame and frame-frame registrations. The attitude stability error is primarily due to earth sensor noise/jitter. The orbit/attitude determination error is due to large thermal deformations and spacecraft yaw which is not controlled, except through quarter orbit roll/yaw coupling. Inductosyn linearity, which is included in the servo pointing, is separated from the other servo errors because it is a major error in the GOES-I design. The major non-repeatable errors are expected to be due to the effects of clouds and radiance gradients. All of these error sources are reduced or eliminated by the control system, servo design, and material/structural changes proposed for Options II/III.

The error totals given in the tables for items (1) through (6) result from a Root Sum Square (RSS) combination of the errors which comprise each category. The total for item (7), however, is calculated differently because of the use of SSAA. SSAA is a process by which pointing error is monitored for 2-3 hours, and, if a bias error greater than some threshold (10μr, for example) is detected, a correction is introduced into the IMC signal to compensate for the error. The error for item (7) was therefore estimated as 10μr plus 10% of the RSS total of its two components (orbit/attitude model and non-repeatable error). The 10% of the RSS total is included to account for the error which SSAA does not remove successfully.

Figures 10.3.2-1 and 10.3.2-2 summarize the INR performance assessments for GOES I-M and Option I, using bar charts which show the six largest error sources (all except item (5)). However, item 5, AOCE interface error, is included in the total. The only difference between GOES I-M and Option I which affects INR performance is the earth sensor configuration, so the tables and figures for the two systems are nearly identical.

10.3.2.2 GOES I-M Performance Results

10.3.2.2.1 Navigation

Figure 10.3.2-2 illustrates that the predicted navigation performance of the GOES I-M system is 64.7μr (including a 50% margin); thus the system is expected to meet the 112μr requirement. Long term error from calculating the IMC correction signal is the largest source of navigation error (26.0μr), followed by attitude stability (22.0μr).

10.3.2.2.2 Within-frame registration

Figure 10.3.2-2 indicates that the predicted within-frame registration performance of the GOES I-M system is 74.6μr (including a 50% margin), which exceeds the 42μr requirement.

Although the long term error from non-repeatability decreased from navigation levels, many of the short term errors increased by the square root of two because of their random nature. The net effect is a moderate increase in overall error. As in navigation, attitude stability and long term error are the top two sources, but imager pointing also shows a significant contribution. Because there are several sources showing strong contributions to the total error, reduction of the total to meet the specification would require several different improvements to the system.

10.3.2.2.3 Frame-to-frame registration

Figure 10.3.2-2 indicates that the predicted frame-to-frame registration performance of the GOES I-M system is 68.8μr (including a 50% margin), and the system is, therefore, expected to meet the 84μr requirement. The overall error is slightly less than in the within-frame case, largely because of a significant reduction in imager pointing error. This reduction occurs because servo bias errors are essentially the same for the same pixel in two images of the same area of the earth and do not contribute to this error source. The distribution of error is otherwise similar to the within-frame case, with attitude stability being the largest contributor.

10.3.2.3 Option I (Improved GOES-I) Performance Results

10.3.2.3.1 Navigation

Figure 10.3.2-1 shows that the predicted navigation error performance of the Option I system is 61.6μr (including a 50% margin), which represents a slight improvement over the GOES I-M system. All of the improvement is due to the inclusion of an improved earth sensing system in the Option I design, which leads to a reduction in attitude stability error. As in the GOES I-M budget, long term error in the IMC signal shows the greatest contribution to the total error. The Option I system is expected to meet the 112μr navigation error requirement.

10.3.2.3.2 Within-frame registration

Figure 10.3.2-1 shows that the predicted within-frame registration error performance of the Option I system is 69.1μr (including a 50% margin) which exceeds the 42μr requirement. The reduction in attitude stability error from GOES I-M levels brings the total error without margin to 46.1μr, which approaches the required value. However, several sources still show large contributions to the total error which indicates that achieving the performance goal will be difficult with the Option I design.

10.3.2.3.3 Frame-frame registration

Figure 10.3.2-1 shows that the predicted frame-to-frame registration performance of the Option I system is 62.8μr (including a 50% margin), which exceeds the 42μr requirement.
Excluding the margin, the error is 41.9μr and just meets the requirement. Imager pointing error is reduced from within frame levels, due to the absence of servo bias error. With this reduction, the total error is primarily a function of only two sources: attitude stability and long term IMC error. Further improvement in either of these two areas would provide some margin for meeting the requirement.

10.4 Option II Control and Pointing Subsystems

10.4.1 Option II Overview

10.4.1.1 Option II Description

The Option II control system functional block diagram is given in Figure 10.4.1-1; it shows the major system elements and the command and data flow between these elements. Figure 10.4.1-2 contains the spacecraft control and pointing system conceptual block diagram. Both figures are referred to in the following paragraphs. Figure 10.4.1-3 shows the configuration of the Option II and III spacecraft and some of the key features, including the orientation of the star trackers and the redesigned solar arrays to minimize solar torque effects. Table 10.4.1-1 summarizes the Option II/III improvements with respect to the Option I/GOES-I systems.

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FIGURE 10.3.2-1

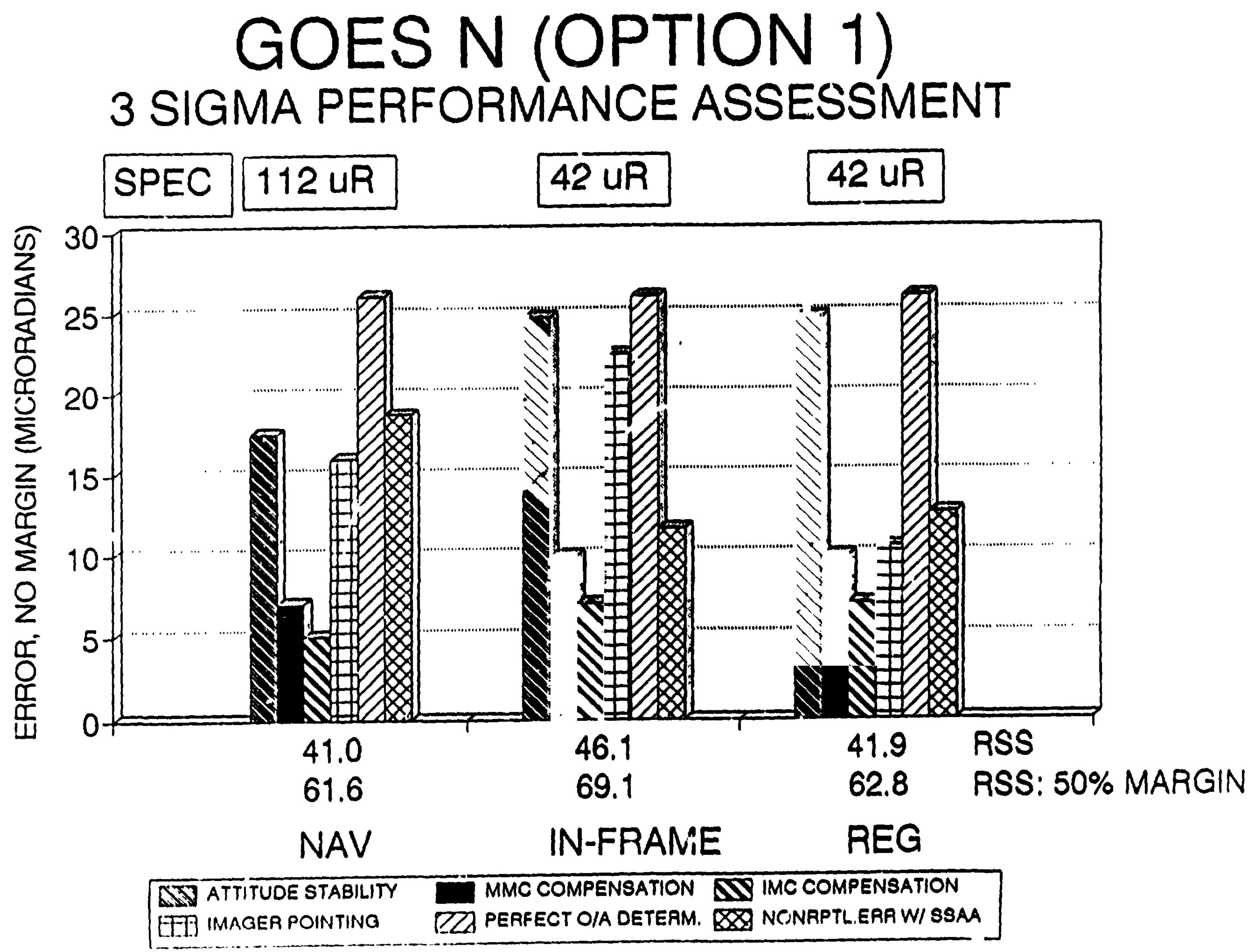


FIGURE 10.3.2-2

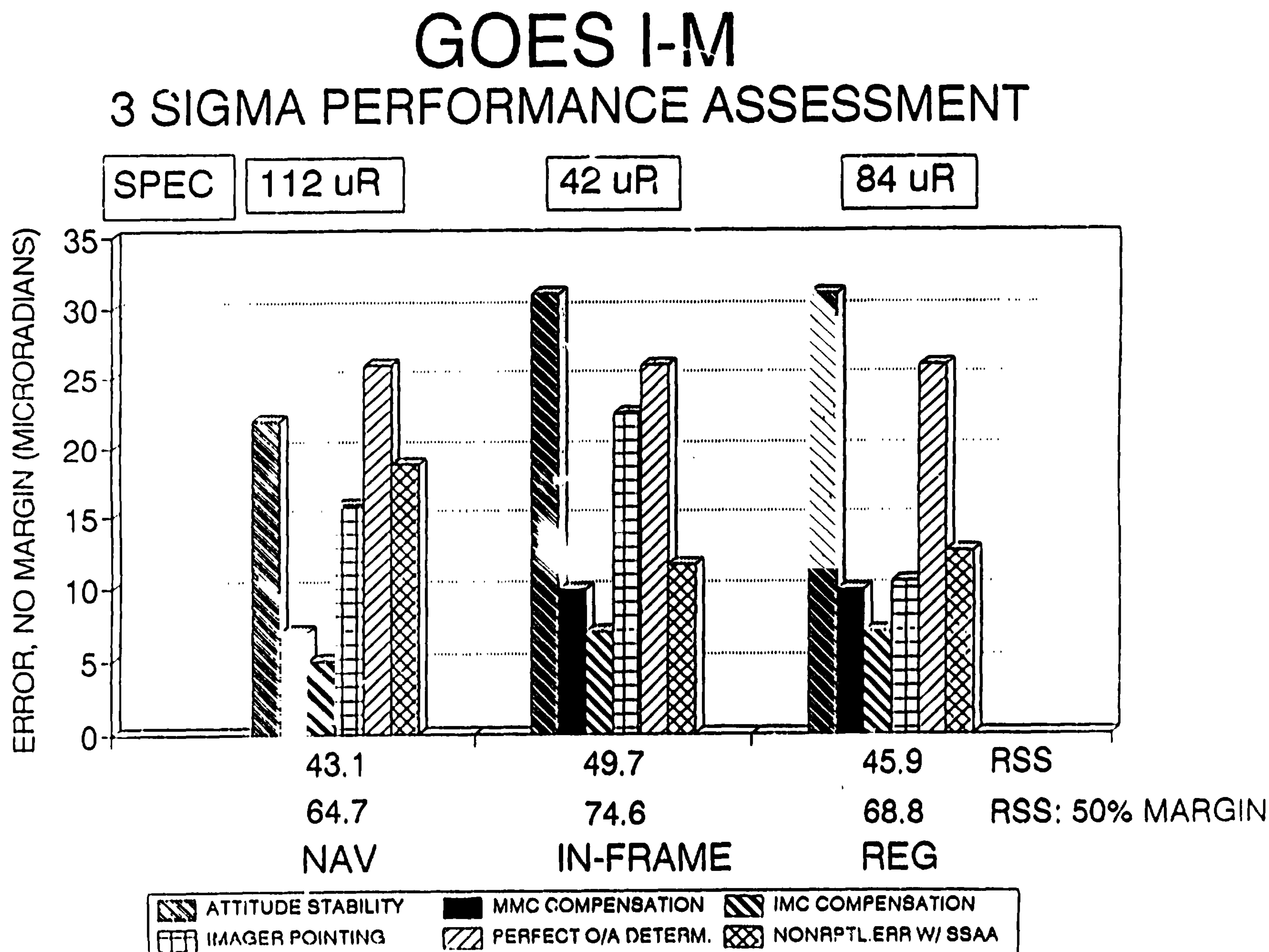
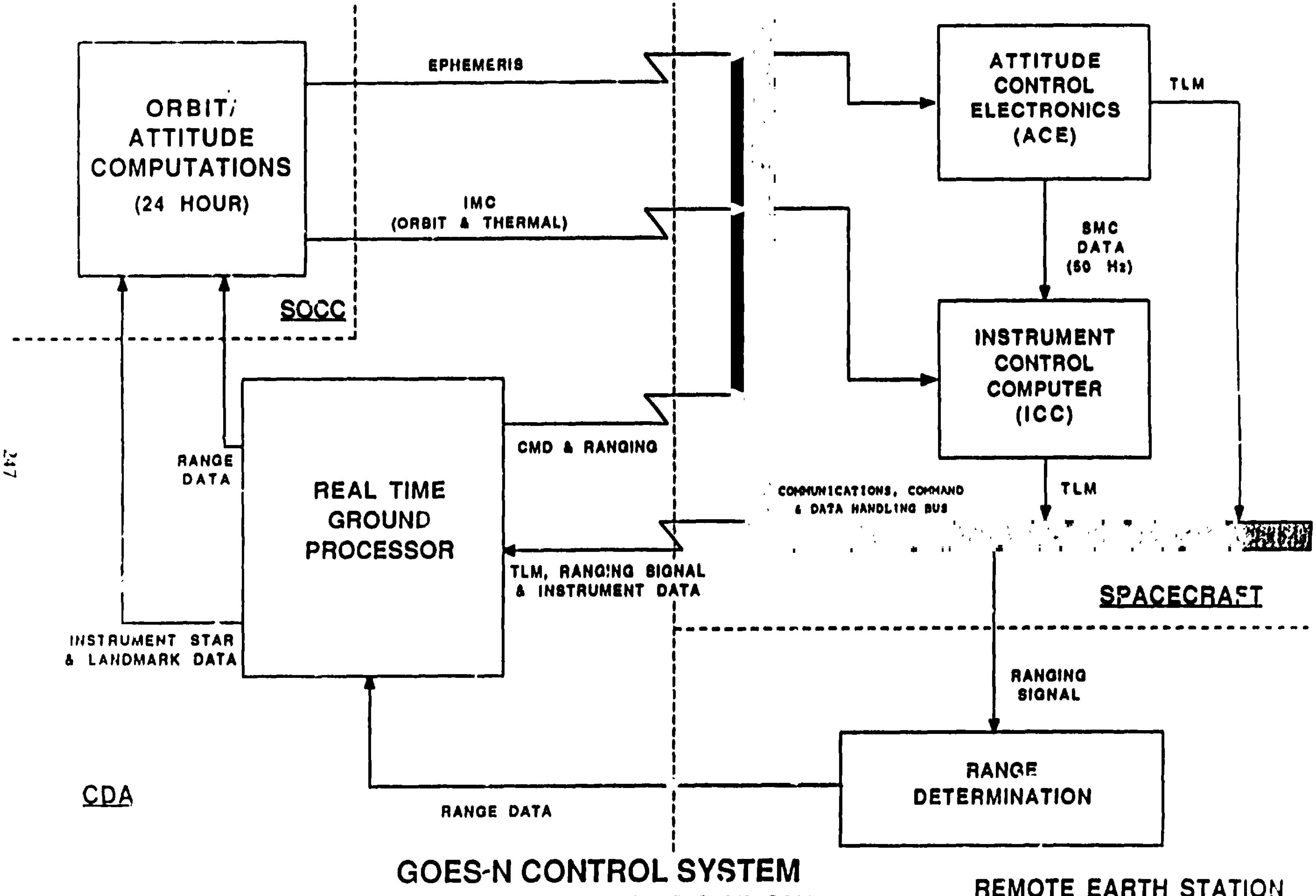
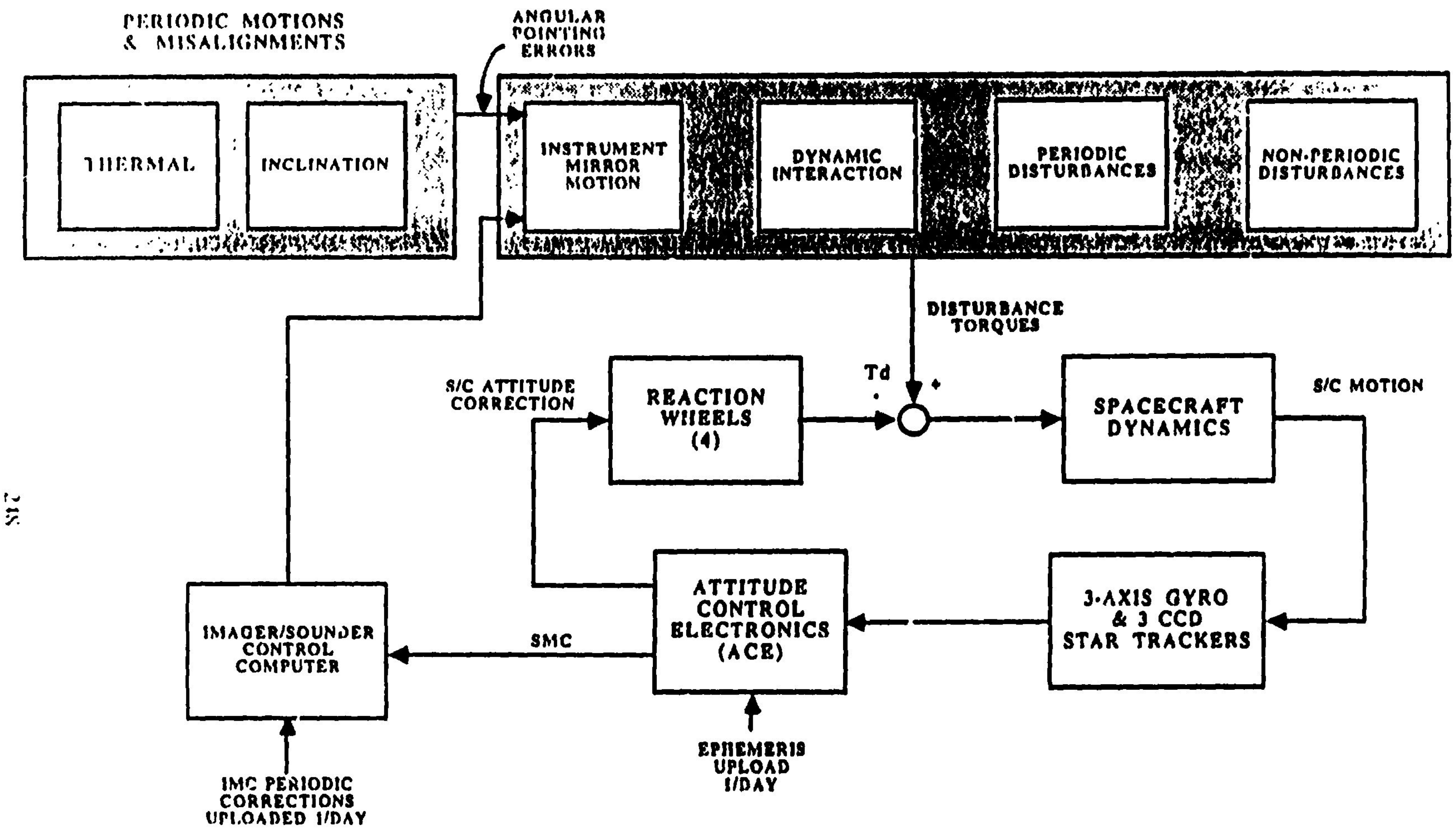


FIGURE 10.4.1-1



GOES-N CONTROL SYSTEM
COMMAND AND DATA FLOW

FIGURE 10.4.1-2



GOES N OPTIONS II & III
SPACECRAFT CONTROL SYSTEM
CONCEPTUAL BLOCK DIAGRAM

FIGURE 10.4.1-3

GOES-N CONTROL SYSTEM
OPTIONS II & III

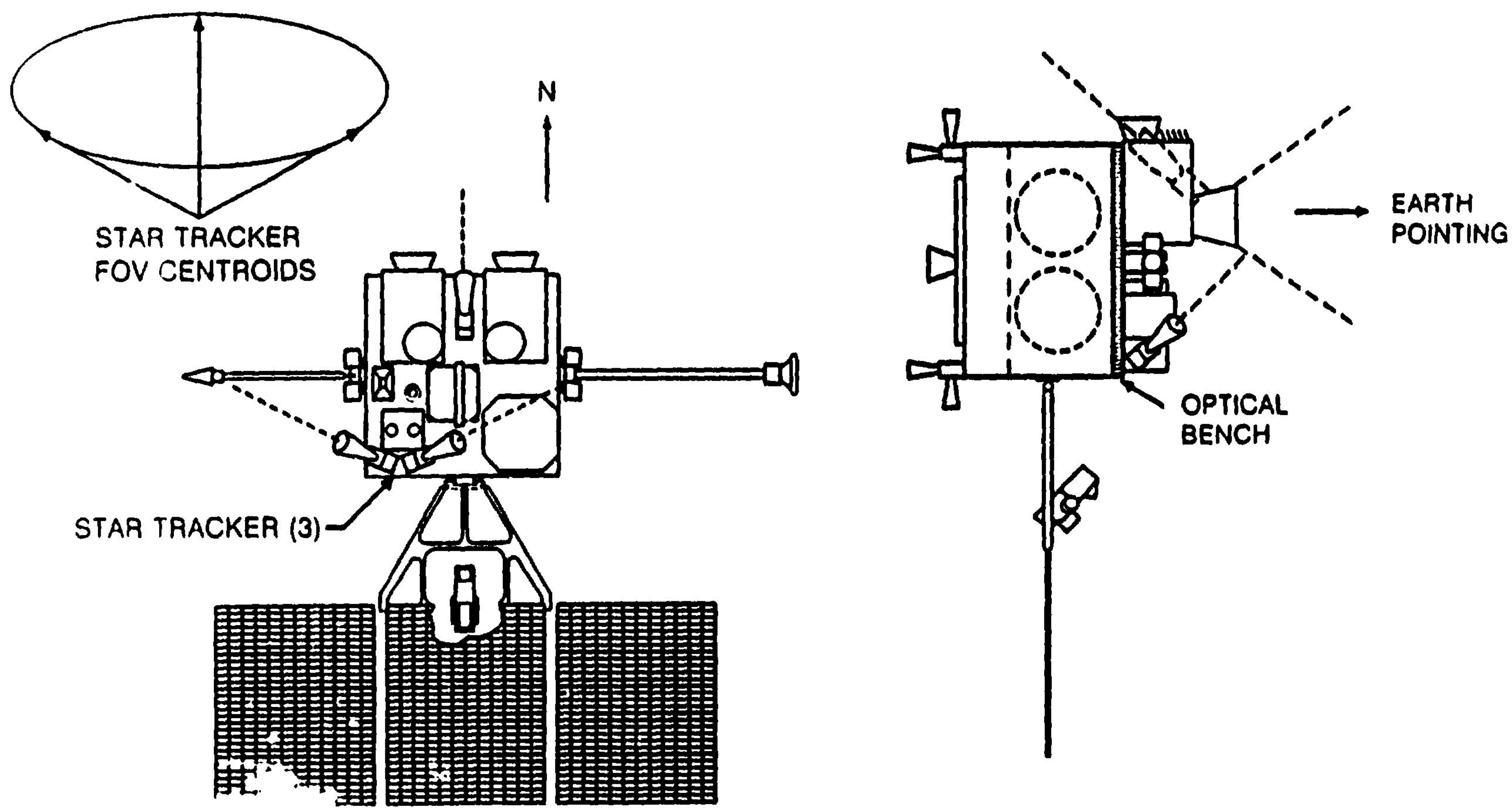


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TABLE 10.4.1-1
Option II/III improvements with respect to Option I/GOES-I

AREA OF CHANGE	IMPROVEMENTS
OPTION II	
STAR TRACKER/GYRO	SPACECRAFT JITTER YAW CONTROL
ZERO MOMENTUM BIAS/REACTION WHEELS	DYNAMIC INTERACTION STATIONKEEPING RECOVERY TIME
OPTICAL BENCH	THERMAL DEFORMATIONS, STRUCTURE/ MODAL FREQUENCY PERFORMANCE
SPACECRAFT MOTION COMPENSATION REPOINTING	REALTIME MIRROR COMPENSATION (FOR ALL DYNAMIC INTERACTION)
INSTRUMENT SERVO - 3" OPTICAL ENCODER	IMPROVED INSTRUMENT POINTING
SOUNDER REDESIGN	THERMAL DEFORMATIONS, STRUCTURAL/ MODAL FREQUENCY PERFORMANCE
BIANNUAL YAW FLIP	IMPROVED COOLER PERFORMANCE*
RECONFIGURED SOLAR ARRAY	MINIMIZE SOLAR TORQUE EFFECTS
OPTION III	
ALL OF THE ABOVE	
INSTRUMENT REDESIGN - IMPROVED INSTRUMENT POINTING 5" OPTICAL ENCODER	THERMAL DEFORMATIONS, STRUCTURAL/ MODAL FREQUENCY PERFORMANCE

* BIANNUAL SPACECRAFT YAW FLIP WILL NOT BE REQUIRED FOR OPTION III IF A MECHANICAL REFRIGERATOR AND REDESIGNED IMAGER ARE USED

The Option II system is an inertially referenced system, using star trackers and very stable gyroscopes to maintain the spacecraft attitude in roll, pitch and yaw. The advantage of this implementation over the GOES I-M earth referenced, earth sensor system is a significant reduction in jitter. Also, the pitch axis is maintained parallel with the earth's north-south axis throughout the orbit. However, since this implementation is not an earth referenced system, it is more sensitive to orbit errors, requiring better orbit determination. As a result, two remote sites to receive ranging data contained in the processed data stream (i.e., analogous to the retransmitted CVAR data stream in GOES I-M) will be required. These sites could be unmanned or be located at sites that already receive processed data.

Referring to Figure 10.4.1-2, the INR operation on the spacecraft relies on the pointing direction determination of the star tracker/gyro system to generate error signals in roll, pitch and yaw. The error signals are processed in the ACE to produce two sets of control signals:

- Low frequency torque signals to continuously maintain the spacecraft pointing by controlling the speed and direction of the reaction wheels at a 0.1Hz controller bandwidth
- High frequency attitude error signals for repointing the instrument mirrors to compensate for the attitude errors that cannot be followed by the above "closed loop" star tracker/gyro, ACE, and reaction wheels control subsystem; this mirror compensation is termed SMC

The new feature of this control system is SMC, which replaces the open loop MMC on GOES I-M. SMC uses the realtime error signal sensed by the star tracker/gyro to correct for any higher frequency pointing errors that cannot be compensated by the control system. The SMC signal is added to the IMC signal, in the same manner that MMC is added to IMC on the GOES-I spacecraft. (Appendix A provides additional details of the SMC system.)

The control system ground processing will be similar to GOES I-M for IMC attitude determination based on landmark and star data obtained through the instrument. The IMC is determined by ground processing of 24 hours of data, with the instantaneous mirror pointing correction computed on the spacecraft (like GOES I-M). However, the IMC in the GOES-N system is used to compensate only for inclination and thermal variations between the instrument focal plane and star tracker/gyro system. In addition, the resulting error due to imperfect IMC corrections will be less than in GOES-I, because the use of an optical bench and the redesigned sounder (the redesign of the imager is part of Option III) will result in significantly smaller overall thermal deformations to be corrected.

In comparison with the GOES I-M control system, the GOES-N control system provides:

- Control for roll, pitch, and yaw axes
- Wider bandwidth control loops to better track perturbations
- Rapid recovery within minutes following a Station Keeping (SK) maneuver
- Lower jitter
- Immunity to clouds or radiance gradients
- Realtime repointing of the mirrors based on error signals from the control system (i.e., not models), which permits sensing of dynamic interactions due to any cause including mirror motion and low frequency flexible body effects
- Smaller IMC corrections that will only need to correct for inclination and thermal distortions
- An SSAA capability as a backup, if required, to compensate for slowly varying pointing errors

In addition, the Option II and III spacecraft will not have a solar sail and trim tab, which results in an improvement in the passive cooler performance. Thruster firings will be used about once per day to unload the wheel momentum (Appendix A.3) resulting from the absence of the solar sail and trim tab. These thruster firings will be ≈ 0.5sec in duration from two 5lb thrusters; and the improved control system will accommodate these firings without an interruption in service.

An initial assessment indicated that continuous stationkeeping could be achieved by increasing the thruster firing to ~ 5sec duration. However, additional effort is required to validate this concept, and develop the design and operational philosophy as well as determine any constraints. The primary purpose of continuous stationkeeping is to maintain the spacecraft inclination within tight limits, thereby minimizing the magnitude and rate of change of the required IMC correction. As a result, larger instrument focal plane arrays can be used as a means of minimizing the time required for fabrication and alignment.

As a means of further lowering the passive cooler operational temperatures by reducing the amount of reflected heat from the sun, the spacecraft will be "flipped" about the yaw axis biannually. Large angle slew maneuvers have been performed on all inertial pointed spacecraft and is considered a safe procedure.

Finally, as shown in Figure 10.4.1-3, the solar array is redesigned to move the center of pressure closer to the spacecraft body to reduce the solar torque effect.

The net effect of the above is a significant improvement in navigation, within frame and frame-frame registration as well as lowering the passive cooler temperature 10 - 20 degrees C below GOES-I and mitigating instrument implementation and alignment. More importantly, the Option II (and Option III) INR control system has less risk than the unflown GOES-I INR system, because the hardware and concepts all have flight heritage, and the design is inherently more robust and able to compensate larger and/or unexpected error sources.

10.4.1.2 Controller Hardware Description

Figure 10.4.1-1 depicts a hardware functional block diagram of the Option II/III attitude control system. The major elements of the control system are star trackers and inertial reference sensors for attitude determination, attitude control electronics for computation, and a set of four reaction wheels for control actuation. The DRIRU II inertial reference unit, developed by Teledyne is baselined as the primary attitude sensor. The 35lb DRIRU II uses dually redundant dry-tuned gyros to sense incremental changes in spacecraft inertial attitude. A 15Hz or higher DRIRU bandwidth with an output quantization of 0.0125arcsec/pulse is required to provide high quality SMC data. In addition, the DRIRU II sample frequency should be 50Hz or higher. The DRIRU II was selected for its excellent mechanical drift properties and extensive flight experience.

An array of three CCD star trackers succeed in (by viewing inertially fixed targets) removing the drift inherent in a gyro-based attitude sensing system. The star tracker characteristics chosen include a 4 degree by 4 degree FOV with sensitivity down to 6th magnitude stars. The trackers are pointed 120 degree apart about a 35 degree half angle cone pointed due north in the celestial field. Candidate trackers include the Ball Aerospace CT-601, the Hughes Danbury ASTRA-II, and the JPL ASTROS tracker.

The ACE proposed for GOES-N is based on the SEDS computer developed at GSFC for the small explorer program. The SEDS uses an 80386-based processor with an 80387 co-processor operating at a clock speed of 16MHz. Data I/O functions between the processor and the sensors and actuators are performed using MIL STD 1773 data bus architecture.

A set of four reaction wheels is the torque actuation system for the on-orbit mode. In contrast to the Option I system, the wheels do not provide a momentum bias to the spacecraft but operate near the zero momentum condition. The wheels are set in a pyramidal arrangement to provide redundancy. The four wheel system is estimated to weight 100lbs. Each reaction wheel provides 13in-oz of control torque and can absorb 50ft-lb-sec of stored spacecraft momentum.

Secular momentum buildup is managed on a daily basis by coupled thruster firings. Similar to the Option I spacecraft, the Option II/III controller design incorporates 5lb thrusters. Magnetic wheel unloading for this configuration was not baselined.

Acquisition and stationkeeping maneuvers are performed using the coarse and fine sun sensors, a low cost earth sensor and the DRIRU II gyro.

10.4.1.3 Instrument Pointing and Control Elements

The Option II instrument concepts incorporate several changes to the GOES-I designs to achieve better pointing performance. The changes are intended to address the areas of the GOES-I design which impose the greatest limitations on pointing performance.

First, the Option II sounder will be redesigned using GFRP material in an attempt to reduce the structural control interaction difficulties found in the GOES-I design. This new sounder design will produce a stiffer instrument that is also much less susceptible to thermal distortion. The mechanical configuration of the new design may employ either a two mirror system or a single mirror two axis scan assembly, depending on the results of future study of these concepts. The new configuration will still have motors and shaft angle sensors on opposing sides of shafts, because it was found that locating them on the same side aggravates stability problems of the servo.

The Option II imager, which has a less demanding scan profile than the sounder, will employ the same structure as used in GOES-I. In Option III, the imager structure will also be redesigned.

A second design improvement is the use of 3inch disk optical encoders instead of inductosyns as shaft angle sensors in the servos. A comparison of the optical encoders with the inductosyns has shown that the optical encoders offer superior performance.

The third change to the GOES-I design addresses the servo controller for both the imager and the sounder. A new controller will be implemented using a more effective control strategy. Several viable alternatives for a new control strategy have been identified in this study (Section 10.4.2.2). Most promising among these is the use of a pre-filtering/feed-forward design concept to improve the sounder step and settle performance.

Another controller modification is the adoption of a digital implementation. The major benefit of a digital implementation is its ability to be tuned on-orbit. This reduces the risk of degraded servo pointing performance due to structural mode frequency shifts that may result from launch vibration, thermal and/or zero gravity effects. In addition, a digital design can accommodate several control strategies. The final decision to pursue an analog or digital implementation must consider all of the relevant factors including computation requirements, power consumption, cost, etc[1]. However, based on the effort to date, the inherent capability of the digital implementation to accommodate changes warrants its inclusion in the Option II/III system.

10.4.2 Option II Design Considerations

A wide spectrum of control subsystem configuration and instrument design improvements were considered for the Option II spacecraft design. For the Option II and III controller design, a "clean slate" approach was taken, with the primary goal to maximize system performance (accuracy and jitter). However, to minimize programmatic risks and to reduce spacecraft design cost, unproven and advanced technology concepts and hardware were not considered.

The instrument study for GOES-N is primarily a GOES-I instrument design improvement study. Due to funding limitations, only a redesign of the GOES I-M one-mirror, two-axis gimbal system was considered. Note, however, that a preponderance of the results from this study (e.g., sensor/motor co-location, structural material selection and feedforward compensation) can be applied to a dual mirror servo system.

The following paragraphs highlight the design trade-offs performed during the Option II design study. Table 10.4.2-1 presents the major system drivers, the design changes selected to address these drivers, and the resulting system impacts. For details/specifics of the various system trades, refer to Appendices A and B.

10.4.2.1 Control Subsystem Alternatives

A number of control subsystems were assessed for use on the GOES-N spacecraft (Appendix A3.1, Alternative Configurations Studied). Included were the following generic approaches with various implementation alternatives for the real time control of the attitude:

- Star detection with three star trackers
- Polaris star tracker and earth sensors
- Detection of ground beacons
- Use of position determination satellites

10.4.2.1.1 Baseline Control Subsystem Configuration

The selected GOES-N control subsystem employs star detection with three star trackers and a flight proven IRU. This approach was selected because it provides about the best INR performance with very low implementation risk.

The recommended subsystem utilizes 3 star trackers spaced at 120 degree around the pitch axis and canted down 35 degree from the celestial pole (Figure 10.4.1-3). Failure of a single star

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[1] Note that these have not been fully addressed to date due to study limitations.

tracker only causes slight attitude performance degradation; thus, full redundancy is maintained for this configuration. The associated IRU is the redundant DRIRU II which has flown on a number of spacecraft. The operation of this subsystem is described in the preceding Section 10.4.1.

The following sections synopsize the other approaches considered and rejected for the reasons specified. More details are provided in Appendix A.3.

10.4.2.1.2 Polaris Star Detectors

The use of Polaris star trackers in conjunction with the existing earth sensor, were considered as a means of potentially simplifying the requirement of the baseline approach to continuously track different stars. This approach would eliminate the need for complex star catalogs and will provide precise spacecraft control along the roll and yaw axes. The primary drawback of this approach is that, without additional star trackers, the spacecraft pitch cannot be controlled anywhere near that required to meet the GOES-N performance. In addition, the spacecraft would need at least 2 Polaris trackers to satisfy redundancy requirements. Since this controls architecture cannot meet the stringent GOES-N performance requirements, it was dropped from further study.

10.4.2.1.3 Detection of Ground Beacons

The use of ground beacons is potentially desirable because the beacons, like stars, would provide point sources for controlling the spacecraft attitude and would be earth referenced. Thus, the jitter performance would be similar to the baseline subsystem, but would only incur about a sixth of any error in orbit position. Moreover, comparable INR performance to the baseline Option II system could be achieved without additional ranging stations (i.e., the orbit could be determined as in GOES-I using instrument star and landmark measurements).

TABLE 10.4.2-1
OPTIONS II & III SYSTEM TRADES

DRIVER	DESIGN CHANGE(S)	IMPACT
NAVIGATION/REGISTRATION STABILITY	GYRO/STAR TRACKER ZERO MOMENTUM CONTROLLER	MULTISTATION RANGING REQUIRED FOR EARTH POINTED SPACECRAFT
IMAGER/SOUNDER COOLER PATCH TEMPERATURE	- REMOVE SOLAR SAIL/TRIM TAB - NO MAG TORQUERS - ELIMINATE COOLER SUN SHADES	DAILY THRUSTER FIRINGS ORBIT UNCERTAINTY YAW AXIS FLIP
INSTRUMENT POINTING ACCURACY	OPTICAL ENCODER	REMOVE INDUCTOSYN
INSTRUMENT POINTING STABILITY	MODIFIED STRUCTURE & MODIFIED MOUNTING	INCREASE INSTRUMENT STRUCTURAL FREQUENCIES & MINIMIZE THERMAL DEFORMATIONS
	IMPROVED SERVO CONTROLLER	DIGITAL PROCESSING
CHANNEL-TO-CHANNEL ALIGNMENT	LARGE FOCAL PLANE	REQUIRES RESAMPLING OR CONTINUOUS S[illegible] IN-FLIGHT ALIGNMENT TECHNIQUES* MINIMIZE BEAM SPLITTERS

* NOT CURRENTLY BASELINE

This approach was not recommended for the following reasons:

- Most laser beacons are severely attenuated by cloud cover, which would require numerous locations, widely distributed to ensure a high probability that 2 - 3 beacons would always be visible.
- Microwave beacons at the frequencies likely to be available for this application are attenuated by precipitation. Sitting, while not as severe as for laser beacons, would still be a problem.
- Both laser and microwave beacons would require national and international Consultative Committee International Radio/Consultative Committee on International Telegraph and Telephone (CCIR/CCITT) coordination before they could be introduced, often a long and involved process, in addition to the usual frequency coordination process necessary before installation of transmission equipment at a new site.
- Laser beacons might require that airplanes be excluded from the airspace above the beacons.

- Both laser and microwave beacons would require some amount of routine maintenance and repair that would appear to be at least as expensive as for the proposed ranging stations, if not more expensive because of the need for additional sites.

The use of an interferometer on the spacecraft in conjunction with ground based beacons was also considered. This application using ground based beacons was also not recommended for most of the above reasons. In addition, the attitude determination requires that the antenna/receiver separations of 3m be known to 30μm to achieve the allocated 10μr of attitude uncertainty. Thermal deformations alone will make this difficult.

10.4.2.1.4 Use of Position Determination Satellites for Orbit Determination

Both the GPS system and the TDRSS plan to incorporate means by which geostationary satellites can continuously receive their transmissions, and thereby determine their locations/orbit. Given the uncertainty in both future program funding and development time, this means of orbit determination is not recommended. However, if/when either of these programs do provide the capability to continuously determine location, they should be considered in lieu of multiple ranging stations.

10.4.2.2 Future Control System Improvements

10.4.2.2.1 Gyroscope Improvements

The use of advanced development IRUs for GOES-N is considered too risky at this time. However, if any of the advanced IRU's do become proven through test and/or flight they should be reexamined for use on GOES. As discussed in Appendix A3.1, there may be an improvement in power, weight, life and/or increased accuracy.

Two different gyro technologies warrant monitoring during the GOES-N study phase, because they have matured to the level where flight qualified units may be available at the turn of the century. These are the Fiberoptic Rotation Sensors (FORS) under development at the JPL, and the Hemispheric Resonator Gyroscope (HRG) being developed by Delco. Both units are in various test phases at the Charles Stark Draper Laboratories. Currently, the FORS is being developed as an advanced technology replacement of the DRIRU II, requiring less power with a longer life expectation due to no moving parts and comparable noise and drift characteristics. In addition, increasing the coil length and/or its diameter provides a straightforward means of improving the FORS performance beyond that of the DRIRU II.

The HRG, being developed by Delco exhibits high stability (i.e., low drift) vis-a-vis the DRIRU II, requiring updates in the tens of minutes instead of fractions of a minute. As a result, a GOES control system with this gyro package would utilize star measurements made by the instruments approximately every 15 minutes to update the gyroscopes.

The potential advantages of these extremely stable gyros are the elimination of the star trackers and referencing of the control system to the instrument focal plane instead of the spacecraft. The latter advantage results in improved INR performance and the potential for eliminating the proposed IMC function.

10.4.2.2.2 Star Catalog Improvements

The current subset of the star catalog proposed for GOES-N has an average star location uncertainty of 4μr, a major source of the controller error (Appendix C). It is anticipated that, by the year 2000, the GOES star catalog subset will be significantly improved as a result of efforts such as programs associated with the HST.

Contact should be maintained with the organizations responsible for updating the star catalog to ensure that the GOES star catalog contains the most recent star locations.

10.4.2.3 Instrument Design Improvement Studies

A study of the current GOES-I instrument design was performed to identify areas where changes could be implemented to enhance pointing performance and improve controller robustness. Both the instrument structure and servo controller were examined. As discussed in Section 10.4.2, the instrument design improvement study was constrained to modifications of the GOES-I instrument servo (1 mirror, 2 axes gimbal system); however, most of the results equally apply to a 2 mirror system. In addition, diurnal thermal deformation performance improvements due to the improved materials design were not studied. Sections 10.4.2.3.1 and 10.4.2.3.2 summarize the results from the specific changes that were considered.

10.4.2.3.1 Instrument Structure Design Considerations

The pointing performance of the existing GOES-I servo controller is limited by the structural bending modes (or frequencies) of the instrument. An examination of a frequency response of the GOES-I east-west controller axis illustrates the typical problem that arises in designing the servo controller. (Figure 10.4.2-1) As shown, the instrument structure provides a "triple punch" of highly observable low, medium, and high frequency modes. The low frequency modes (50-90Hz) impact system performance, and the mid-range (250-600Hz) and high frequency (1000-2000Hz) modes impact system stability margins. Painstaking design practices were brought to bear to achieve the 45Hz controller design for the GOES-I east-west servo and ensure that stability margins were met. To improve system performance for GOES-N, various structural modification studies were performed to reduce the control-structure interaction in the above three frequency ranges.

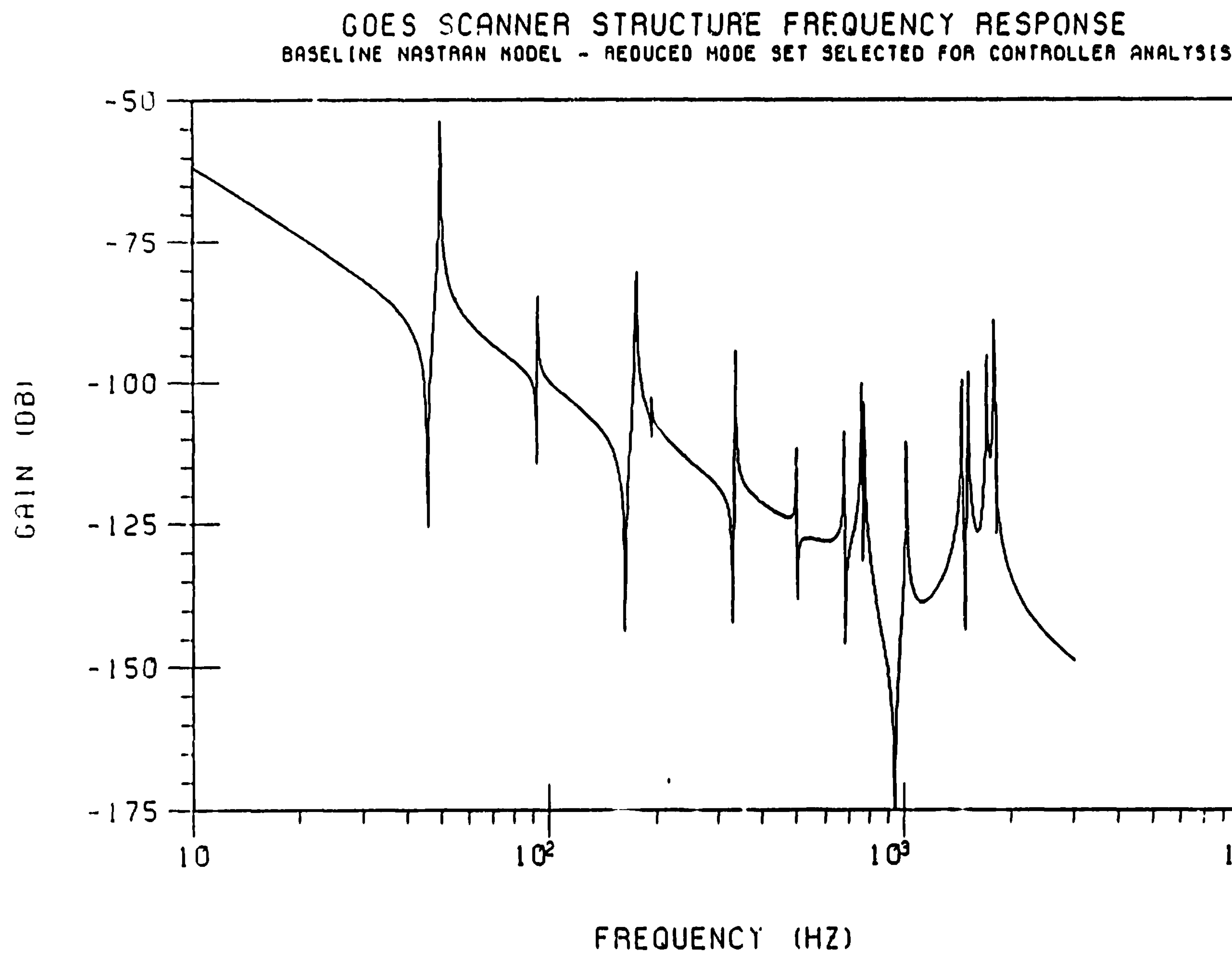


FIGURE 10.4.2-1 Baseline structure frequency response: sorted mode set (17 modes)

Sections 10.4.2.3.1.1 through 10.4.2.3.1.3 document structural modifications that were considered in an attempt to produce favorable changes in the instrument's frequency response. With the improved frequency response, it was anticipated that the controller design effort might be made easier, and the GOES-N requirements might be met. For modifications which did produce an improvement in the frequency response, the servo controller was redesigned to determine if a performance improvement could be obtained. The controller redesigns are further discussed in Section 10.4.2.3.2.1.

10.4.2.3.1.1 Co-located Motor/Encoder

One of the factors which limits the performance of the GOES-I servo controller is the presence of high frequency flexibility in the structure. Usually, high frequency resonances are attenuated naturally by the inertia of the structure. However, in the imager and sounder, the primary torsion mode of the east-west shaft is of sufficient magnitude to impact the stability of the servo controller. The result is an undesirable limit on the bandwidth and, hence, performance, that can be achieved.

In an attempt to remove the effects of shaft flexibility from the system, a proposal to move the inductosyn sensor to the same side of the shaft as the motor was considered. A subsequent analysis (Appendix B.1) produced the unexpected result that the stability problem was aggravated in the new configuration. A closer examination of the analysis results determined that the relocation of the inductosyn caused the torsion mode to become more observable to the servo controller. This approach was therefore abandoned.

10.4.2.3.1.2 Two Point Mirror Mount

Another proposed method for minimizing the effect of shaft flexibility was to change the mirror mount from a one point mount at the center of the shaft to a two point mount at each end of the shaft. One end of the mirror was attached rigidly to the shaft while the other end was attached by a collar type joint to allow thermal expansion of the mirror. Because the mirror could not be attached rigidly at each end of the shaft, the frequency response of this new configuration still showed significant high frequency flexibility. Although some improvement in mid-frequency shaft bending modes was noted, a controller redesign for the new structure failed to produce any gain in bandwidth, system robustness, or step and settle performance.

10.4.2.3.1.3 Improved Materials - Beryllium and Graphite Fiber Reinforced Plastic (GFRP) designs

In addition to high frequency flexibility, the design of the instrument servo is also hampered by the presence of structural modes at low frequencies which are close to the required controller bandwidth. As a result, stiffer materials were considered in an attempt to raise the lowest frequencies of the structure and increase their separation from the controller bandwidth.
The first material change that was considered was to use the current instrument design with the aluminum parts replaced by beryllium. A subsequent analysis showed that the frequencies only showed slight increases which were not sufficient to help the servo design effort. A more extensive structural modification was therefore required. As a result, a new instrument

configuration was considered which utilized the current two axis scan assembly, but the support structure was changed to a stiffer cylindrical arrangement. GFRP material was used to construct the new support structure. An analysis of the GFRP configuration showed that the changes did produce an appreciable improvement in the fundamental frequency (from about 50 to 90Hz). A controller redesign was therefore performed for the new structure to assess the performance improvement that could be obtained (Appendix B.1). The subsequent controller design resulted in a bandwidth that is less than the GOES-I controller due to the self imposed tighter stability requirements. However, after adding a prefilter to the compensation design, it was found the design met the GOES-N requirements with margin. (Section 10.4.2.2.2.1).

The GFRP design concept was also motivated in part by a desire to minimize thermal effects on instrument pointing. GFRP has a coefficient of thermal expansion that is an order of magnitude less than that for beryllium or aluminum. An instrument redesign employing GFRP material can therefore be expected to exhibit less thermal snapping and cyclic deformation than the GOES-I design.

10.4.2.3.2 Instrument Servo Design

This section documents the efforts which were made to identify improved control strategies for use in the GOES-N system. These efforts, which are summarized in Sections 10.4.2.3.2.1 through 10.4.2.3.2.3, demonstrate the difficulty in designing a robust controller to a more stringent set of specifications than was required of the GOES-I instruments. More details of these efforts are contained in Appendix B.2. Sections 10.4.2.3.2.4 and 10.4.2.3.2.5 cover other design issues which must be addressed to improve performance, and Section 10.4.2.3.2.6 summarizes the servo design conclusions.

Because the requirements for the sounder east-west servo are more stringent than those of the imager east-west servo and the imager and sounder north-south servo, and because the mechanical designs of the imager and sounder are identical, only the controller design for the sounder east-west servo was undertaken. The east-west motion of the sounder mirror is required to settle to within 1.9% (5.5μr optical) of a 280μr step input in 28ms. The required gain margin on all phase-stabilized modes is at least 8dB, with at least 30 degrees phase margin; and all gain-stabilized flexible-body modes must have a gain margin of at least 15dB. To ensure performance robustness, these margins must hold despite uncertainty in modal frequencies of 20% and minimum damping of 0.1% for each mode.

10.4.2.3.2.1 Classical Control Redesign

The purpose of the study reported in Appendix B.2 was to determine if the GOES-I instrument could be made to meet the GOES-N requirements by improving the structure and then redesigning the controller using the same analog filtering approach as was used in the GOES-I controller design. In this approach, a proportional-plus-integral-plus-derivative (PID) controller was used in conjunction with an inverse Chebyshev filter and lead compensation network. Of the structural modifications considered, only the two point mirror mount and GFRP concepts showed enough improvement in the structure to merit a controller redesign. The controller redesign, with the GFRP structure exhibits a 30Hz controller bandwidth. The bandwidth of this redesign is somewhat less that than that achieved on GOES-I, but the redesign is significantly more robust (less sensitive to parameter variations). Without a prefilter, neither the two point mirror mount nor the GFRP design could satisfy the GOES-N sounder step and settle requirement. In an attempt to improve the performance of the designs, a feed-forward compensation filter was included in the revised designs to adjust the transient response of the closed-loop systems.

10.4.2.3.2.2 Feed-forward Compensation Filter

A feed-forward compensation approach (Appendix B.1) was undertaken to determine whether the sounder east-west step and settle performance could be improved to meet GOES-N requirements. The purpose of feed-forward compensation is to improve the closed-loop system's slow response (in situations where low bandwidth is required for stability) to achieve faster response to a command signal. Figure 10.4.2-2 illustrates the feed-forward control concept. Three different compensations were attempted as documented in Appendix B.1.

With an appropriate feed-forward compensation filter included, both the two point mirror mount and GFRP designs met the step and settle requirement using a linear simulation. However, the filter required by the two point mirror mount design was of high order and indicated that the design would probably be sensitive to variations in the frequencies of the flexible modes. By contrast, the GFRP concept required a simple feed-forward filter that only models rigid body characteristics of the plant.

For this reason, a GFRP design is considered to be the most feasible candidate for achieving the GOES-N requirements in an actual implementation using the classical control redesign and the feed-forward compensation field.

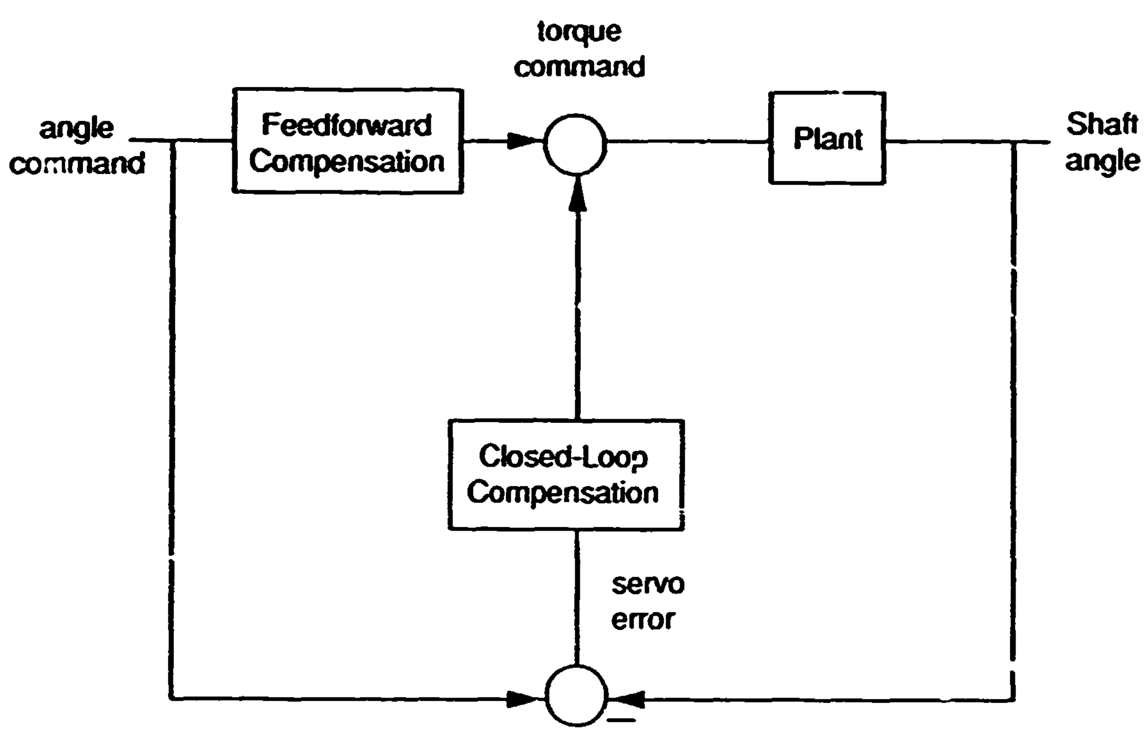
10.4.2.3.2.3 Observer Based Control

A modern control approach to the servo design is discussed in Appendix B.2. In this approach, observer-state feedback is used to stabilize certain flexible-body modes and to achieve the required settling time and accuracy. Funding for this effort was extremely limited, and consequently, the results to date are somewhat inconclusive. In addition, this design concept has not yet been spaceflight proven on very high bandwidth instruments.

The resulting sixth order controller possesses a closed-loop bandwidth of 24Hz; lower than the GOES-I design but with a higher system damping (0.9 overall damping ratio). Simulations indicate that the closed-loop system is robustly stable with respect to a ± 20% variation in the modal frequencies analyzed; however, when some additional high frequency modes with large modal gains were added to the instrument structural model, they were destabilized by the observer feedback. Near the end of the study, it was noted that the Loop Transfer Recovery (LTR) method could dramatically improve stability robustness to unmodeled structural modes while maintaining system performance. This technique should be looked at in more depth in future instruments studies.

Figure 10.4.2-2

Basic Concept



10.4.2.3.2.4 Optical Encoder vs. Inductosyn

In an effort to reduce measurement error in the servo, optical encoders were considered as an alternative to the inductosyns for sensing shaft angle. An error performance comparison of the two devices showed that the optical encoder offers an order of magnitude reduction in random linearity errors and a 25% decrease in bias linearity errors, largely because of the simpler electronics required to implement the device. Moreover, the optical encoder system will be less expensive to build, test, and calibrate due to the decreased electronics sensitivity. One drawback of the optical encoder approach is that it requires some redesign of the instrument structure if the current GOES-I design is retained.

However, the optical encoder becomes the sensor of choice for the redesigned instruments of Option II and III due to its improved accuracy, reduced electronics sensitivity (especially to noise), and reduced cost.

10.4.2.3.2.5 Digital Image and Spacecraft Motion Compensation (IMC/SMC) Interface

The end-to-end line of sight pointing error for GOES-I is corrected using IMC and MMC. IMC compensates for low frequency uncontrolled motion from nadir including orbit inclination line-of-sight motion and spacecraft/instrument thermal distortion effects. MMC corrects for uncontrolled disturbances in the spacecraft pointing due to the mirror motions of the instruments, especially the black body calibration slews which are performed to calibrate the infrared channels of the instruments. Note that for GOES-N, the MMC is replaced by the real-time SMC. For GOES-I, the IMC and MMC are computed in real time in the AOCE computer on the spacecraft using information uploaded from the ground system and sent to the instruments as an analog signal. The errors introduced by this approach are within GOES-I allocations but are too large if GOES-N is to meet its pointing requirements.

In the GOES-I design, the AOCE computer generates an IMC/MMC signal every 128ms. The digital compensation signal is converted to an analog voltage and sent to the instrument as a signal with a maximum level of plus or minus 10v. In the instrument, this is received in a differential amplifier, switched through the proper gain setup resistors, and converted into a digital portion which goes to the inductosyn drivers and to a ±8μr analog portion which is summed into the servo error. This process introduces errors in the IMC response of the instrument which are estimated to be about 5μr in the GOES-I system. This process is quite complex and sensitive from an electronics standpoint. Going to an all digital interface can significantly reduce these errors.

The recommended approach for GOES-N, which provides the best total performance, is to move the IMC computations to a computer in the imager or sounder. The OATS ground computer would then interface directly with the instrument computers providing IMC thermal distortion prediction data to the computer once a day. The ACC would provide orbital location and MMC (for Option I) or real-time SMC (for Options II/III) information through a simple serial interface.

This design would significantly simplify the interface between the instruments and the control system and eliminate the interface errors of the GOES-I system. This is the preferred approach for the new imager and high spectral resolution sounder. If the imager on the Option I or II system goes to an optical encoder then this approach is also preferred for these instruments.

10.4.2.3.2.6 East-West Flex Pivot Design Study

The primary goal of this study was to determine the feasibility of using flex pivots and magnetic actuation as an alternative to the existing east-west servo; particularly for the imager. Flex pivots offer several advantages over the east-west bearing system on-board GOES-I. They provide very linear, smooth and repeatable torque characteristics. As a result, they eliminate bearing torque noise, eliminate nonlinear friction effects, and provide improved scan accuracy and reduced scan jitter. They also provide an enhancement in reliability and system life due to the elimination of the limited rotation east-west bearings.

Flex pivots, developed by Lucas Aerospace (formerly available from Bendix), have clearly illustrated their ability to meet the ruggedness and life requirement of the GOES scanner. Figure 10.4.2-3 depicts a typical flex pivot and its characteristics. The demonstrated life and on-orbit operation of the flex pivots on the LANDSAT TM and the ASTRO-1 UIT IMC (flown on the Space Shuttle Columbia) provide a clear indication that GOES mission requirements can be easily met.

A conceptual design of the flex pivot drive assembly was developed and is described in Appendix B.8 The proposed implementation assumes closed loop position servo control using feedback from a high density optical encoder. The drive motor is a limited angle dc torque motor with a rare earth permanent magnet rotor.

The flex pivot suspended east-west scan system design locks feasible and very attractive. The primary outstanding issue is whether adequate centering of a high accuracy encoder along the pivot rotational axis is feasible. This can easily be resolved through simple experimental verification. Inexpensive, low level research to resolve this issue is highly recommended.

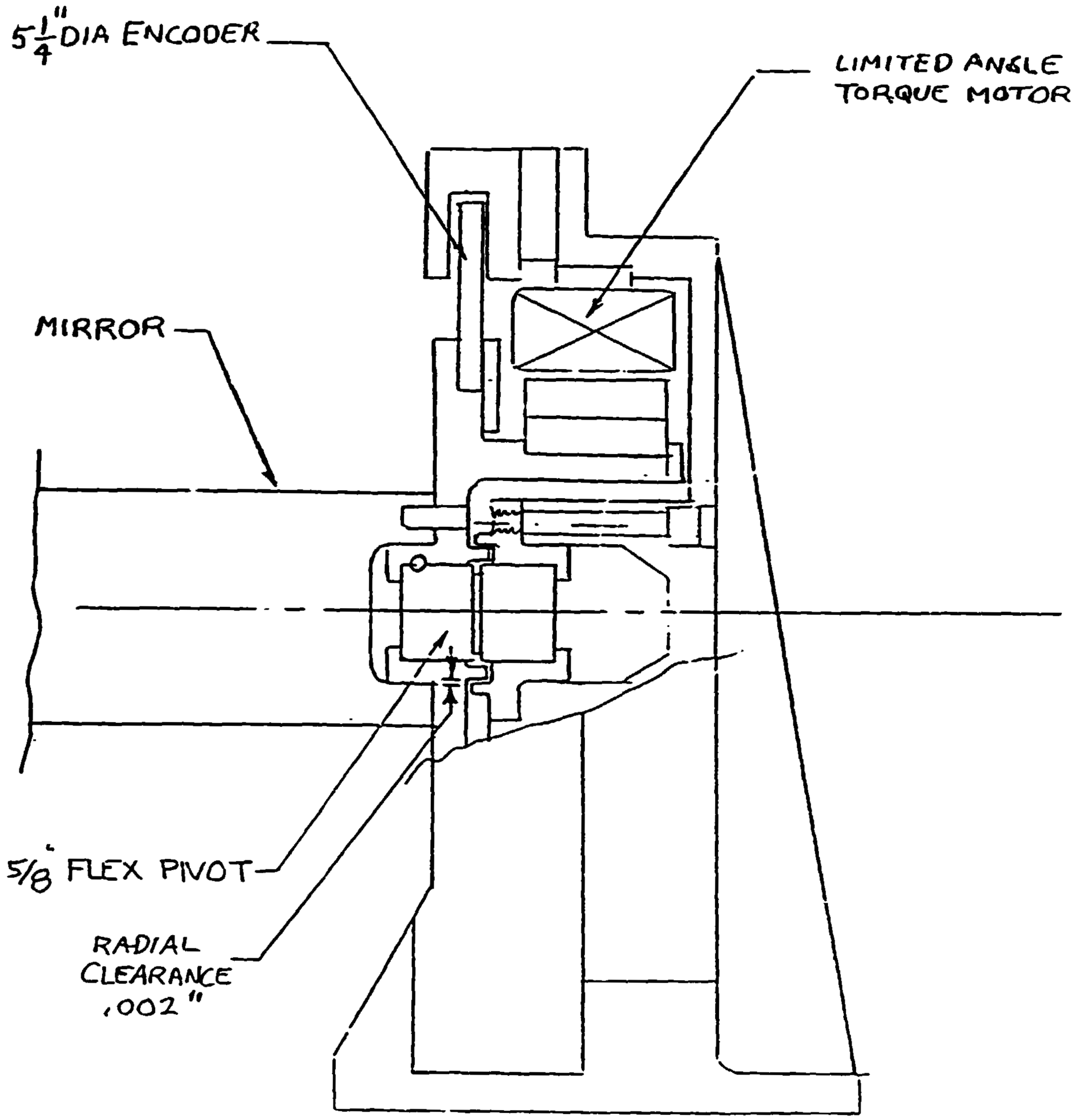
10.4.3 Option II Performance and Results Summary

10.4.3.1 Option II Performance Budget

The pointing performance assessment results for the selected Option II system are given in Tables 10.4.3.1-1 through 10.4.3.1-4. In each of the tables, the error is grouped into six major categories which combine to form the total error:

1. Attitude control (line 8),
2. Dynamic interaction - rigid body (line 22),
3. Dynamic interaction - non rigid body (line 28),
4. Image Motion Compensation (IMC, line 33),
5. Spacecraft Motion Compensation (SMC, line 44), and
6. Instrument pointing (line 48).

Figure 10.4.2-3



FLEX PIVOT DRIVE ASSEMBLY

The error totals given in the tables for items (1) through (6) are computed by RSSing the errors which comprise each category. The only exception is the orbit/attitude model and non-repeatable error (line 38), which is calculated as 10μr + 10% of the RSS total of its components on lines 39 and 42, because of projected use of SSAA as in GOES-I (Section 10.3.2).

Figure 10.4.3.1-1 is a bar chart which provides a summary of the INR performance of the Option II system. The error totals for each of six categories are shown so that the relative contribution of each can be examined. A quick comparison of the Option II totals with Option I show that pointing performance has been greatly improved, with total error decreasing by approximately a factor of two. Option II achieves the improved performance primarily through the use of a gyro/star tracker system which offers better attitude stability and by using GFRP material which reduces thermal deformation effects and, hence, IMC requirements for the sounder. A full description of the allocation budget entries is given in Appendix C.

10.4.3.1.1 Navigation

Figure 10.4.3.1-1 shows that the predicted navigation error performance of the Option II system is 34.0μr (including a 50% margin), which slightly exceeds the 33.0μr requirement. IMC is the largest error source, with attitude control and instrument pointing also providing contributions that are nearly as large. Even with the margin included, the Option II system only slightly exceeds the requirement, so the actual implementation may achieve the desired performance.

10.4.3.1.2 Within-Frame Registration

Figure 10.4.3.1-1 shows that the predicted within-frame error performance of the Option II system is 37.3μr (including a 50% margin) which exceeds the 14.0μr requirement. The total error has increased from navigation levels, largely because both the instrument pointing and IMC errors increased by the square root of two due to their random nature. The increase is partly offset by a decrease in attitude control error, which is primarily due to the fact that bias error from attitude estimation does not affect within-frame registration as it does navigation. The large disparity between the predicted performance and the requirement indicates that it will be very difficult to design a system which achieves the performance goal.

10.4.3.1.3 Frame-frame Registration

Figure 10.4.3.1-1 shows that the predicted frame to frame registration performance of the Option II system is 32.7μr (including a 50% margin) which exceeds the 14.0μr requirement. The error distribution is similar to the within-frame registration case with the exception of instrument pointing error which is greatly reduced due to the absence of servo bias error. It is evident that the predicted performance still falls far short of the goal and, like within-frame registration, will be difficult to achieve.

10.4.3.2 Assessment of Results

TABLE 10.4.3.1-1
TOP LEVEL ALLOCATION: OPTION II

	GOES OPTION II		
	NAVIGATION (μr)	WITHIN_FRAME REGISTRATION (μr)	90 MINUTE REGISTRATION (μr)
COMBINED ERROR WITH 50% MARGIN	34.0	37.3	32.7
COMBINED ERROR	22.6	24.8	21.8
ATTITUDE CONTROL	12.2	5.5	7.5
DYNAMIC INTERFACE RIGID BODY	6.3	8.9	8.9
DYNAMIC INTERFACE NONRIGID BODY	4.1	5.8	5.8
IMC DIURNAL COMPENSATION	12.9	13.9	15.2
SMC NEAR REALTIME COMPENSATION	4.5	6.3	6.3
INSTRUMENT POINTING	11.0	15.5	5.8
% ATTITUDE CONTROL	30.0	13.3	28.0
% DYNAMIC INTERFACE RIGID BODY	8.0	34.3	39.3
% DYNAMIC INTERFACE NONRIGID BODY	3.4	14.6	16.7
% IMC DIURNAL COMPENSATION	33.2	83.2	113.8
% SMC NEAR REALTIME COMPENSATION	4.0	17.1	19.6
% INSTRUMENT POINTING	24.2	103.8	16.3
NOAA REQUIREMENT	33.0	14.0	14.0

TABLE 10.4.3.1-2

ALLOCATION - SPACECRAFT OPTION 2 NAVIGATION, 09-Oct-90

		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
1	REVISED GOES N BUDGET: IRU/STAR TRACKER				
2	FILE NAME: IRU_NAV2.W01				NOAA REQ'T: 33 uR
3		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
4					
5	TOTAL - 1ST LEVEL W/ 50% MARGIN				34.0
6	TOTAL - 1ST LEVEL				22.6
7	SAT. ATTITUDE STABILITY				14.4
8	ATTITUDE CONTROL			12.2	
9	STAR CATALOG LOCATION ERROR		4.0		
10	ATTITUDE ESTIMATION		11.1		
11	GYRO NOISE (#)	0.7			
12	GYRO DRIFT	0.0			
13	STAR MSMNT. ERROR	0.0			
14	EPHEMERIS UNCERTAINTY	9.9			
15	RESIDUAL MISALIGNMENT	4.9			
16	CONTROL LAW		1.7		
17	QUANTIZATION	1.4			
18	COMPUTATIONAL DELAY	1.0			
19	REACTION WHL./TACH. PERFORMANCE		2.8		
20	TACH. QUANTIZATION	2.0			
21	TACH. NOISE	2.0			
22	DYNAMIC INTERACTION - RIGID BODY			6.3	
23	IMGR/SNDR UNCOMP. MIRROR MOTION*1.41		6.0		
24	RESIDUAL MIRROR MOTION	4.2			
25	RESIDUAL MODELING ERROR	0.0			
26	RW IMBALANCE/FRICTION		2.0		
27	SOLAR ARRAY STEPPING		0.0		
28	DYNAMIC INTERACTION - NON RIGID BODY			4.1	
29	MIRROR MOTION		1.0		
30	THERMAL SNAPPING		4.0		
31	OTHER		0.0		
32	MOTION COMPENSATION - INSTR.POINTING				17.5
33	IMC (24 HOUR PERIODIC CORRECTIONS)			12.9	
34	S/C INTERFACE		2.0		
35	TIMING MISMATCH				
36	NUMERICAL APPROXIMATION				
37	PERFECT O/A DETERMIN		2.0		
38	O/A MODEL & NONRPTL. ERR (W/SSAA)		12.5		
39	ORBIT/ATTITUDE MODEL	25.0			
40	THERMAL (INSTR. & OPT. BENCH)	25.0			
41	MODEL PARAMETERS	0.0			
42	NONRPTBL.ERR	5.0			
43	HEATER OPS.	5.0			
44	SMC - NEAR REAL TIME COMPENSATION			4.5	
45	HI FREQ GYRO NOISE		1.4		
46	SAMPLING		1.4		
47	PARAMETER MISMATCH		4.0		
48	INSTRUMENT POINTING			11.0	
49	IMC & SMC SERVO ERROR * 1.41		2.8		
50	PROCESSING ERROR		2.0		
51	INTER.TORQ		2.0		
52	CKT.DRIFT		0.4		
53	QUAD.ERRORS		0.0		
54	LINEARITY		0.8		
55	LINEARITY BIAS		8.8		
56	NOISE/JITTER		2.0		
57	STEP/SETTLE		1.0		
58	DET.ROTATION		4.2		
59	VIDEO DELAY		2.0		
60	(#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMNT. ERROR AFTER KALMAN FILTERING				

TABLE 10.4.3.1-3

ALLOCATION - SPACECRAFT OPTION 2 WITHIN-FRAME, 09-Oct-90

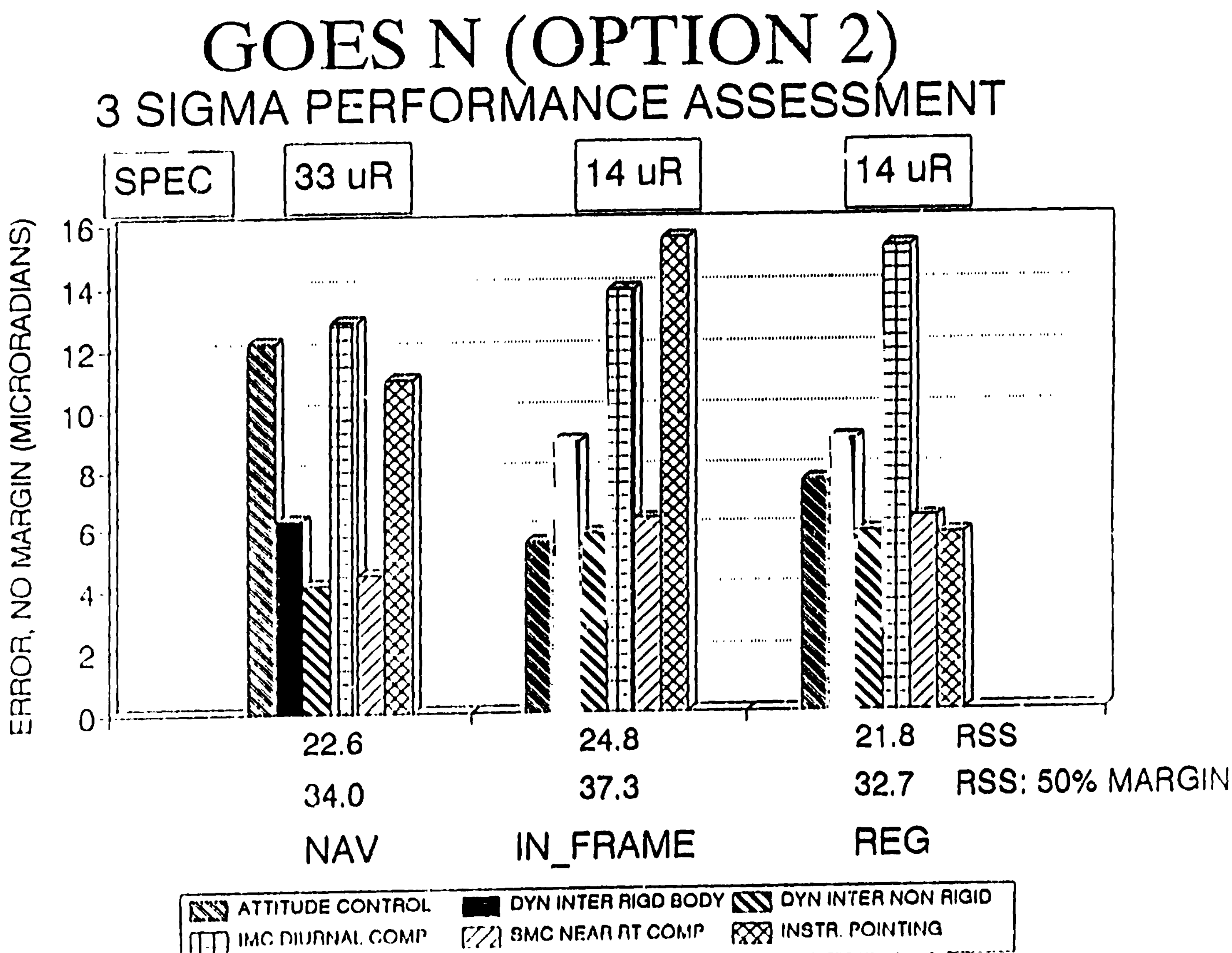
1	REVISED GOES N BUDGET: IRU/STAR TRACKER				
2	FILE NAME: IRU_INF2.WQ1			NOAA REQ'T:	14 uR
3		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
4					
5	TOTAL - 1ST LEVEL W/ 50% MARGIN				37.3
6	TOTAL - 1ST LEVEL				24.8
7	SAT. ATTITUDE STABILITY				12.0
8	ATTITUDE CONTROL			5.5	
9	STAR CATALOG LOCATION ERROR		2.0		
10	ATTITUDE ESTIMATION		2.2		
11	GYRO NOISE * 1.41 (#)	1.0			
12	GYRO DRIFT	0.0			
13	STAR MSMNT. ERROR	0.0			
14	EPHEMERIS UNCERTAINTY	2.0			
15	RESIDUAL MISALIGNMENT	0			
16	CONTROL LAW * 1.41		2.4		
17	QUANTIZATION	1.4			
18	COMPUTATIONAL DELAY	1.0			
19	REACTION WHL./TACH. PERFORMANCE*1.41		4.0		
20	TACH. QUANTIZATION	2.0			
21	TACH. NOISE	2.0			
22	DYNAMIC INTERACTION - RIGID BODY * 1.41			8.9	
23	INGR/SNDR UNCOMP. MIRROR MOTION*1.41		6.0		
24	RESIDUAL MIRROR MOTION	4.2			
25	RESIDUAL MODELING ERROR	0.0			
26	RW IMBALANCE/FRICTION		2.0		
27	SOLAR ARRAY STEPPING		0.0		
28	DYNAMIC INTERACTION-NON RIGID BODY*1.41			5.8	
29	MIRROR MOTION		1.0		
30	THERMAL SNAPPING		4.0		
31	OTHER		0.0		
32	MOTION COMPENSATION - INSTR.POINTING				21.8
33	IMC (24 HOUR PERIODIC CORRECTIONS)			13.9	
34	S/C INTERFACE		2.0		
35	TIMING MISMATCH				
36	NUMERICAL APPROXIMATION				
37	PERFECT O/A DETERMIN		10.0		
38	O/A MODEL & NONRPTL. ERR (W/SSAA)		9.4		
39	ORBIT/ATTITUDE MODEL	8.0			
40	THERMAL (INSTR. & OPT. BENCH)	8.0			
41	MODEL PARAMETERS	0.0			
42	NONRPTBL.ERR	5.0			
43	HEATER OPS.	5.0			
44	SMC - NEAR REALTIME COMPENSATION * 1.41			6.3	
45	HI FREQ GYRO NOISE		1.4		
46	SAMPLING		1.4		
47	PARAMETER MISMATCH		4.0		
48	INSTRUMENT POINTING			15.5	
49	IMC & SMC SERVO ERROR * 2.0		4.0		
50	PROCESSING ERROR*1.41		2.8		
51	INTER.TORQ * 1.41		2.8		
52	CKT.DRIFT * 1.41		0.6		
53	QUAD.ERROR		0.0		
54	LINEARITY * 1.41		1.1		
55	LINEARITY BIAS * 1.41		12.4		
56	NOISE/JITTER * 1.41		2.3		
57	STEP/SETTLE * 1.41		1.4		
58	DET.ROTATION * 1.41		5.9		
59	VIDEO DELAY * 1.41		2.8		
60	(#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMNT. ERROR AFTER KALMAN FILTERING				

TABLE 10.4.3.1-4

ALLOCATION - SPACECRAFT OPTION 2 REGISTRATION, 07 Oct 90

1	REVISED GOES N BUDGET: IRU/STAR TRACKER				
2	FILE NAME: IRU_REG2.WQ1				NOAA REQ'T: 14 uR
3		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
4					
5	TOTAL - 1ST LEVEL W/ 50% MARGIN				32.7
6	TOTAL - 1ST LEVEL				21.8
7	SAT. ATTITUDE STABILITY				13.1
8	ATTITUDE CONTROL			7.5	
9	STAR CATALOG LOCATION ERROR		3.0		
10	ATTITUDE ESTIMATION		5.1		
11	GYRO NOISE * 1.4142 (#)	1.0			
12	GYRO DRIFT	0.0			
13	STAR MSMNT. ERROR	0.0			
14	EPHEMERIS UNCERTAINTY	5.0			
15	RESIDUAL MISALIGNMENT	0			
16	CONTROL LAW * 1.41		2.4		
17	QUANTIZATION	1.4			
18	COMPUTATIONAL DELAY	1.0			
19	REACTION WHL./TACH. PERFORMANCE*1.41		4.0		
20	TACH. QUANTIZATION	2.0			
21	TACH. NOISE	2.0			
22	DYNAMIC INTERACTION - RIGID BODY*1.41			8.9	
23	INGR/SHL & UNCOMP. MIRROR MOTION*1.41		6.0		
24	RESIDUAL MIRROR MOTION	4.2			
25	RESIDUAL MODELING ERROR	0.0			
26	RW IMBALANCE/FRICTION		2.0		
27	SOLAR ARRAY STEPPING		0.0		
28	DYNAMIC INTERACTION-NON RIGID BODY*1.41			5.5	
29	MIRROR MOTION		1.0		
30	THERMAL SNAPPING		4.0		
31	OTHER		0.0		
32	MOTION COMPENSATION - INSTR.POINTING				17.5
33	IMC (24 HOUR PERIODIC CORRECTIONS)			15.2	
34	S/C INTERFACE		2.0		
35	TIMING MISMATCH				
36	NUMERICAL APPROXIMATION				
37	PERFECT O/A DETERMIN		10.0		
38	O/A MODEL & NONRPTL. ERR (W/SSAA)		11.3		
39	ORBIT/ATTITUDE MODEL	12.0			
40	THERMAL (INSTR. & OPT. BENCH)	12.0			
41	MODEL PARAMETERS	0.0			
42	NONRPTBL.ERR	5.0			
43	HEATER OPS.	5.0			
44	SMC - NEAR REAL TIME COMPENSATION*1.41			6.3	
45	HI FREQ GYRO NOISE		1.4		
46	SAMPLING		1.4		
47	PARAMETER MISMATCH		4.0		
48	INSTRUMENT POINTING			5.8	
49	IMC & SMC SERVO ERROR * 1.41		2.8		
50	PROCESSING ERROR		2.0		
51	INTER.TORQ		2.0		
52	CKT.DRIFT * 1.41		0.6		
53	QUAD.ERRORS		0.0		
54	LINEARITY * 1.41		1.1		
55	LINEARITY BIAS		0.0		
56	NOISE/JITTER * 1.41		2.5		
57	STEP/SETTLE		0.0		
58	DET.ROTATION		0.0		
59	VIDEO DELAY * 1.41		2.8		
60	(#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMNT. ERROR AFTER KALMAN FILTERING				

FIGURE 10.4.3.1-1



10.5 Option III Control and Pointing Subsystems

10.5.1 Option III Overview

10.5.1.1 Option III Description

The Option III control system is identical to the Option II control system (Figures 10.4.1-1, 10.4.1-2, and 10.4.1-3). The improvement in performance is primarily due to the redesign of the instrument with better thermal properties. Ancillary improvements are realized in the instrument pointing as a result of an improved imager structure with a higher first modal frequency and a larger optical encoder which improves servo performance.

10.5.3.1 Option III Performance Budget

Tables 10.5.3.1-1 through 10.5.3.1-4 give the predicted INR performance of the Option III design. The tables are organized into the same six categories as those presented for the Option II case.

Figure 10.5.3.1-1 is a bar chart summarizing the information contained in the tables, and shows the relative contribution of each category to the total error. Overall performance is only slightly improved over Option II Levels.

10.5.3.1.1 Navigation

Figure 10.5.3.1-1 indicates that the predicted navigation error performance of the Option III system is 32.6μr (including a 50% margin), and the system therefore meets the 33μr requirement. The performance is slightly better than that in the Option II case because of improved thermal properties of the imager which is constructed of GFRP in Option III. The error distribution is otherwise similar to that for Option II.

10.5.3.1.2 Within-Frame Registration

Figure 10.5.3.1-1 indicates that the predicted within-frame registration performance of the Option III system is 33.3μr (including a 50% margin) which exceeds the 14.0μr requirement.
As in Option II, the large disparity between the predicted performance and the requirement indicates that achieving the goal will be difficult using current techniques.

10.5.3.1.3 Frame-frame Registration

Figure 10.5.3.1-1 indicates that the predicted frame-to-frame registration performance of the Option III system is 28.7μr (including a 50% margin) which exceeds the 14.0μr requirement. The error distribution is similar to that for the within frame case, except for instrument pointing which is decreased due to the negligible servo bias error

TABLE 10.5.3.1-1
TOP LEVEL ALLOCATION: OPTION III

	GOES OPTION III		
	NAVIGATION (µr)	**WITHIN_FRAME REGISTRATION (µr)**	**90 MINUTE FRAME-FRAME (µr)**
COMBINED ERROR WITH 50% MARGIN	32.6	33.3	28.7
COMBINED ERROR	21.8	22.2	19.1
ATTITUDE CONTROL	12.2	5.5	7.5
DYNAMIC INTERFACE RIGID BODY	6.3	8.9	8.9
DYNAMIC INTERFACE NONRIGID BODY	4.1	5.8	5.8
IMC DIURNAL COMPENSATION	11.4	8.7	11.4
SMC NEAR REALTIME COMPENSATION	4.5	6.3	6.3
INSTRUMENT POINTING	10.8	15.3	5.1
% ATTITUDE CONTROL	31.3	14.9	[illegible]
% DYNAMIC INTERFACE RIGID BODY	8.4	38.3	44.8
% DYNAMIC INTERFACE NONRIGID BODY	3.6	16.3	19.0
% IMC DIURNAL COMPENSATION	27.0	36.7	72.4
% SMC NEAR REALTIME COMPENSATION	4.2	19.1	22.3
% INSTRUMENT POINTING	24.5	112.7	14.7
NOAA REQUIREMENT	33.0	14.0	14.0

TABLE 10.5.3.1-2

ALLOCATION SPACECRAFT OPTION 3 NAVIGATION, 09 OCT 90

1 REVISED GOES N BUDGET: IRU/STAR TRACKER

2 FILE NAME: IRU_NAV3.W01 NOAA REQ'T: 33 uR

		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
5	TOTAL - 1ST LEVEL W/ 50% MARGIN				32.6
6	TOTAL - 1ST LEVEL				21.8
7	SAT. ATTITUDE STABILITY				14.4
8	ATTITUDE CONTROL			12.2	
9	STAR CATALOG LOCATION ERROR		4.0		
10	ATTITUDE ESTIMATION		11.1		
11	GYRO NOISE (#)	0.7			
12	GYRO DRIFT	0.0			
13	STAR MSMNT. ERROR	0.0			
14	EPHEMERIS UNCERTAINTY	9.9			
15	RESIDUAL MISALIGNMENT	4.9			
16	CONTROL LAW		1.7		
17	QUANTIZATION	1.4			
18	COMPUTATIONAL DELAY	1.0			
19	REACTION WHL./TACH. PERFORMANCE		2.8		
20	TACH. QUANTIZATION	2.0			
21	TACH. NOISE	2.0			
22	DYNAMIC INTERACTION - RIGID BODY			6.3	
23	INGR/SNDR UNCOMP. MIRROR MOTION*1.41		6.0		
24	RESIDUAL MIRROR MOTION	4.2			
25	RESIDUAL MODELING ERROR	0.0			
26	RW INBALANCE/FRICTION		2.0		
27	SOLAR ARRAY STEPPING		0.0		
28	DYNAMIC INTERACTION - NON RIGID BODY			4.1	
29	MIRROR MOTION		1.0		
30	THERMAL SNAPPING		4.0		
31	OTHER		0.0		
32	MOTION COMPENSATION - INSTR.POINTING				16.3
33	IMC (24 HOUR PERIODIC CORRECTIONS)			11.4	
34	S/C INTERFACE		2.0		
35	TIMING MISMATCH				
36	NUMERICAL APPROXIMATION				
37	PERFECT O/A DETERMIN (IMR SIMULATR)		2.0		
38	O/A MODEL & NONRPTL. ERR (W/SSAA)		11.0		
39	ORBIT/ATTITUDE MODEL	10.0			
40	THERMAL (INSTR. & S/C)	10.0			
41	MODEL PARAMETERS	0.0			
42	NONRPTBL.ERR	2.0			
43	HEATER OPS.	2.0			
44	SMC - NEAR REAL TIME COMPENSATION			4.5	
45	HI FREQ GYRO NOISE		1.4		
46	SAMPLING		1.4		
47	PARAMETER MISMATCH		4.0		
48	INSTRUMENT POINTING			10.8	
49	IMC & SMC SERVC ERROR * 1.41		2.8		
50	PROCESSING ERROR		2.0		
51	INTER.TORQ		2.0		
52	CKT.DRIFT		0.4		
53	QUAD.ERRORS		0.0		
54	LINEARITY		0.4		
55	LINEARITY BIAS		8.8		
56	NOISE/JITTER		1.0		
57	STEP/SETTLE		1.0		
58	DET.ROTATION		4.2		
59	VIDEO DELAY		2.0		

60 (#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMNT. ERROR AFTER KALMAN FILTERING

TABLE 10.5.3.1-3

ALLOCATION - SPACECRAFT OPTION 3   WITHIN-FRAME, 09 OCT 90

REVISED GOES N BUDGET: IRU/STAR TRACKER

FILE NAME: IRU_INF3.W01   NOAA REQ'T: 14 uR

	4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
TOTAL - 1ST LEVEL W/ 50% MARGIN				33.3
TOTAL - 1ST LEVEL				22.2
SAT. ATTITUDE STABILITY				12.0
ATTITUDE CONTROL			5.5	
STAR CATALOG LOCATION ERROR		2.0		
ATTITUDE ESTIMATION		2.2		
GYRO NOISE * 1.4142 (#)	1.0			
GYRO DRIFT	0.0			
STAR MSMNT. ERROR	0.0			
EPHEMERIS UNCERTAINTY	2.0			
RESIDUAL MISALIGNMENT	0			
CONTROL LAW * 1.41		2.4		
QUANTIZATION	1.4			
COMPUTATIONAL DELAY	1.0			
REACTION WHL./TACH. PERFORMANCE*1.41		4.0		
TACH. QUANTIZATION	2.0			
TACH. NOISE	2.0			
DYNAMIC INTERACTION - RIGID BODY * 1.41			8.9	
INGR/SNDR UNCOMP. MIRROR MOTION*1.41		6.0		
RESIDUAL MIRROR MOTION	4.2			
RESIDUAL MODELING ERROR	0.0			
RW IMBALANCE/FRICTION		2.0		
SOLAR ARRAY STEPPING		0.0		
DYNAMIC INTERACTION-NON RIGID BODY*1.41			5.8	
MIRROR MOTION		1.0		
THERMAL SNAPPING		4.0		
OTHER		0.0		
MOTION COMPENSATION - INSTR.POINTING				18.7
INC (24 HOUR PERIODIC CORRECTIONS)			8.7	
S/C INTERFACE		2.0		
TIMING MISMATCH				
NUMERICAL APPROXIMATION				
PERFECT O/A DETERMIN (INR SIMULATR)		2.0		
O/A MODEL & NONRPTL. ERR (W/SSAA)		8.2		
ORBIT/ATTITUDE MODEL	8.0			
THERMAL (INSTR. & S/C)	8.0			
MODEL PARAMETERS	0.0			
NONRPTBL.ERR	2.0			
HEATER OPS.	2.0			
SMC - NEAR REALTIME COMPENSATION * 1.41			6.3	
HI FREQ GYRO NOISE		1.4		
SAMPLING		1.4		
PARAMETER MISMATCH		4.0		
INSTRUMENT POINTING			15.3	
INC & SMC SERVO ERROR * 2.0		4.0		
PROCESSING ERROR * 1.41		2.8		
INTER.TORQ * 1.41		2.8		
CKT.DRIFT * 1.41		0.6		
QUAD.ERRORS		0.0		
LINEARITY * 1.41		0.5		
LINEARITY BIAS * 1.41		12.4		
NOISE/JITTER * 1.41		1.4		
STEP/SETTLE * 1.41		1.4		
DET.ROTATION * 1.41		5.9		
VIDEO DELAY * 1.41		2.8		

(#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMT ERROR AFTER KALMAN FILTERING

TABLE 10.5.3.1-4

ALLOCATION - SPACECRAFT OPTION 3 REGISTRATION, 09-Oct-90

1 REVISED GOES N BUDGET: IRU/STAR TRACKER

2 FILE NAME IRU_REG3.WQ1 NOAA REQ'T: 14 uR

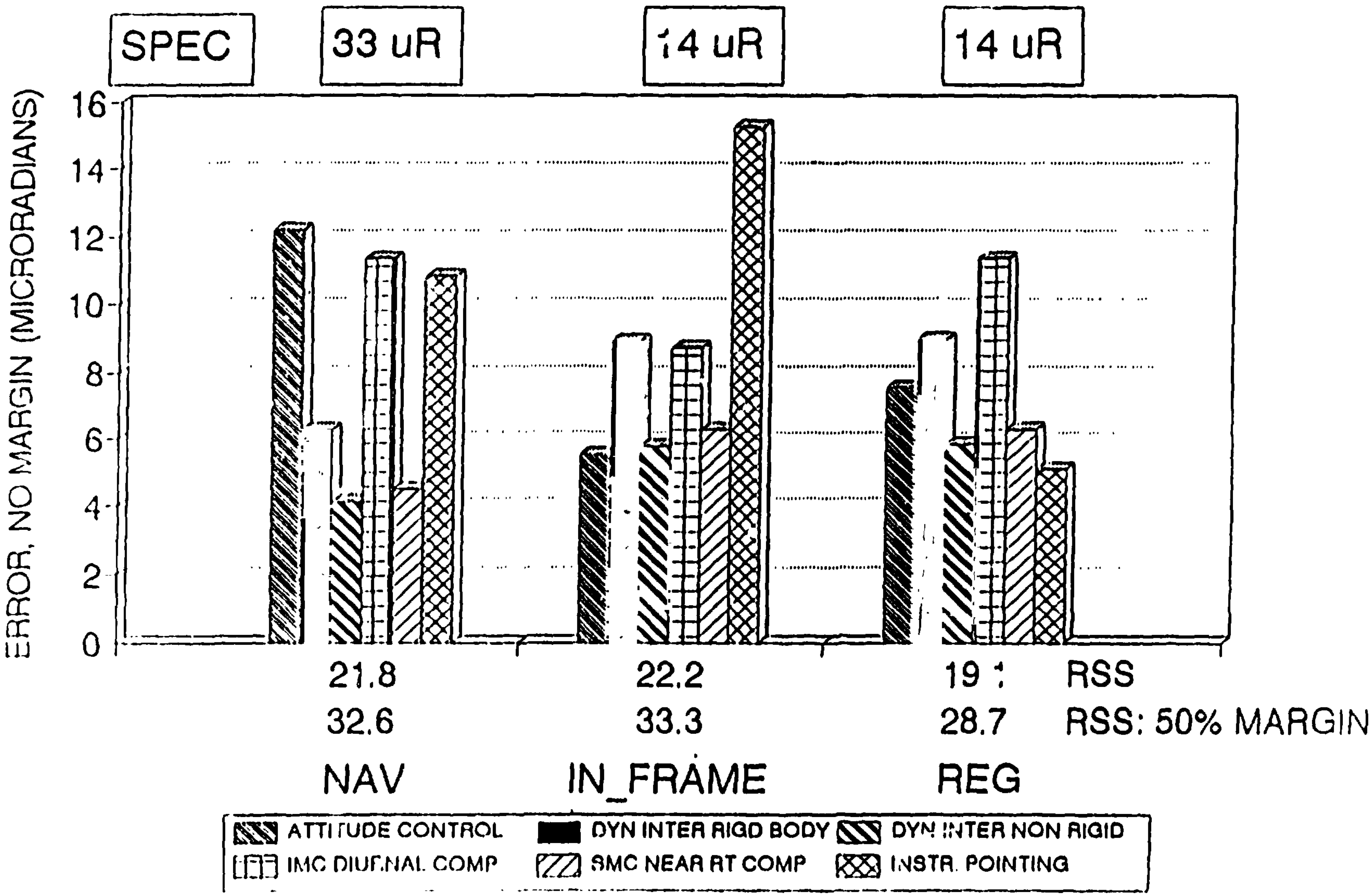
#		4TH LEVEL	3RD LEVEL	2ND LEVEL	1ST LEVEL
5	TOTAL - 1ST LEVEL W/ 50% MARGIN				28.7
6	TOTAL - 1ST LEVEL				19.1
7	SAT. ATTITUDE STABILITY				13.1
8	ATTITUDE CONTROL			7.5	
9	STAR CATALOG LOCATION ERROR		3.0		
10	ATTITUDE ESTIMATION		5.1		
11	GYRO NOISE * 1.4142 (#)	1.0			
12	GYRO DRIFT	0.0			
13	STAR MSMNT. ERROR	0.0			
14	EPHEMERIS UNCERTAINTY	5.0			
15	RESIDUAL MISALIGNMENT	0			
16	CONTROL LAW * 1.41		2.4		
17	QUANTIZATION	1.4			
18	COMPUTATIONAL DELAY	1.0			
19	REACTION WHL./TACH. PERFORMANCE *1.41		4.0		
20	TACH. QUANTIZATION	2.0			
21	TACH. NOISE	2.0			
22	DYNAMIC INTERACTION - RIGID BODY * 1.41			8.9	
23	INGR/SNDR UNCOMP. MIRROR MOTION*1.41		6.0		
24	RESIDUAL MIRROR MOTION	3.0			
25	RESIDUAL MODELING ERROR	3.0			
26	RW IMBALANCE/FRICTION		2.0		
27	SOLAR ARRAY STEPPING		0.0		
28	DYNAMIC INTERACTION-NON RIGID BODY*1.41			5.8	
29	MIRROR MOTION		1.0		
30	THERMAL SNAPPING		4.0		
31	OTHER		0.0		
32	MOTION COMPENSATION - INSTR.POINTING				14.0
33	INC (24 HOUR PERIODIC CORRECTIONS)			11.4	
34	S/C INTERFACE		2.0		
35	TIMING MISMATCH				
36	NUMERICAL APPROXIMATION				
37	PERFECT O/A DETERMIN (INR SIMULATR)		2.0		
38	O/A MODEL & NONRPTL. ERR (W/SSAA)		11.0		
39	ORBIT/ATTITUDE MODEL	10.0			
40	THERMAL (INSTR. & S/C)	10.0			
41	MODEL PARAMETERS	0.0			
42	NONRPTBL.ERR	2.0			
43	HEATER OPS.	2.0			
44	SMC -NEAR REAL TIME COMPENSATION * 1.41			6.3	
45	HI FREQ GYRO NOISE		1.4		
46	SAMPLING		1.4		
47	PARAMETER MISMATCH		4.0		
48	INSTRUMENT POINTING			5.1	
49	INC & SMC SERVO ERROR * 1.41		2.8		
50	PROCESSING ERROR		2.0		
51	INTER.TORQ		2.0		
52	CKT.DRIFT * 1.41		0.6		
53	QUAD.ERRORS		0.0		
54	LINEARITY * 1.41		0.5		
55	LINEARITY BIAS		0.0		
56	NOISE/JITTER * 1.41		1.4		
57	STEP/SETTLE		0.0		
58	DET.ROTATION		0.0		
59	VIDEO DELAY * 1.41		2.8		

60 (#) INCLUDES EFFECTS OF GYRO DRIFT & STAR MSMNT. ERROR AFTER KALMAN FILTERING

FIGURE 10.5.3.1-1

GOES N (OPTION 3)

3 SIGMA PERFORMANCE ASSESSMENT



10.6 Recommended Additional Studies/Investigations

Table 10.6-1 summarizes the INR related studies/investigations that are recommended to be completed before the start of the Phase-B effort. A brief description of the purpose and expected results from each is provided below. The recommended INR studies are grouped under the following headings:

- Dynamic interaction
- Attitude control - ephemeris uncertainty
- Attitude control
- Semiannual 180 degrees spacecraft yaw flip
- Servo 2 mirror GFRP structure
- Optical bench
- Wheel mounts

10.6.1 Dynamic Interaction Study

The purpose of the dynamic interaction study is to determine the impacts to the spacecraft controller resulting from a S&R interferometer, a mechanical refrigerator, and solar pointing instrument motion. A primary effort in this study is the development of a spacecraft structural model, which can then be tailored to determine the dynamic interaction effects of a S&R, refrigerator, and solar pointing instrument motion.

TABLE 10.6.1-1
RECOMMENDATIONS FOR FOLLOW-ON STUDIES

- **DYNAMIC INTERACTION**
    - CONTROLLER IMPACTS RESULTING FROM:
        - S&R INTERFEROMETERS
        - MECHANICAL REFRIGERATORS
        - SOLAR POINTING INSTRUMENT MOTION
- **ATTITUDE CONTROL (EPHEMERIS UNCERTAINTY)**
    - IN-DEPTH ORBIT DETERMINATION PERFORMANCE ESTIMATION
    - THRUSTER PLACEMENT TO MINIMIZE CONTAMINATION OF INSTRUMENTS/COOLERS
    - CONTINUOUS STATIONKEEPING
    - RESAMPLING (IF REQUIRED)
- **ATTITUDE CONTROL**
    - STATIONKEEPING & HOUSEKEEPING MANEUVER & RECOVERY SIMULATIONS

- ACS INTERFEROMETRY MAGNETIC CONTROL IMPACTS ON SPACECRAFT
- CONTROL SYSTEM/INSTRUMENTS INTERFACE DEFINITION
- ACE COMPUTER/SYSTEM BUS DESCRIPTION

- **SEMIANNUAL 180 DEGREES SPACECRAFT YAW AXIS FLIP**
  - STAR TRACKER STAR AVAILABILITY
  - INSTRUMENT IMPACTS

- **SERVO: 2 MIRROR GFRP STRUCTURE**
  - STRUCTURAL MODEL
  - SERVO PERFORMANCE
  - THERMAL PERFORMANCE

- **OPTICAL BENCH**
  - STRUCTURAL MODEL
  - THERMAL PERFORMANCE

- **WHEEL MOUNTS**
  - SOFT MOUNT VS MAGNETIC BEARINGS

The primary concerns with the S&R interferometer are the potential for thermal snapping and potentially undesirable modal frequencies. For the mechanical refrigerator, the normal pumping motions would be investigated to determine the impact on INR performance. Similarly, the motion from solar pointing instruments needs to be evaluated to determine the effects on spacecraft pointing.

10.6.2 Attitude Control - Ephemeris Uncertainty

The effects of orbit determination uncertainty needs to be further analyzed to determine performance degradations resulting from ranging at candidate sites selected by NOAA. This analysis would be done parametrically to assess the uncertainty based on the use of different sites, and different ranging accuracies associated with different implementations.

The placement of thrusters to eliminate/minimize contamination of both instruments and coolers, while providing the capability to unload the daily wheel momentum buildup, needs to be carefully evaluated. As a part of this effort, the capability to use the daily wheel unloadings to also provide continuous stationkeeping would also be examined. If this is determined to be impractical, separate thruster firings for nearly continuous stationkeeping would be evaluated.

If the use of thrusters for continuous stationkeeping is not feasible, it will then be necessary to evaluate the use of resampling as a means of providing fixed grid images with a large focal plane. That is, either continuous stationkeeping to keep the inclination within tight bounds to minimize IMC rate change or resampling is required to support the IMC correction needed for fixed grid images when a large instrument focal plane is used.

However, it is strongly recc · nended that resampling also be evaluated, because of its potential to correct or mitigate unexpected problems. An investigation of resampling would include an assessment of how to best combine the INR resampling requirements with current NWS resampling activities to provide different map projections for users. IMC rate changes or resampling is required to support the IMC corrections needed for fixed grid images when a large instrument focal plane is used.

10.6.3 Attitude Control

The needed attitude control studies are:

- Simulations of housekeeping/stationkeeping maneuvers to ensure that recovery times are a fraction (¼ or less) of an hour
- Further investigation of an ACS interferometer to determine if this is practical (e.g., geographical locations to mitigate weather effects, obtaining a frequency allocation) and a more cost effective approach than star detectors; if it is, then the study will provide an evaluation of an interferometer for providing the ephemeris.
- Refinement of the impacts of magnetic control on spacecraft weight and power
- Detailed definition of the control system and instrument interfaces
- Description of the ACE computer and system bus

10.6.4 Semiannual 180 degrees Yaw Axis Flip (Star availability)

This procedure to provide the lowest passive refrigerator temperatures requires that an in depth analysis of star availability in both the Northern and Southern hemispheres be performed to ensure the required availability of stars.

10.6.5 Servo Performance for a Two Mirror, Graphite Fiber Reinforced Plastic (GFRP) Instrument

An analysis of the servo performance that is obtainable for an instrument with two mirrors and designed with GFRP is needed. This analysis would first develop a structural model from which the overall servo performance could be determined. The thermal performance of the new structure also needs to be determined.

10.6.6 Performance of an Optical Bench

The determination of the performar of an optical bench requires that both a structural and thermal model be developed for the proposed types of mountings.

10.6.7 Evaluation of Wheel Mounts

A tradeoff comparison study between wheel soft mounts and magnetic bearings is required. This study will result in the selection of the best reaction wheel mounting scheme for GOES-N considering performance, risk, and cost.

10.7 Recommended Research

In order to achieve the within-frame and frame-frame registration requirements of 14μr, a significant change in the instrument design will be required to overcome current error sources. Referring to Tables 10.4.3.1-1 and 10.5.3.1-1 and Appendix C, the primary error in the within-frame registration is due to instrument pointing, and, for the frame-frame registration, the error, is due to thermal variations.

One approach to reduce both these errors is to provide real time error position sensing through the instrument. This technique is an adaption of the approach used on missions that require very accurate pointing/registration such as HST. The adaption is necessary to extend the technique from fixed pointing applications (e.g., staring at a star) to imaging the earth. Conceptually, this approach continuously determines the difference between an earth reference signal (e.g., a beacon) at a known location and the expected pointing position of the instrument with respect to that reference signal. By continuously monitoring the measured (observed) difference between the known signal and the current pointing position, a continuous pointing error can be developed that is referenced to the earth. This error generation is analogous to the generation of a servo error using an Inductosyn encoder or optical encoder, except that the feedback path and error signal are now referenced to the earth and include the pointing error. Like any closed loop servo, errors in pointing due to any cause (e.g., thermal effects, instrument pointing) will be attenuated in near real time.

For the near term, it is recommended that a research and development effort be initiated for an instrument with the capability to continuously sense the position of an earth beacon at a known location and de rmine the error in pointing, if any, with the desired pointing position. One approach based on current technology would use 1000 x 1000 or 2000 x 2000 visible detector arrays in the instrument to continuously monitor the location of a beacon. The array(s) in the near term would not be used for imaging.

For the long term, the development of large visible detector arrays to both image and be the sensor portion of the pointing error detection should be undertaken.

11.0 SYSTEM SURVEYS

11.1 Space Environment Monitor

11.1.1 Introduction

11.1.1.1 Summary of Requirements

The requirements for the GOES-N SEM contained in the "Statement of Guidelines and Requirements: GOES-N Phase-A Study" are summarized in Table 11.1-1, reproduced from that document. The first four instruments, i.e. the EPS, magnetometer, Full-disk XRS, and the SXI are identified as the "Baseline" payload for GOES I-M, and will be carried over into GOES-N, although with some enhancement of the range of particle energies covered by the EPS. It should also be noted that the SXI will not be flown until late in the GOES I-M series. The remainder of the requirements in Table 11.1-1, i.e., the EUV Spectrometer, the SVM/Hαl and the Radio Beacon TEC, were classified as potential improvements to the SEM, with final selection and determination of funding to be deferred until after completion of the study.

Following the format established in the "Guidelines" fc the imager and the sounder as to core requirements, options, and enhancements, the Study Team identified the first four instruments as "core", and the remainder as "options". Our classifications are then as presented in Table 11.1-2.

11.1.1.2 Approach

11.1.1.2.1 Requirements Met by GOES-I

The requirements listed above for the magnetometer and the full disk XRS are unchanged from the specified performance for GOES-I. Since the existing instruments are expected to meet those requirements, no effort has been devoted to alternate instrumentation approaches. It has, of course, been necessary to consider system level impacts of these requirements, such as the level of magnetic interference imposed by the spacecraft for the magnetometer, and provision of appropriate FOV and pointing for the XRS.

11.1.1.2.2 Enhanced Requirements for Earth Environment Observations

The EPS, LPS and Radio Beacon jointly monitor several parameters of the particle environment as ordered by the earth magnetic field. The approach taken was to survey existing instruments to define candidates for these instruments. Impacts were then determined for incorporation into spacecraft models. Most of these instruments make modest demands of spacecraft resources and are largely available with proven designs.

11.1.1.2.3 Enhanced Requirements for Solar Observations

Addition of the SXI, the EUV Spectrometer, the SVM, and the Hαl to GOES-N would result in a dramatic increase in the solar observation capabilities of GOES-N relative to current spacecraft. Incorporation of separate sensors for the entire suite would result in a correspondingly large (and very likely impractical) impact to the spacecraft design and resources. Since it appeared unlikely that the entire complement could or would be implemented, and there was a need to define supporting spacecraft systems early, it was decided to size the spacecraft solar observation platform to accommodate the core XRS and SXI instruments and one other significant (i.e. 20 kg class) solar observing instrument. The SVM was arbitrarily selected for inclusion in the Option III spacecraft model because more definitive information was available at the time than for the other solar observations and because it appeared feasible to incorporate an Hαl mode in the same instrument, thereby partially covering at least one additional requirement. Options for satisfying the requirements for EUV monitoring are discussed in Section 11.1.3.2.7.

Meetings were held with several Principal Investigator groups to discuss instrumental techniques for satisfying the requirements for solar observations on GOES-N. From those meetings, spacecraft resource requirements were estimated for each flight instrument, and incorporated in the appropriate spacecraft models.

11.1.3 Survey Results

11.1.3.1 Payload Complements

Table 11.1-3 shows the SEM payload carried on GOES I-M, the baseline spacecraft system for the purpose of this study. Note that although the SXI is included, it will not be flown until late in the GOES I-M program. The payload included in the Option I model as shown in Table 11.1.3-2 is modified from the baseline by the inclusion of a modified EPS to provide the additional data channels identified by NOAA as core requirements for GOES-N. Although the LPS was identified by NOAA as an optional requirement, its demands on the overall spacecraft are so modest that it has also been included in the Option I model.

Since no enhancements of the SEM payload were added in constructing the Option II spacecraft model, Table 11.1.3-2 reflects the SEM payload for Option II as well. It should be noted however that the spacecraft model for payload accommodations in Option II does include provision for a solar pointing platform capable of accommodating the SVM. Addition of that instrument to Option II is therefore relatively straightforward, given adequate weight and power margins.

Table 11.1.3-3 shows the configuration for the SEM modeled in the option III spacecraft. The SVM/Hαl and the Radio Beacon have been added. With Option III, all of the requirements of the "Guidelines" have been addressed to some extent with the exception of the Solar EUV Monitor. Possibilities for addressing this requirement are discussed in Section 11.1.3.2.7 and in Appendix C

11.1.3.2 Performance Issues

11.1.3.2.1 Magnetometer

Requirements for the magnetometer as listed in Table 11.1-1 are unchanged from the specified capability of GOES I-M. It is assumed that the instrument flown there will be acceptable for GOES-N as well. However, the GOES I-M flight magnetometers have had some difficulty with stability of sensitivity and zero offset, and have not been delivered to the spacecraft as of this writing. Of particular concern has been an observed susceptibility to zero shift after exposure to low and moderate perming fields. The solution at the current time is deperming of the sensors at the launch base. However, a more permanent solution of reducing or removing the susceptibility is recommended for GOES-N.

It is noted that the quality of the data returned by the magnetometer on past and current GOES spacecraft has been limited more by the magnetic cleanliness of the spacecraft than by the performance of the instrument. On the GOES I-M spacecraft, where the proposed six meter magnetometer boom has been reduced to three meters, very careful calibration of and correction for the magnetic signature of the torquing coils flown as part of the attitude control system will be required if the overall performance objectives are to be met. Other sources of interference are expected to be significant as well, and some may also require correction, such as the XRS signature generated as the solar array rotates with respect to the magnetometer. For GOES-N, which will have undoubtedly more sources of magnetic interference, attempts should be made to reduce the signature of as many sources as possible, either by a more stringent magnetic control plan or by returning to the concept of a longer boom.

The Option II and Option III spacecraft attitude control system proposed for GOES-N eliminates the solar sail in order to improve the performance of the earth viewing instruments' passive radiation coolers. Depending on magnetic torquing to compensate for the deleted solar sail resulted in required magnetometer booms as long as nine meters, and even then objectionable magnetic signatures would have been difficult to deal with. Partly for this reason, the Option II and III spacecraft abandon magnetic torquing in favor of reaction wheel unloading by thruster activity. The spacecraft model includes a six meter magnetometer boom. At six meters, and with no magnetic torquing, the magnetometer data on GOES-N should be free of spacecraft field contamination for the first time in any GOES spacecraft. In order to avoid problems with multiple boom segment deployment and stability, Astromast style booms are recommended.

When long deployable booms are used one must also be concerned with the stability of the frame of reference for the magnetometer and with the dynamics of the flexible spacecraft structure. These aspects have not been treated within the scope of this survey, and should be addressed as early as possible in future activity.

11.1.3.2.2 X-Ray Sensor (XRS)

The requirements for the total disk XRS are also unchanged from GOES I-M, and the instrument used there is also expected to meet those requirements. However the adaptation of the ion chamber detector, which has been used since the inception of the SMS/GOES program, to the three axis stabilized GOES I-M has not been flight proven. This adaptation requires a different approach to the removal of the contamination of the measurement by the background ambient energetic particle population. Performance of the XRS for GOES-N must be revisited after demonstration of in-flight performance for GOES-I.

The XRS will also be impacted by the additional solar viewing instruments on GOES-N. The concept developed for the Option I and Option II spacecraft depends on boresighting the XRS and the SXI. Provision can be made for offset pointing to correct bias between the instruments and the high-accuracy sun sensor used for control of the solar pointing platform, and to enable offset pointing of the SXI for coronal imaging. However, with this concept, the small FOV of the XRS will result in compromising its d[illegible] during periods of offset pointing. For the Option III spacecraft, the problem is compounded. The SVM concept utilizes a very limited range (< 1arcmin) compensation for jitter and minor offset by either an articulated secondary mirror (for a Cassegrain telescope design) or a separate image motion compensation mirror (for the case of a refractive telescope design). All instruments must still be boresighted to high accuracy in ground test. This concept results in compromising the Solar Magnetograph operation as well as the XRS during periods of SXI offset pointing.

Fortunately, there is no requirement for long term continuous monitoring of the solar corona. The Option II and Option III attitude control system concept, with its on-board sensing and correction of spacecraft motion, should allow stepping the solar pointing platform by the required 16 or 32arcmin to allow the image of the solar corona to be generated, followed by an immediate return to the solar disc monitoring mode. The impact to the XRS and the SVM should be negligible. However, the dynamic response of a flexible spacecraft model to this stimulus has not been modeled, nor has the stability of the system, even in the absence of such stimuli. Such a stability analysis should be conducted before Phase-B begins.

11.1.3.2.3 Solar X-Ray Imager (SXI)

The SXI is a transitional instrument in that it will be incorporated in the GOES I-M program late in the series. As of this date, it is the only approved GOES I-M payload item which remains to be developed (The LMS is a likely additional payload item in this category). In summary, the SXI development is quite advanced relative to the other enhancements to the SEM because it has long been the highest priority item for enhancement of the SEM capabilities. NOAA's SEL and the NASA MSFC jointly carried out a feasibility study and brassboard demonstration starting in 1979 (Cessna, et al., 1983) for an instrument to be carried aboard a spinning spacecraft such as those used through the GOES-7 spacecraft currently in operation. Proposals for incorporation of the instrument on the GOES-7 series (GOES G-H) were solicited from the spacecraft contractor, but funding limitations prevented its incorporation at that time. The SXI was the first candidate for growth on the current GOES I-M development program and was the subject of an accommodation study carried out by the spacecraft contractor soon after contract award (Space Systems/Loral, 1985). The study led to the incorporation of several features in the spacecraft design to facilitate the eventual flight of the SXI. The accommodation study included the solicitation in 1984 of proposals for the instrument development, and the proposals were amended in 1985 to reflect desired improvements in instrument performance. A Memorandum of Agreement exists between NOAA and the USAF under which NOAA is to fly one or more SXI on the GOES I-M program, with USAF funding. The GOES project at GSFC has been directed to implement this agreement, and plans are currently underway to update the accommodation study and proceed with a contractual arrangement to incorporate the instrument late in the GOES I-M series.

The technical issues which remain of concern are the choice of detectors to be used in the instrument, the quality of the X-ray grazing incidence mirror, and the dimensional stability of the telescope metering structure. There are several candidates for a detector array, all of which involve some level of development. An X-ray imaging mirror of excellent quality, albeit different collecting area and focal length, has been fabricated and demonstrated as part of the Solar X-ray Telescope (SXT) development for the Solar-A spacecraft, giving confidence that this issue is technically manageable. Techniques are available for building dimensionally stable metering structures, but they may involve exotic materials and processes. In short, the SXI is a very realizable instrument, but these technical issues must be addressed with the best engineering practice if problems are to be avoided.

11.1.3.2.4 Energetic Particles Sensor (EPS)

The EPS requirements listed in the "Guidelines" add significant new coverage to the energy ranges and particle types monitored on GOES I-M. The additional information on heavy ions can be obtained by modification of the existing GOES-I EPS package, and coverage of protons and electrons down to the 30keV range (given as a core requirement) can be obtained through the recommended approach of adding the TIROS MEPED telescope to the EPS package, as has been done in spacecraft Options I, II, and III. However, there remain some areas where the instrument package proposed does not fully satisfy requirements.

First, coverage of alpha particles down to 30keV/n is not provided. A new time-of-flight type of sensor would be required to separate the alpha particles from protons. Such sensors can be built, but are state-of-the-art designs, and were not addressed by this study in time to be incorporated in the spacecraft models. Further review of availability and performance of these instruments needs to be accomplished in the next phase of the GOES-N activity. The GOES-I EPS only provides alpha particle coverage down to 0.8MeV/n.

Secondly, discussions with SEL scientists during the study revealed a requirement for fairly detailed pitch angle distribution for protons and electrons below approximately 100keV. This prompted the use of a more complex instrument than might have otherwise been used for the LPS, to meet an "optional" requirement for monitoring electrons and protons up to 30keV. The LPS provides very good "quasi"-three dimensional coverage in this energy range. The MEPED, which is included to provide coverage above 30keV, only has two defined directions. The rather broad acceptance angle of the MEPED insures the integrity of the measurement, i.e., there are no broad directional components of the population which are not sampled by the instrument, but the pitch angle resolution obtained is correspondingly coarse. This issue should be revisited by NOAA to clarify the requirements for spatial resolution in this energy regime.

11.1.3.2.5 Solar Vector Magnetograph/Hα Imager (SVM/HαI)

No flight proven prototype for a SVM exists. At least three instrument groups have been active in flight projects and proposals for remote sensing of solar magnetic fields. They are the group headed by Dr. David Rust at Johns Hopkins University APL, the group under Dr. Mona Hagyard at NASA MSFC, and the group headed by Dr. Alan Title, at the LPARL. All three have also been involved in ground based magnetographs, as have been a number of other exclusively ground based observers. In the course of this study, we have consulted with each of these three groups. Of particular interest is Dr. Hagyard's pre Phase-A study for a magnetograph for the SAMEX (Solar Activity Measurement Experiments) mission (Hagyard, 1988). This excellent treatise addresses most of the technical concerns and potential problem areas associated with development of a spaceborne magnetograph although the 0.5arcsec resolution required for SAMEX results in an instrument much too large for GOES.

The magnetograph is by far the most technically challenging of the enhancements under consideration for the GOES-N SEM. Several design requirements involve technical requirements at the state-of-the-art for optical system design. These all need to be addressed as part of a full study for the magnetograph. The scope of these issues is such that substantial involvement of one or more of the experienced groups will be required to realize a space-borne magnetograph for GOES.

First, remote sensing of magnetic fields at the photosphere of the sun requires determination with very high sensitivity of the state of polarization of the light received by the sensor. This means that the incidental polarization introduced by the instrument must be nearly zero, placing stringent requirements on optical system design, materials, and optical coatings.

Secondly, achieving the required sensitivity with state of the art detectors requires processing of multiple images, which must, therefore, be co-registered to better than the 1arcsec pixel size desired. The accurate co-registration must be maintained over the 5 minute period or so required to obtain the required sensitivity. This requirement can only be met by very precise servo control of the platform or by correlation tracking of the solar image from frame to frame.

All measurements must be taken within the spectral bandwidth of the magnetically sensitive resonance line, which requires realization of very narrow spectral bandwidth filters in the measurement instrument. A number of alternative approaches have been proposed, some of which have been flight and/or ground proven, and others more developmental. A more detailed study should be conducted to select the best cost/risk/performance alternative. Finally, realization of the HαI requirements in the same package requires this narrow-band sensing performance in multiple spectral bands.

Information incorporated in the spacecraft models for the SVM, as in Table 11.1-5, was based on scaling down a ground based prototype early in the study. Dr. Title has looked at the modifications required to his MDI instrument for the SOHO spacecraft to convert it to an SVM (As originally proposed, the instrument had a full vector magnetograph mode). A more thorough modeling of the optics and electronics associated with the SVM for GOES (which does not require all of the optics and electronics included in MDI) must be done before committing to a system design with the weights allocated as in the spacecraft model. One of the major system concerns, as mentioned in Section 11.1.3.2.2 above, is the interaction of the augmented solar pointing platform with the spacecraft control system, each with its respective stringent stability requirements. This interaction is to a large extent driven by the weight carried on the solar platform. Note that the concerns about instrument boresighting discussed in Section 11.1.3.2.2 are of even greater concern to the magnetograph.

11.1.3.2.6 Radio Beacon Measurement of Total Electron Content (TEC)

This measurement technique is intended to monitor the TEC along the line of sight between the spacecraft and one of several ground stations by measuring the differential group delay between a code sequence transmitted at two frequencies in the VHF/UHF radio bands. In the past, similar data has been retrieved from the Faraday rotation of linearly polarized signals of opportunity from a number of different spacecraft transmitting at these frequencies. These signals of opportunity have become quite sparse in recent years, and for this reason there has been interest in providing dedicated beacons on a operational basis. In addition the quality of the data retrieved through the code modulation technique would be considerably improved over the earlier Faraday rotation analysis.

The spacecraft resources requirements listed in the tables for the radio beacon are very conservative since they are derived from proposals for implementation on the earlier spinning GOES spacecraft, where multiple spinning whip antennas at VHF and a triplexer modification to feed the UHF signal through the despin bearing assembly to a despun sleeve dipole antenna were required. The implementation on a three axis stabilized spacecraft is obviously much simpler.

NOAA SEL has reported that the USAF has already implemented a capability for TEC monitoring through the GPS where ionospheric corrections are needed for propagation delay correction. Since the large number of spacecraft in the GPS program provide much better coverage than could ever be achieved on GOES, this development has resulted in some reduction in priority for the Radio Beacon on GOES-N, notwithstanding that it can be implemented on GOES at modest cost. If it is determined that the capability should be included in GOES-N, the RF equipment and spacecraft resources required should be refined and the ground system support requirements reviewed as part of the Phase-B effort.

11.1.3.2.7 Solar Extreme Ultraviolet (EUV) Monitor

Since the solar pointing platform was not sized to include a solar EUV monitor in addition to the SVM/Hαl, this instrument does not appear in the tables defining the spacecraft options. The decision to accommodate the SVM/Hαl was, however, arbitrary, and not based on any stated NOAA priority. The EUV monitor is addressed on the assumption that it might replace the SVM/Hαl. Discussions with SEL personnel resulted in a statement of requirements that included spectral coverage from 100 to 1700Å with a spectral resolution of 1Å, defined dynamic range, absolute calibration to better than 5% in flight, and observing frequency of at least one spectrum every 30 minute.

The driving requirement for the EUV instrument is absolute accuracy. EUV radiometers are notoriously susceptible to contamination effects which have in some instances reduced signal throughput by orders of magnitude. Proven in-flight calibration sources have not been achieved at reasonable power, weight, and reliability. Since the degradation effects are normally spectrally selective, a truly satisfactory source must cover the spectral bandwidth of interest. Some types of detectors, which must often operate without protective windows in order to achieve usable sensitivity, have inherent stability problems. The overall experience indicates that strict contamination control will be required to maintain useable sensitivity, and that external calibration must be provided to have confidence in the measured spectral flux. It is not likely that the 5% level can be achieved without an extensive development program for in-flight calibration sources.

Two options for addressing the broad requirements are, based on discussions with Dr. Thomas Woods of the University of Colorado, and with Drs. Smith and Parkinson at the Smithsonian Center for Astrophysics. The indication is that a multiple sensor package can be defined which would be compatible with the weight and volume available as a replacement for the SVM/Hαl. An extensive development program for in-flight calibration would be necessary to approach the 5% calibration requirement, and no fallback position to provide partial recovery of the SVM/Hαl is apparent.

In view of the lack of confidence in achieving the required absolute accuracy, it is recommended that the EUV requirement for GOES-N be addressed by a single small grazing incidence spectrograph covering the spectral range from perhaps 100 to 1200Å. This instrument could be developed to fly "piggy-back" on one of the instruments, much as the small XRS flies "piggy-back" on the other. A combination of stellar calibration and sounding rocket under-flights would be used to maintain the absolute accuracy. Dr. Woods believes that ±20% should be achievable. By this approach, useful data could be obtained on GOES-N whereas no direct data at all is otherwise available. In the meantime, a program should be undertaken to develop small, low power, reliable in-flight calibration sources to enable improving the absolute accuracy of EUV measurements to the ±5% desired.

11.1.4 Summary

The results of this survey indicate that given a spacecraft concept along the lines of that outlined in Option III model and the development of the small EUV spectrograph proposed above, all of the requirements of the "Guidelines" for the Space Environment Monitor on GOES-N can be addressed to some extent. It has not been within the scope of this survey to develop a detailed performance analysis. Substantial additional analysis is necessary to predict quantitative performance expectations for the instrument concepts in such areas as (1) the sensitivity, spectral resolution, total spectral range and calibration accuracy of the EUV spectrometer; (2) sensitivity, MTF, signal processing analysis and algorithm validity analysis for remotely sensed solar magnetic fields (and Hα images) for the SVM/Hαl; (3) atomic number and energy band discrimination capability and contamination analysis for the desired heavy ion analysis in the EPS; and (4) detailed optical performance analysis and detector performance and reliability trade off for the SXI. In most areas, however, the desired performance levels are comparable to or less than that achieved by or specified for the prototype instruments which have been surveyed. A notable exception is the absolute calibration accuracy of the solar EUV monitor.

11.1.5 Recommendations

11.1.5.1 Magnetometer

1. Continue with the development of the Option II/Option III Spacecraft ACS to eliminate magnetic torquing as a source of interference.
2. Include a 6 meter Astromast style deployable boom in a Phase-A/B flexible-body stability analysis to verify the compatibility with pointing stability requirements for both the magnetometer and the earth viewing instruments.
3. If it is shown necessary to use a boom shorter than 6 meters, stringent magnetic control and acceptance test requirements must be placed on <u>all</u> spacecraft subsystems.
4. Boom and sensor packages must be acceptance tested separately in a zero field test facility (including post perm/deperm tests) to verify the magnetic stability of the sensor assembly.
5. The spacecraft level zero field magnetic test requirement should be restored, at least for the qualification spacecraft test.
6. A solution should be found to the observed susceptibility of the GOES-I instrument to perming in low to moderate fields.

11.1.5.2 X-Ray Sensor (XRS)

1. Confirm in-flight performance expectations on GOES-I.
2. Develop concepts for boresighting the XRS to other solar observing instruments.

11.1.5.3 Solar X-Ray Imager (SXI)

1. Perform an SXI detector trade-off study to identify the preferred approach.
2. Prepare specification for the SXI grazing incidence mirror and obtain cost/schedule quotes from potential suppliers.
3. Perform preliminary SXI thermal/structural design and materials selection for metering structure and evaluate thermal effects on optical system performance.
4. Perform preliminary SXI data processing electronics design and update power estimates.
5. Update SXI mass estimates.
6. Compete GOES-N units to industry and GFE to the spacecraft contractor.

11.1.5.4 Energetic Particles Sensor (EPS)

1. Perform EPS energy deposition analysis in the current telescope/dome/HEPAD to confirm logic, thresholds and energy/atomic number separation performance for the $Z \geq 3$ channels.
2. Study a separate time-of-flight EPS sensor to monitor alpha particle flux for 30keV/n to 800keV/n alpha particles.
3. Compete GOES-N alpha particle flux monitor to industry and GFE to the spacecraft contracter.

11.1.5.5 Solar Vector Magnetograph (SVM)

1. Perform full study for SVM

- Prepare preliminary perfo.mance specification
- System definition tradeoffs (light collection, polarimeter, image stabilizer, filters, detectors).
- Optical system layout and packaging.
- Preliminary signal processing requirements definition.
- Preliminary electronics design.
- Preliminary Interface Specification.
- Make or buy decision.

2. Build GOES-N units in-house or compete via Phase-B/C/D to industry, and GFE to spacecraft contractor.

11.1.5.6 Solar Extreme Ultraviolet (EUV) Spectrometer

1. Perform full study for a small, grazing incidence spectrograph.

- Preliminary design and performance analysis.
- Preliminary performance specification.
- Optical system layout.
- Preliminary data processing and electronics design.
- Preliminary interface specification

2. Compete to industry and GFE to spacecraft contractor.
3. Undertake a program to develop space qualified, low power, broadband, reliable EUV calibration sources.

11.1.5.7 Solar Pointing Platform (SPP)

1. Preliminary electromechanical and structural SPP design.
2. Preliminary stability and pointing performance analysis for both earth and solar viewing instrument platforms.
3. Preliminary interface specification.

REFERENCES

1. Cessna, J. R., R. B. Hoover, R. N. Grubb, P. L. Orswell, and J. H Taylor, "The GOES X-Ray Imager Feasibility Demonstration," NOAA Technical Report Earth Resources Laboratory (ERL) 423-SEL41, February, 1983 .
2. Ford Aerospace Corporation, "Solar X-Ray Imager Implementation on the GOES I/J/K/L/M Spacecraft," WDL-TR10602, January, 198[illegible]
3. Hagyard, M. J., G. A. Gary, and E. A. West, "The SAMEX Vector Magnetograph," NASA Technical Memorandum 4048, June, 19[illegible]

TABLE 11.1.1-1A
GOES-N CANDIDATE INSTRUMENTS - SEM

INSTRUMENT	CADENCE	DYNAMIC RANGE	T/M BPS	COMMENTS
ENERGETIC PARTICLE SENSOR	30 sec in ≤ 30keV to 4 MeV	TBD	20	Crude directionality required above 1 MeV
MAGNETOMETER	0.5 SEC	-400 TO +400 nT	100	Specifications assume spacecraft field is accounted for
FULL-DISK X-RAY	≤ 3 sec	GOES I-M	10	Fewer range changes than in present instrument are desirable
SOLAR X-RAY IMAGER	60 sec	GOES I-M	$2x10^5$ ($5x10^4$)	Must have EUV filter to acquire routine EUV images
LOCAL PLASMA	≤ 3 sec @ channel		50	Crude directionality
EUV SPECTROMETER	0.5 TO 1.0 hr.	TBD	10	Must be well calibrated for several lines in 1-2000 range
SOLAR MAGNETOGRAPH	10 minute	-.03 to 0.3 T	$2x10^4$	Multiple wavelength (heights) desirable. Accuracy set by technological limits
Hα IMAGER	≤ 60 sec	TBD	$1x10^6$	Line-center and continuum
RADIO BEACON	N/A	N/A	1	Continuously broadcast two frequencies in 100-400 MHz range; total power 1 W

TABLE 11.1.1-1B
GOES-N CANDIDATE INSTRUMENTS - SEM

INSTRUMENT	MEASURES	FOV	RESOLUTION	
			SPECTRAL	SPATIAL
ENERGETIC PARTICLE SENSOR	30keV to 700MeV/n p and Alpha ≤ 30keV to 4MeV > 3 particle fluence	---	3 channels/ decade	---
MAGNETOMETER	Ambient vector field	---	---	---
FULL-DISK X-RAY	0.5–4 and 1–8Å solar brightness	WD*	0.5–4Å band	WD
SOLAR X-RAY IMAGER	X-ray images	≥ 1.5 R_s T	TBD	5x5 $arcsec_2$
LOCAL PLASMA	Charged particle flux	---	~ 15 channels	TBD
EUV SPECTROMETER	Average EUV brightness	WD	TBD	WD
SOLAR MAGNETOGRAPH	Solar vector magnetic field	WD*	TBD	2x2 arcsec
Hα IMAGER	Hα images	WD*	0.5Å	1x1 arcsec
RADIO BEACON	N/A	N/A	N/A	N/A

WD = WHOLE DISK
* = FOV MIGHT BE SMALLER THAN WHOLE DISK

TABLE 11.1.1-2
GOES-N SEM REQUIREMENTS SUMMARY

AREA	CORE REQUIREMENTS	OPTIONS	ENHANCEMENTS
ENERGETIC PARTICLES	**RC31** PROTONS AND ALPHAS 30keV>700MeV/NUCLEON ELECTRONS $\leq$30keV-4MeV HEAVY IONS FLUENCE ($Z\geq3$) E>100MeV/n,E>10GeV/n	**R031** ELECTRONS AND POSITIVE IONS 10eV-30keV	
MAGNETIC FIELDS	**RC32 (met)** 3 COMPONENTS OF THE VECTOR FIELD TO <nT ACCURACY		
TOTAL ELECTRON CONTENT		**RO32** IONOSPHERIC RADIO BEACON MEASURES POLARIZATION ROTATION AND DIFFERENTIAL TIME DELAY AT VHF	
SOLAR OBSERVATIONS	**RC33 (met)** FULL-DISK X-RAY SENSOR FLUX IN 0.5-4 AND 1.8 Å BANDS	**R033** SOLAR EUV SPECTROMETER TIME INTEGRATED FLUX IN SEVERAL SPECTRAL LINES	
	RC34 (met)* SOLAR X-RAY IMAGER CORONA IMAGES IN SEVERAL BANDS	**R034** SOLAR MAGNETOGRAPH PHOTOSPHERIC VECTOR FIELD IN EACH ACTIVE REGION WITH 2.5 mT SENSITIVITY IN EACH COMPONENT	
		RO35 SOLAR HYDROGEN ALPHA LINE IMAGER HIGH FRAME RATE (1 MINUTE) SOLAR IMAGES IN HYDROGEN ALPHA LINE & CONTINUUM	

* CONTRACTUAL ARRANGEMENT WITH LAS IS IN PROGRESS

TABLE 11.1.3-1
SPACE ENVIRONMENT MONITOR COMPLEMENT - BASELINE

INSTRUMENT	MASS (KG)	POWER (WATTS)	TELEMETRY (KBPS)
MAGNETOMETER	5.9	3.7	0.096
ENERGETIC PARTICLES SENSOR	9.6	10.8	0.032
SOLAR X-RAY SENSOR	5.1	2.4	0.040
SOLAR X-RAY IMAGER	12.6	10.0	100.0*
TOTALS	**33.2**	**26.9**	**100.2**

* PRIME TELEMETRY FOR THE SOLAR X-RAY IMAGER IS VIA THE MULTI-USE DATA LINK. HOUSEKEEPING AT LOW DATA RATE WILL BE VIA PCM TELEMETRY

TABLE 11.1.3-2
SPACE ENVIRONMENT MONITOR COMPLEMENT - OPTIONS I AND II

INSTRUMENT	MASS (KG)	POWER (WATTS)	TELEMETRY (KBPS)
MAGNETOMETER	5.9	3.7	0.096
ENERGETIC PARTICLES SENSOR	15.2	10.8	0.032
SOLAR X-RAY SENSOR	5.1	2.4	[illegible]
SOLAR X-RAY IMAGER	12.6	10.0	100.0*
LOCAL PLASMA SENSOR	6.4	3.5	32.0*
TOTALS	**45.2**	**36.4**	**132.2**

* PRIME TELEMETRY FOR THE SOLAR X-RAY IMAGER AND LOCAL PLASMA SENSOR IS VIA THE MULTI-USE DATA LINK. HOUSEKEEPING AT LOW DATA RATE WILL BE VIA PCM TELEMETRY

TABLE 11.1.3-3
SPACE ENVIRONMENT MONITOR COMPLEMENT - OPTION III

INSTRUMENT	MASS (KG)	POWER (WATTS)	TELEMETRY (KBPS)
MAGNETOMETER	5.9	3.7	0.096
ENERGETIC PARTICLES SENSOR	15.2	16.8	0.032
SOLAR X-RAY SENSOR	5.1	2.4	0.040
SOLAR X-RAY IMAGER	12.6	10.0	100.0*
LOCAL PLASMA SENSOR	6.4	3.5	32.0*
SOLAR MAGNETOGRAPH/Hα	22.0	50.0	150.0*
RADIO BEACON	3.2	60.0	2000.0**
TOTALS	70.4	146.4	2282.1

* PRIME TELEMETRY FOR THE SOLAR MAGNETOGRAPH, SOLAR X-RAY IMAGER, AND LOCAL PLASMA SENSOR IS VIA THE MULTI-USE DATA LINK. HOUSEKEEPING AT LOW DATA RATE WILL BE VIA PCM TELEMETRY

** TELEMETRY FOR THE RADIO BEACON IS VIA DEDICATED VHF/UHF LINKS. HOUSEKEEPING AT LOW DATA RATE IS VIA PCM TELEMETRY

11.2 Search and Rescue Survey

11.2.1 Survey Requirements

The S&R system survey requirements were twofold. One was to determine the feasibility of earth locating 406MHz distress beacon signals from geosynchronous orbit to an accuracy of 20k or, alternatively, determine what position location accuracies are feasible. The second requirement was to define requirements for implementing an operational 406MHz S&R ground system, including interfaces with the USMCC.

11.2.2 Technical Approach

The project studied the results of experiments conducted with the 406MHz system installed on the GOES-7 spacecraft and NASA work being done on position location from geosynchronous orbit. In addition, the survey team contacted SSAI, Inc. personnel responsible for maintaining the USMCC database to determine the state of planning for incorporation of the 406MHz receive system into the operational S&R system. The project also performed its own independent analysis of achievable position location accuracies and proposed an alternative design.

11.2.3 Survey Results

Survey findings were that Canada already uses GOES-7 406MHz distress beacon data operationally and that plans exist for incorporating the 406MHz system into the operational S&R system in the GOES-I timeframe. Consequently, the project decided that there was no need to continue the ground system requirements definition effort. The remaining survey effort was devoted to analysis of position location. The following paragraphs describe the status of the S&R system and the analysis efforts accomplished during the survey.

11.2.3.1 Search and Rescue System Background

The 406MHz S&R system design uses a digital format in which a user identification is embedded. An extended format has also been proposed that would permit the addition of coordinate information derived from a navigation system on board the vehicle carrying the distress beacon transponder. An actively transmitting distress beacon repeats its message every 50 seconds, transmitting at 2400bps.

The initial experiments at NASA (as well as Canada and France) using the GOES-7 spacecraft were successful in proving the technical feasibility of the geosynchronous S&R system. These experiments centered on detecting distress beacon signals and included demodulation of received signals. A second series of experiments, hampered by the loss of the GOES test facility at GSFC, is to include decoding of information carried by the beacon signals.

Currently, the S&R system relies on low earth orbiting satellites for the relay of distress beacon signals and to provide position information based on frequency shift due to the movement of the spacecraft relative to the distress beacon (Doppler frequency shift). The system limitation is that a distress beacon could be active for several hours before a COSPAS/SARSAT flyby. A geosynchronous spacecraft, on the other hand, would detect a transmitting distress beacon within its footprint in a matter of minutes. User identification embedded in the transmission would provide some information that might help in pinpointing an area where the distress beacon was activated. But without a position location capability (or coordinate data derived from a navigation system), determining the distress beacon's position would still require a COSPAS/SARSAT flyby.

Therein lies the desire to provide a location capability on geosynchronous spacecraft. However, the zero elevation angle for geosynchronous spacecraft occurs at about 80 degree latitude, meaning that polar coverage cannot be provided. Three geosynchronous spacecraft will provide worldwide equatorial coverage, but on the order of six spacecraft would be needed for adequate coverage at latitudes above 60 degrees. An alternative to using geosynchronous spacecraft is to deploy a constellation of low earth orbit COSPAS/SARSAT spacecraft to provide more frequent coverage. Another, but less desirable, alternative is to require that vehicles carry navigation systems to provide coordinate data in the distress signal.

11.2.3.2 Position Location System Accuracy

An interferometer was proposed for use on geosynchronous spacecraft. NASA Technical Report 2907, ***Geostationary Position Location Alternatives for 406 MHz Distress Beacons***, dated March 1, 1990, describes an interferometer requiring two orthogonal booms about ten meters in length, each with two antennas to receive distress beacon signals. An associated electronics package would compute the difference in phase between the signals received by the various antennas. The phase information would be downlinked to the S&R system receive station on the ground for computation of the position of the transmitting distress beacon and distribution of the position information to the USMCC. The interferometer described in the report would provide a position location uncertainty of about 50km at the subsatellite point, with the uncertainty increasing with latitude. However, by averaging phase difference information over multiple distress beacon message transmissions, the position uncertainty can be reduced by the square root of the number of messages over which the measurement is made.

A follow-on NASA study, ***GOES-N Search & Rescue Interferometer Feasibility Study***, dated January 14, 1991, investigated the feasibility of implementing an interferometer on the GOES-N spacecraft. Figure 11.2-1, taken from this report, shows a conceptual implementation of this interferometer on a GOES-I bus. Quoting from the conclusions drawn from that study, "... zero momentum active ACS for GOES-N can accommodate the necessary appendages for the S&R interferometer. There do not seem to be any major show stoppers that would prevent the S&R Interferometer implementation on the GOES-N with the active ACS option [Option II and III spacecraft]. This does not imply that it is easy to do. A conclusion that may be drawn from this study is that the GOES-N mission is already a very difficult and challenging one, and the addition of the S&R interferometers does not add substantially to this challenge. Further study is needed to refine the system parameters and spacecraft impacts in terms of power, size, weight, and antenna/Astromast stowage configuration..."

11.2.3.3 Alternative Interferometer Implementation

At the second study quarterly review, it was stated that a S&R interferometer implementation would not be included in any of the GOES-N spacecraft options being analyzed. The principal reason for this decision revolved around the negative impacts that the long booms would have on image navigation and registration performance, which were already below required performance. An interferometer had not been considered in any of the attitude control system studies that had been funded. Given that the feasibility study did not become available until 1991, there were no data available from which to evaluate the impacts on the control system.

As a result of discussions at the third quarterly review, a S&R interferometer was incorporated into what was to be an additional spacecraft option (Option IIIA) to be studied after the GOES-N study was completed. As a result of that agreement, the project team conducted an independent analysis of the position location problem and developed an alternative configuration that did not require the long Astromast booms. Figure 11.2-2 shows a conceptual implementation of this alternative interferometer using GOES-I UHF antennas.

The output of an interferometer is a phase difference measurement between the signals received by the interferometer antennas. For accuracy, a long baseline between antennas is desirable. However, if the baseline length is such that the phase difference between received signals can exceed 2π radians (360 degrees), measurements will be ambiguous; that is, a phase difference measurement of 370 degrees is the same as a 10 degree phase difference. Therefore, a short baseline is also required to resolve the ambiguity. Therein lies the need for multiple antennas. For the interferometer shown in Figure 11.2-2, the short diagonal provides an eight-foot baseline for ambiguity resolution, and the longer, 12.8-foot baseline provides a position uncertainty of 67.7km at nadir, assuming that the phase measurement error/jitter is about 0.01 radians 1σ. The position uncertainty can be reduced by averaging over multiple distress beacon transmissions, as stated earlier.

11.2.4 Spacecraft Impacts

The principal impacts of an interferometer on the spacecraft are the increased spacecraft inertia, particularly if long booms are used, and dynamic interactions caused by thermal bending and flexible body dynamics of booms and antennas. In addition, there is the problem of accommodation of the structures on the spacecraft and within the launch vehicle fairing. The weight and power estimates given for the Astromast interferometer implementation were 35kg and 35W of prime power.

11.2.5 Ground System Impacts

The addition of an interferometer on the GOES-N spacecraft would have no impact on the GOES ground system. The impact to the S&R ground network would primarily be the need for additional processing power for position computations.

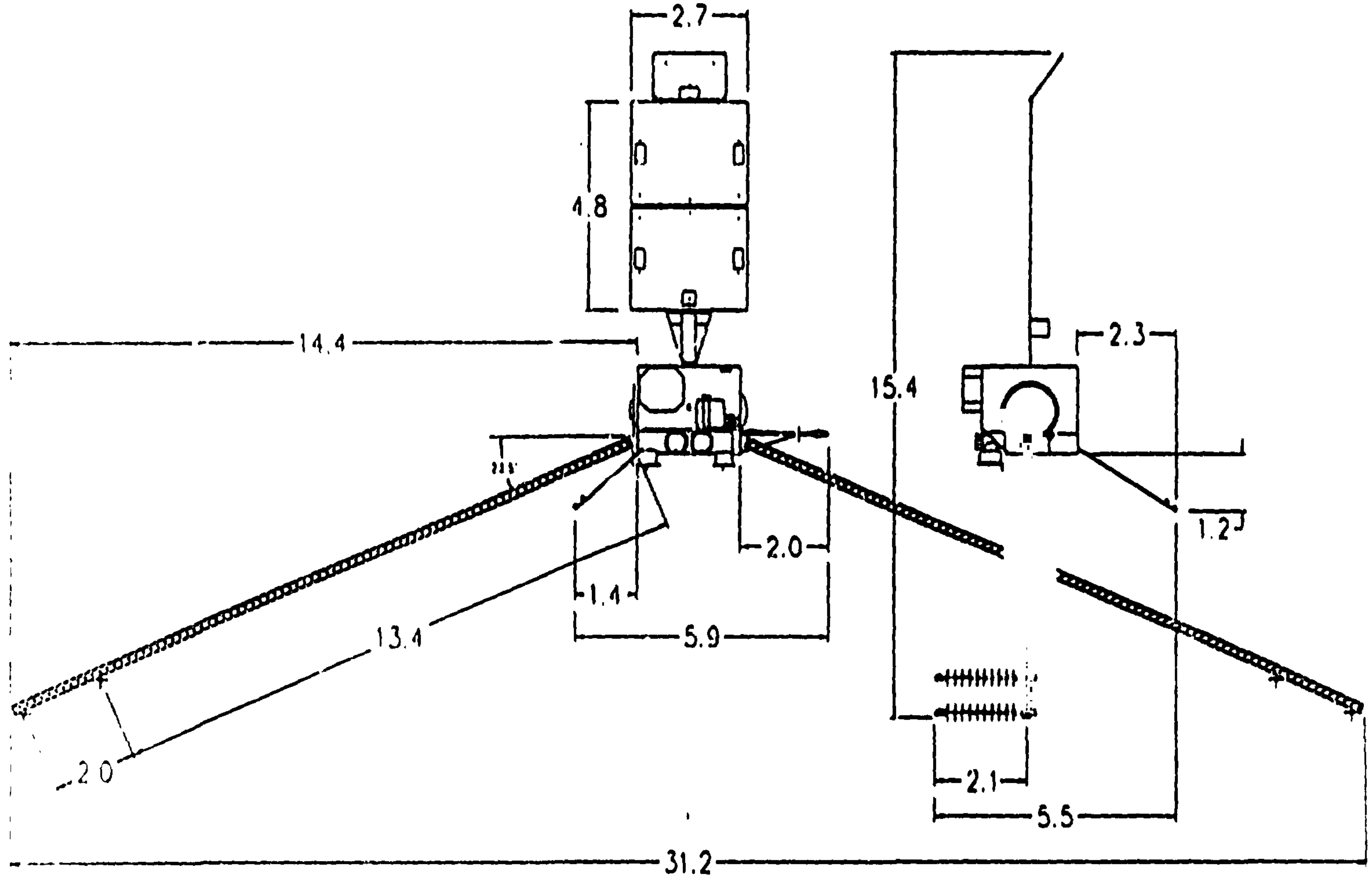


Figure 11.2-1

GOES-N with SarSal Interferometer Deployed

Dimension in Meters

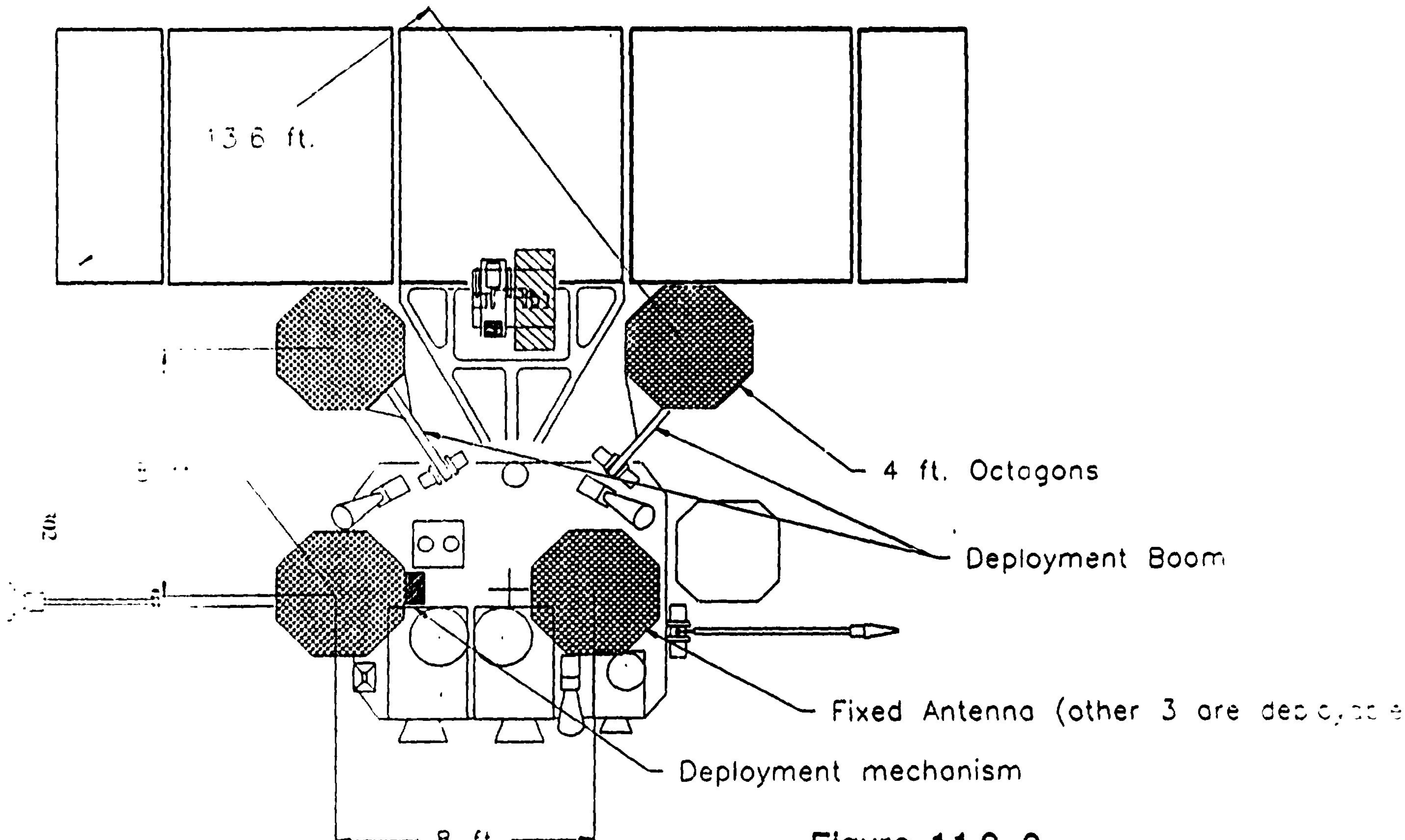


Figure 11.2-2
Option III
New SAR Configuration
(earth viewing side)

11.2.6 Conclusions and Recommendations

The feasibility of the 406MHz S&F system has been adequately proved. The use of interferometers for determining the location of distress beacons from geosynchronous orbit, on the other hand, has not been tested. The conceptual studies performed to date indicate that the technique should work, and that more study and a flight experiment are warranted. The project believes, however, that the GOES program, with its stringent pointing and stability requirements, is not the appropriate vehicle for this research. Furthermore, before proceeding with additional development of an interferometer, a tradeoff analysis should be performed to determine whether or not a constellation of small, dedicated, low earth orbiting satellites would not be a more economical solution.

11.3 WEFAX

11.3.1 Survey Requirements

The study requirements were to determine the impacts on the spacecraft, the ground system, and WEFAX receive stations of adding three channels in the WEFAX band to the existing analog channel. The new channels are a second analog WEFAX channel, a digital WEFAX channel operating at 19.2kbps, and a 50kbps data channel (termed the NOAA Port). An additional requirement was to determine the impacts to the spacecraft of operation during eclipse periods.

11.3.2 Technical Approach

The study team's initial approach to the survey was to interview NOAA WEFAX experts to validate the requirements and discuss the makeup of the WEFAX service during the GOES-N time-frame. The next step was to develop alternative spacecraft configurations to provide the additional channels. Link budgets from the GOES-I predicted performance were developed to determine spacecraft and CDA facility EIRP requirements. In turn, these EIRP's were used to estimate weight and prime power requirements for the new channels for input to the RAO cost model. Because of the lack of weight margin on the Option I baseline spacecraft platform, the additional channels and eclipse operation were included only in Options II and III. A single analog channel was used for Option I.

11.3.3 Summary of Survey Results

NOAA personnel interviewed during this survey were C. Staton (Chief, Data Collection and Direct Broadcast Branch, NOAA/NESDIS) and J. Green (WEFAX Coordinator, NOAA/NESDIS). One of the discussion topics was analog versus digital WEFAX. The push worldwide is to phase out analog WEFAX in favor of digital WEFAX, with the late 1990's as a target for NOAA. The second analog WEFAX channel therefore, appears to be a weak requirement for the GOES-N time-frame. NOAA should reexamine this requirement. Another topic of discussion was the NOAA Port channel. The use of the term NOAA port for the 50kbps data channel caused confusion with the planned AWIPS NOAA Port channel. In fact, the purpose of the 50kbps channel is to broadcast DCS platform response data from the CDA to DCS users and also to distribute some NOAA weather products. This channel will replace a DOMSAT service leased by NOAA to upgrade the dial-up service currently in use.

During the course of the final study presentation to NOAA, a comment was made indicating that the requirement for operation through eclipse may be very weak. NOAA should give this requirement thorough consideration because of its large impact on the spacecraft power generation and storage system. Any reduction in eclipse operation will result in spacecraft platform weight and cost reduction.

11.3.4 Link Calculations

The first step in developing spacecraft configurations to satisfy the four-channel WEFAX requirement was to determine the EIRP required for each channel. Link performance was calculated for each of the channels using predicted and worst case performance specifications for the GOES-I WEFAX channel. Th· GOES-I links were used because they provide an accepted level of service to the same ground stations to be used with the GOES-N spacecraft. Table 11.3-1 shows the GOES-I link calculations for the Wallops CDA to spacecraft uplink and the spacecraft to WEFAX receive station downlink. Table 11.3-2 shows the performance of the four channels given the worst case received carrier-to-noise ratio derived from Table 11.3-1. Using a transmit power of 12w (40.7dBm) per channel, the link margins range from 4.5dB for the 50kbps channel to 8.7dB for the digital WEFAX channel. Operation of all four channels at the same power level will simplify the design of a spacecraft configuration utilizing separate transmitters for each channel by allowing the use of identical interchangeable transmitters. Nc :. that spacecraft transmit power could be reduced by tightening the G/T specification of the WEFAX receive stations.

11.3.5 Alternative Spacecraft Configurations

Two spacecraft configurations were considered for Options II and III to provide the additional three channels. One consisted of separate power amplifiers (PA) for each channel. The other alternative consisted of one transmitter for all four channels. In both cases a common S-band receiver is used on the spacecraft to receive the uplink signals. In its presentations c the study team, HAC favored the separate transmitters approach while LAS favored the single transmitter approach.

11.3.5.1 Separate Transmitters

Operation of all four WEFAX channels at the same transmit power permits the use of identical solid state power amplifier (SSPA), with two spares as backup for the four primary PA. The use of separate P/ is the most flexible from the standpoint of eclipse operations, because individual channels can be turned on and off to conserve power In addition, intermodulation products a:e

TABLE 11.3-1
GOES-I WEFAX Channel Predicted and Worst Case Performance
(Earth Edge)

PARAMETER	CDA to Spacecraft		CDA TO APT	
	PREDICTED	WORST CASE	PREDICTED	WORST CASE
TX POWER (dBm)	51.0	51.0	40.7	40.7
TX LINE LOSS (dB)	-	-	2.7	2.9
TX ANTENNA GAIN (dB)	-	-	17.2	16.5
NET EIRP (dBm)	96.7	96.7	55.2	54.3
TX ANT. POINTING LOSS (dB)*	0.5	0.5	0	0
FREE SPACE LOSS (dB)	191.0	191.0	189.4	189.4
POLARIZATION LOSS (dB)	0.2	0.2	0.2	0.2
RX PWR REF TO ISOTROPIC (dBm)	-95.0	-95.0	-134.4	-135.3
RX ANTENNA GAIN (dB)	12.9	11.0	-	-
RX ANTENNA LINE LOSS (dB)	1.5	1.8	-	-
RX PWR AT RECEIVER (dBm)	-83.6	-85.8	-	-
ANTENNA TEMPERATURE (K)	50.2	50.2	-	-
RECEIVER TEMPERATURE (K)	275.5	438.4	-	-
SYSTEM TEMPERATURE (K)	395.7	570.0	-	-
NOISE PWR AT RECEIVER (dBm/Hz)	-172.5	-171.0	-	-
RX SYSTEM G/T (dB/K)	-14.6	-18.4	-0.3	-0.3
RX C/No (dB-Hz)	89.0	85.2	63.9	63.0

* All spacecraft antenna gains and G/Ts are earth coverage so no pointing losses are taken.

TABLE 11.3-2
Performance of WEFAX Channels with GOES-I Channel Parameters

LINK PERFORMANCE (Worst Case Parameters)	ANALOG AM/FM	ANALOG AM/FM	DIGITAL 19.2 Kbps	DIGITAL 50 Kbps
TURNAROUND C/N_0 (dB-Hz)	63.0	63.0	63.0	63.0
REQ'D FM THRESHOLD (dB) in 30 KHz	10.0	10.0	-	-
RF BANDWIDTH (dB-Hz)	44.8	44.8	-	-
REQUIRED E_b/N_0 for $P_e = 10^{-5}$ (dB) (includes 2 dB implementation loss)	-	-	11.5	11.5
DATA RATE (dB-Hz)	-	-	42.8	47.0
REQUIRED C/N_0 (dB)	54.8	54.8	54.3	58.5
MARGIN (dB)	8.2	8.2	8.7	4.5

not a problem because signal combining is done at RF after application of the signals. Although passive intermodulation products are generated in the RF multiplexer, they are much smaller and easier to eliminate. A minimum separation between carrier frequencies is needed, however, because of the difficulty of building narrow bandpass channel filters at S-band. Also, PA switching increases in complexity with the number of PA, and more commands and telemetry are needed to monitor and control all the PA. Also, the weight and volume of six separate PA will be greater than that of a single PA plus spare. This alternative was selected for Option II because the GOES-I WEFAX PA design could be used directly for each of the channels, minimizing cost and risk.

11.3.5.2 Single Transmitter

Another reason for selecting the separate transmitters approach for Option II was that it was thought that a traveling wave tube amplifier (TWTA) would be needed to obtain the required output power. When work started on the Option III weight and power requirements, however, it was learned that a 50-watt SSPA suitable for the WEFAX application is planned for use in the Advanced TDRSS program. The project concluded that a single transmitter and spare would weight less than the six separate PA and would take up less volume, as well as being less complex from the standpoint of PA switching, telemetry and commanding. The RF multiplexer is also simpler because combining filters would not be necessary for the separate WEFAX carriers.

The single transmitter would be operated in saturated mode for maximum power efficiency, meaning that intermodulation products (sum and differences of the carrier frequencies) would be generated. The carrier frequencies would have to be selected such that no intermodulation products fall within the WEFAX channel bandwidth, which is a simple matter for only four narrow-band signals. Given its many advantages, the project selected a single transmitter approach for the Option III cost study.

11.3.5.3 Weight and Prime Power Estimates

In determining weight for the different configurations, the project used GOES-I WEFAX component values derived from the GOES Mass Properties Report, except for the Option III SSPA, which was based on the weight of a TDRSS 50W S-band SSPA. Prime power calculations were determined using an efficiency of 25 percent for saturated SSPA. For a 12W output per channel, this translates to about 50W of the prime power per WEFAX channel, or about 200W total. Table 11.3-3 summarizes the weight and power requirements for each of the options, with the Option I weight equal to the GOES-I as-built weights. These weight estimates do not include the receive system, which is shared with other links.

If the requirement for the second analog channel were dropped, the Option II weight would drop by about 30 percent (to about 14kg), assuming only one spare SSPA is provided for the three channels. The weight of the single transmitter configuration, however, would probably not change significantly. Prime power requirements should drop by about 25 percent (to 150W) for both alternatives.

11.3.6 Ground Segment Impacts

11.3.6.1 Impacts to the Command and Data Acquisition (CDA)

The addition of three WEFAX channels would require baseband equipment at the CDA for the transmission and reception of the new channels. Additional bandwidth would also be required between SOCC and Wallops to accommodate the data rate of the new channels. Using LAS predicted GOES-I performance specifications, the 125W uplink transmit power allocation for the single GOES-I WEFAX channel will be sufficient for all four GOES-N channels. This is because the receive S-band antenna on the GOES-I spacecraft has a G/T about 10dB better than the specification value of -25dB/K. Note that the uplink receive carrier-to-noise ratio (Rx C/N) in Table 11.3-1 is more than 22dB higher than the downlink Rx C/N. This is considerably more than needed. Reduction of the CDA uplink to 30W per WEFAX channel will reduce intermodulation products among the WEFAX channels in the CDA transmitter.

TABLE 11.3-3
WEFAX Mass and Prime Power

	OPTION I (GOES-I)	OPTION II (Separate PAs)	OPTION III (Single PA)
MASS (Kg)	6	20	12
POWER (Watts)	50	200	200

11.3.6.2 Impacts to WEFAX Receive Stations

WEFAX receive stations will only need to be upgraded if they are to receive the new channels. The upgrades will consist of baseband signal processing equipment to demodulate the new signals and a power divider to provide an output signal for each baseband channel train. Given improvements in low noise amplifier (LNA) and the reduced cost of these devices, it would be beneficial to tighten receive station G/T specifications for the new channels. Improvements in receive station performance could be translated into reduced spacecraft transmit power requirements, which in turn implies less weight for power generation and battery capacity and lower thermal loading on the spacecraft. Since the 50kbps channels margin is lower than that of the other channels, it is important that users of this channel pay close attention to achieving the nominal G/T or better.

11.3.7 Conclusions and Recommendations

A major finding of the survey was that the second analog WEFAX channel may not be needed. NOAA should reexamine this requirement. The requirement for operation through eclipse should also be reconsidered; comments made by NOAA at the final study presentation indicated that eclipse operation may not be a strong requirement. The removal of these requirements would result in a reduction in the size and weight of the power generation and storage subsystems on the spacecraft.

As noted earlier, HAC selected a separate transmitter per channel approach and LAS a single transmitter approach. Both approaches have their merits, although it appears that the single transmitter approach is better for four channels. If the second analog channel is dropped, the difference between the two alternatives would be less. The project recommendation is that it should be left to the spacecraft manufacturer to decide which approach to implement. Also recommended is tightening the S-band receive antenna G/T specification from the GOES-I value of -25dB/K to the GOES-I predicted value of about -15dB/K. This value appears to be easily met with today's current technology.

11.4 Data Collection System

11.4.1 Survey Requirements

The study requirements were to define options for locating interferers in the DCS response channel bandwidth, and to study options for increasing system channel capacity and accommodating higher data rate DCS platforms (DCPs).

11.4.2 Technical Approach

The study initial approach was to review DCS documentation and interview NOAA personnel. The purpose of the interviews was to determine the extent of interference problems within the DCS and to learn about planned changes to the DCS. Concepts for locating interference sources and analyzed plans for providing higher DCP data rates were examined. Based on survey findings, changes required to the spacecraft and the ground system and the spacecraft option in which these changes would be implemented were determined.

11.4.3 Background

The DCS consists of about 8,000 DCPs that relay data to their user organizations through the CDA facility at Wallops Island, Virginia. The DCPs share a 400kHz band consisting of 200 1.5kHz channels, of which about 80 channels are active. Originally, DCPs were polled by the CDA using the DCP Interrogation (DCPI) channel. Later DCPs were designed to transmit their data messages on a preset schedule, eliminating the need to receive the DCPI signal. Currently, only a small number of DCPs are interrogated, and the DPCI channel is used primarily for distributing timing information. The DCPI signal is uplinked to the GOES spacecraft at S-band and downlinked to the DCPs at UHF.

The DCPs uplink their messages to the spacecraft at UHF. In turn, the spacecraft downlinks these signals at S-band. This channel is referred to as the DCPR channel. After demodulation and processing at the CDA, the DCP response messages are made available to users via dial-up services and are also distributed via a DOMSAT for direct reception at user facilities.

11.4.4 Summary of Survey Results

During the survey, C. Staton (NOAA/NESDIS) and C. Settles at the CDA facility, Wallops Island, Virginia were interviewed. Impressions derived from the discussions were that interference is not a major problem and that when there is interference, the cause is usually a malfunctioning DCP transmitting either outside its normal channel or transmitting continuously rather than on its assigned schedule. Concepts for locating or identifying interferers were discussed, but the impression was that DCS users are not interested in interference prevention if the proposed technique involves platform modifications that represent a cost to them.

With regard to higher DCP data rates, provisions have been made in the GOES-I data ingest equipment at the CDA to accept 300bps and 1200bps DCP transmissions. The users, however, are responsible for selecting a modulation scheme for higher rate transmissions and providing demodulators to NOAA to receive these higher rate channels. At present there appear to be no major changes envisioned for the DCS in the GOES-N time-frame, except for the allowance of two contiguous 1.5kHz channels for the 1200kbps users and perhaps an increase of 3dB in downlink EIRP.

In the latter stages of the study, it was learned that the performance of the DCS suffers from degradation due to adjacent channel interference and intermodulation distortion. Attention should be given to these problems to determine what performance improvements can be incorporated into the GOES-N design.

11.4.5 Concepts for Locating/Identifying Interferers

Locating DCS interferers from geosynchronous orbit would be a difficult undertaking, requiring an interferometer approach similar to that which has been proposed for the S&R system. Given what appears to be a low priority placed on locating interferers and the large effort that would be required to implement a location scheme, it was decided not to pursue interference location.

If it is true that most interference is caused by malfunctioning DCPs either transmitting in an adjacent channel due to oscillator drift or transmitting continuously, the capability to identify the malfunctioning DCP appears to a feature built into the monitoring capabilities of the GOES-I DAPS. DCS demodulators at the CDA will append signal strength, frequency (relative to channel center), modulation index, and data quality measurements to the DCP messages sent to the DAPS. Besides making the DCP messages available for retrieval/transmission to users, the DAPS will also generate reports based on the measurements appended by the demodulators that should help to identify malfunctioning DCPs.

More sophistication could be built into the DCS by using the DCPI channel as a service channel to command platforms off if they are malfunctioning or to switch them to a secondary channel if their primary channel is experiencing interference problems. Telemetry data could also be appended to the DCP response messages for use in monitoring DCP operation. Implementation of these ideas, however, would require significant modification of the DCPs to receive the DCPI signal, which is costly, considering the number of platforms in use.

11.4.6 Higher Data Collection Platform (DCP) Transmission Rates

As mentioned previously, a 300bps and 1200bps data ingest capability has been built into the GOES-I DAPS with DCS users responsible for providing demodulators for these new high rate channels. To this end, the DCS users group contracted with the Cyberlink Corporation to study the problem and recommend a modulation scheme. Cyberlink Corporation's report, *An Impact Study of Higher Transmission Rates through the GOES Data Collection System*, dated February 1990, was reviewed in detail as part of this study.

In that report, the authors recommended an 8-PSK, trellis-coded modulation scheme for 1200bps transmissions through 3kHz channels. It was agreed that this modulation scheme will provide good performance; however, two problems with Cyberlink's analysis that could change the recommendation were found. One problem is that the adjacent channel interference degradation computed by Cyberlink appears overly pessimistic; the degradation was estimated rather than computed precisely. The other problem is that the authors of that study neglected to take into account that 8-PSK requires a 3 to 4dB greater theoretical E_b/N_o (energy per bit to noise density ratio) than QPSK to achieve the same probability of error performance. However, they were conservative relative to the coding gain they claimed; so that the error reduces to about 1.5dB. The Cyberlink analysis should be reconsidered before making a final decision on a modulation scheme, because a less complex scheme might be adequate. In particular, it is recommended that the effects of adjacent channel interference be measured for the existing DCS to obtain a better estimate of the degradation for use in the analysis.

Another possible approach is that a separate band (perhaps about 60kHz wide, suitable for twenty 3kHz channels) be set aside for 1200bps DCPs, separating them from the 100bps channel system. This band could be accommodated between the WEFAX channel (at 1691MHz) and the CDA telemetry channel (at 1694MHz).

11.4.7 Data Collection Platform Response (DCPR) Link Performance

As was mentioned earlier, DCPR channel performance improvements would be helpful in the areas of intermodulation distortion and adjacent channel interference. Of the two, the adjacent channel interference is the most difficult to overcome without changes to the DCPs. Reduction of adjacent channel interference can be accomplished either by increasing the spacing between active channels (i.e., using fewer of the available channels) or changing the modulation scheme used by the existing DCPs to a more spectrum-efficient technique. The former has the effect of reducing the number of usable channels, unless the 400kHz channel bandwidth can be increased to provide more channels, and also would require that a number of DCPs be modified to operate on different channels and the addition of demodulation at the CDA. Changing the modulation scheme would require modification of all DCP modulators as well as the DCS demodulators at the CDA.

The DCPR channel operates in a linear mode (backed off from saturation) to minimize intermodulation products among the numerous DCP response signals. To reduce intermod levels further, a carrier at saturation appropriately separated from the DCPR signals could be introduced into the channel. One of the effects of this strong signal would be to suppress the weaker DCPR signals by 6dB (i.e., the strong signal robs transmitter power from the weak signals). More important in this case, however, would be the effect on the intermods. Intermods around the saturating carrier (but outside the bandwidth of the DCPR signals) would increase; but intermodulation product among the DCPR signals would drop by about 16db. In other words, the ratio of the level of the weaker signal to intermodulation product level would improve by about 10dB.

One method of implementing this concept would be to combine one of the WEFAX channels (at saturation) with the DCPR band. This would have the benefits of not only reducing intermodulation product levels in the DCPR band but would also eliminate the DCPR transmitter and spare. Given the difference in power level between a WEFAX channel and the DCPR band (54dBm for the former and a total of 33dBm for the latter), the effect of the DCPR channel would be to reduce the EIRP of the WEFAX signal by about 0.3dB. The 6dB suppression of the weaker DCPR channel by the WEFAX signal can be handled by setting the input level of the DCPR channel 15dB below the WEFAX signal, resulting in a 21dB difference at the output of the transmitter. Although perhaps not done to reduce intermod levels, the DCPR transponders in the GOES 1,2, and 3 spacecraft shared the stretched VISSR channel.

11.4.8 Spacecraft and Ground System Impacts

The GOES spacecraft acts as a "bent pipe" for DCP transmissions. That is, the spacecraft receives response messages uplinked from the DCPs at UHF, converts these signals to S-band, and retransmits them to the CDA (the DCPR link). Due to the limited DCS changes foreseen, the principal change from the GOES-I spacecraft configuration is a 3dB increase in DCPR downlink

EIRP, from 150mW to 300mW, to provide increased margin for the higher rate DCP channels. This should require very little modification to the existing GOES-I DCPR design and should be incorporated in all three GOES-N options. Combining the DCPR channel with one of the WEFAX channels to reduce intermodulation products in the DCPR band and eliminate the need for the DCPR transmitter and spare is also suggested. Implementation of this suggestion would require minor changes to the spacecraft's S-band receive system and the WEFAX transponder and is feasible on any of the three GOES-N options.

The principal changes to the DCS system at the CDA would be additional DAPS ingest equipment if the growth of 300 and 1200bps DCPs warrants, and the installation of additional user-provided demodulators if new channels are activated. If the DCPR channel were combined with one of the WEFAX channels, the DCPR receiver at the CDA would no longer be required but the WEFAX receiver would have to modified to handle the DCPR channel.

11.4.9 Conclusions and Recommendations

Most of the findings of the DCS survey apply to GOES I-M rather than to GOES-N. The only recommendation applying to the GOES-N DCS is an increase in the DCPR downlink EIRP from 150mW to 300mW. No changes to either the CDA or the DCPs are envisioned.

It is also recommended that adjacent channel interference and intermodulation distortion be measured for the current system to determine their effects on channel performance and the need for performance improvements to be incorporated into the GOES-N design. The project also recommends combining the DCPR channel with one of the WEFAX channels to reduce intermodulation products in the DCPR band and eliminate the need for the DCPR transmitter and spare. Implementation of this recommendation is feasible on any of the proposed GOES-N spacecraft options and would result in improved DCPR channel performance and a slight savings in prime power, weight, spacecraft complexity, and cost. It should be pointed out that only the EIRP increase was included in the RAO cost model inputs.

11.5 Products, Process, and Communications

11.5.1 Survey Requirements

The purpose of this survey was to provide an overall systems view of the spacecraft communications system and the ground system. The survey requirements were:

1. Survey ground system operations:
   - Staffing Levels
   - Skill Levels
2. Determine the impacts on telemetry and command processing of the orbit and attitude control system
3. Determine the impact of new instruments and improved image navigation/registration on instrument downlink data rates and data processing
4. Determine the impact of new products and their timeliness on the GVAR format, processing requirements, and required user ground equipment

5. Determine the impact of new instruments on receiving and processing equipment at the SOCC, Suitland, Maryland
6. Determine the impact of new instruments and additional WEFAX channels on CDA transmit and receive equipment and the telemetry and command system
7. Identify and limit the scope of the survey and recommend additional surveys and studies.

11.5.2 Technical Approach

The survey team interviewed NOAA/NESDIS personnel to discuss the requirements and their views on the current system and future plans. Next, the team obtained an instrument complement for each of the three GOES-N options and the data rates of these instruments. The data rates were used to develop alternative spacecraft and ground system configurations to satisfy the data downlink requirements. Link budgets from the GOES-I predicted performance were used as the basis for determining transmit power level requirements. In turn, these transmit power levels were used to develop weight and prime power requirements for input to the RAO cost model. Requirements of the orbit and attitude control system were then to be factored into the telemetry and command system to determine any required changes. Lastly, the data produced by the new instruments and the timeliness of the data were to be analyzed to determine their impact on the GVAR format, ground processing requirements, and user ground equipment.

11.5.3 Summary of Survey Results

NOAA personnel interviewed during the survey included: G. Davis, K. Kelley, W. Mazur, and C. Settles. As was the case with other areas of the study, this survey suffered from the delay of the GOES-I launch, since experience with GOES-I operations were to be the take-off point for determining improvements to overcome deficiencies encountered. This was particularly the case for analysis of ground system operations and ground processing of new products. Concern was expressed about operation of the new GOES-I ground system since GOES-I represents a radical change from the current series of spin-stabilized spacecraft. The GOES-I ground system is much more automated, which requires a higher level of computer literacy among operations personnel. Control of a three-axis stabilized spacecraft will also be more demanding of controllers than the current spacecraft. The need for expert system techniques to simplify troubleshooting and the development of diagnostic tools to simplify orbital verification was brought up. Another concern expressed was the unreliability of the terrestrial communication facilities between SOCC and the CDA due to anomalous propagation conditions during certain seasons of the year. The inclusion of voice channels on GOES-N or the leasing of DOMSAT channels was suggested.

Another factor that limited the survey was that because of the parallel nature of the GOES-N studies, results were not available for inclusion in our study. In addition, several studies that would have provided inputs to the survey (e.g., ground resampling of imager data were not funded).

11.5.4 Spacecraft Configurations

Instrument complements and data rates were used to develop configurations for each of the three spacecraft options. Cost model inputs were developed sequentially, starting with Option I, which consists of a GOES-I platform carrying improved GOES I-M instruments. Options II and III employ a more capable platform which allowed for new instruments and greater data rates. The communication subsystem configurations used in developing inputs for the cost model again closely paralleled the GOES I-M. After completing the cost model inputs, the project began looking for ways to simplify and improve the communication subsystem. These new alternatives are described as modifications to the three options.

11.5.4.1 Option I

Table 11.5-1 lists instrument data rates used in developing weight and prime power inputs for the RAO cost model for all three spacecraft options. The Option I data rates are the same as for the GOES-M spacecraft except for the addition of the LPS (assuming that the SXI is flown on GOES-M). Since the data from this sensor and the SXI are only required by the ERL in Boulder, Colorado, a separate carrier is provided. We called this carrier the MDL, the same as the downlink provided on the GOES-I spacecraft to transmit attitude data to the CDA and the SOCC[2] and on GOES-M to transmit SXI data. The GOES-I MDL QPSK modulator could be used directly since it was designed to handle 200kbps. The SXI data would be transmitted via one channel and the LPS via the quadrature channel. Contrary to the MDL implementation on GOES-I, a redundant transmitter would be provided on the spacecraft. A port would also be provided on the S-band output multiplexer for the MDL output signal, reducing transmission line losses about 2.6dB compared to the GOES-I implementation. In GOES-I the output of the MDL transmitter was combined with the output of the S-band multiplexer through a circulator resulting in the additional line loss. The performance of the MDL link to ERL and the CDA is shown in Table 11.5-2. Imager and sounder SDL and processed data (GVAR) relay link performance, which is the same as in GOES-I, is also shown in Table 11.5-2. UAQPSK modulation, in which the I and Q channels have unequal data rates is used for both the MDL and SDL so that the data outputs of instruments can be fed directly into the modulator input ports. The only other change to the GOES-I communication links is a 3dB increase in the EIRP of the DCPR downlink from 150 to 300mW. The S&R, WEFAX, and the telemetry and command links remain the same as in GOES-I. No ground system changes are required because of spacecraft changes. Changes may be desirable, however, as deficiencies are found in the GOES I-M ground system.

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[2]The terms SOCC and DUS (the Data Utilization Station at the World Weather Building) are used interchangeably.

TABLE 11.5-1
Instrument Data Rates by Spacecraft Option

INSTRUMENT	DATA RATE (kbps) by OPTION		
	I	II	III
Imager	2600	3200	3200
Sounder	40	8600	8600
Aux Imager	N/A	N/A	1750
Lightning Mapper	N/A	64	64
Improved EPS	0.032	0.032	0.032
Solar X-Ray Imager	100	100	100
Magnetometer	0.096	0.096	0.096
X-Ray Sensor	0.032	0.032	0.032
Local Plasma Sensor	32	32	32
Solar Magnetograph	N/A	N/A	150

11.5.4.2 Option I Modifications

The combining of on-orbit telemetry data in the MDL downlink was examined. This would eliminate the on-board CDA telemetry transmitters and the telemetry receiver at ERL[3]. Removal of the CDA telemetry link, which is at 1694Mhz, would permit increasing the DCPR channel bandwidth if additional channels are desired (e.g., to provide a separate band for 1200 bps channels). The DSN telemetry transmitters would, of course, still be available for transfer orbit and emergency conditions wherein operation via the omnidirectional antenna is required. To implement this alternative, a multiplexer would be required on the spacecraft to combine the SXI, LPS, and telemetry bit streams, as well as a demultiplexer at Boulder, the SOCC, and the CDA. The GOES I-M MDL demodulator should be usable with perhaps no modification.

The T&C system was not analyzed to any extent during the survey period. However, feedback from the GOES-I team indicates the the T&C system has reached the full capacity point; few, if any, spare commands and few spare telemetry points are available for expansion. An expanded command set is recommended for GOES-N. An expanded telemetry system with more available telemetry points, longer minor frame, and an increased telemetry rate is also recommended to provide greater flexibility.

[3]Recall that low rate SEM instrument data is commutated with telemetry data.

TABLE 11.5-2
Option I MDL, SDL, and GVAR Link Performance

PARAMETER	MDL		SDL		GVAR
Modulation	UAQPSK		UAQPSK		BPSK
Transmit Power (watts)	2.0		2.0		11.8
E_b/N_o (dB) for $P_e=10^{-6}$ + 2.2 dB Implementation Loss	13.0		13.0		12.7
Channel	I	Q	I	Q	-
Power Split (dB)	1.2	6.0	1	7.	-
Data Rate (kbps)	100	32	2600	40	2110
Receive C/N_o to BDR (dB)	68.6		-		-
Margin to BDR (dB)	4.4	4.6	-	-	-
Receive C/N_o to CDA (dB)	77.7		79.1		-
Margin to CDA (dB)	13.5	13.6	0.9	13.1	-
Receive C/N_o to DUS (dB)	66.8		-		77.5
Margin to DUS (dB)	2.6	2.8	-	-	1.4

Another possibility is to combine the SDL and the MDL (including the on-orbit telemetry) onto one QPSK carrier. The imager data could be transmitted via the I channel and the sounder plus MDL data via the Q channel. The obvious benefit would be the reduction in spacecraft complexity from the elimination of the MDL transmitters. Another benefit is that the SDL center frequency could be moved to provide a wider guard band between the data downlink and the 1660-1670MHz radio astronomy band. The performance of this combined SDL-MDL link using GOES-I worst case performance parameters is shown in the second column of Table 11.5-3. A 7w transmitter would provide sufficient margin at the CDA, the SOCC, and Boulder. The negative I channel margins at Boulder and SOCC are unimportant because the raw imager data would not be processed at either location. A Q channel demultiplexer would be needed at the CDA, the DUS, and Boulder, and the MDL demodulators at SOCC and Boulder would have to be replaced by GOES-I sensor data demodulators.

Elimination of the processed sensor data relay link, alternately called the GVAR or PDR link, should also be considered. The Option I GVAR data rate is nearly the same as the SDL data rate. Elimination of this link would require that the SOCC receive the raw imager and sounder data directly and that the DUS at the World Weather Building perform the GVAR processing. The problem is that there many organizations that receive the GVAR data relay link directly would be affected by this change. The question, then, is whether these users could be phased over to AWIPS, which should be operational in the GOES-N time-frame. AWIPS will distribute remapped weather products derived from GOES instruments (as well as other data) that users would otherwise generate using GVAR data via the NOAA Port channel. GVAR data could still be made available to users on a non-real-time basis via magnetic tape or perhaps even real-time via AWIPS as a separate service provided by the satellite services contractor. Alternatively, GVAR users could receive the raw data and perform the GVAR processing themselves.

TABLE 11.5-3
Performance of Option I Consolidated SDL-MDL Links

PARAMETER	SDL-MDL Separate GVAR		SDL-MDL No GVAR	
Modulation	UAQPSK		UAQPSK	
Transmit Power (w)	7		25	
E_b/N_o (dB) for $P_e=10^{-6}$ + 2.2 dB Implementation Loss	13.0		13.0	
Channel	I	Q	I	Q
Power Split (dB)	1	7	1	7
Data Rate (kbps)	2600	192	2600	192
Receive C/N_o - CDA (dB)	86.2		-	
Margin to CDA (dB)	8.0	13.3	-	-
Receive C/N_o - BDR (dB)	75.6		82.6	
Margin to BDR (dB)	-1.0	5.5	4.5	9.8
Receive C/N_o - DUS (dB)	75.3		80.8	
Margin to DUS (dB)	-2.8	2.5	2.7	8.0

Elimination of the GVAR link would require that a new ranging technique be implemented because a ranging signal is imbedded in the GOES I-M GVAR signal. A ranging signal could probably be added in the WEFAX channel. As shown in the third column of Table 11.5-3, a 25 watt transmitter on the spacecraft would provide a margin of 2.7dB on the SDL I channel to the SOCC/DUS and 8.0dB on the Q channel.

Elimination of the GVAR link would reduce the weight and power requirements of the communication subsystem, reduce spacecraft complexity, and reduce spectrum usage on both the uplink and downlink bands. In addition, the GVAR transmitters at the CDA and the GVAR receivers at SOCC would no longer be needed. The spacecraft weight reductions from eliminating the GVAR, CDA telemetry, and MDL transmitters might provide sufficient margin to allow inclusion of the three additional WEFAX channels in Option I.

Neither weight nor prime power estimates have been developed for these alternatives. Since the cost of the communication subsystem is only a small fraction of the total spacecraft weight and cost, any of the changes discussed would have minimal impact on the overall spacecraft weight and cost numbers. Their benefit would derive from reducing the complexity of the communication subsystem and improving spectrum efficiency. In the project's, opinion, these alternatives pose low technical and schedule risks. Another factor to consider is that if there is a move from S-band to X-band (as was pointed out at the fourth quarterly review), a similar consolidation of the various GOES carriers might be required.

11.5.4.3 Option II

In keeping with the GOES I-M communication system architecture, Table 11.5-4 shows the instruments and data rates assigned to the Option II MDL, SDL, and GVAR links. Option II includes a lightning mapper, an improved imager (1 km resolution) and sounder, the additional three WEFAX channels, the DCS Report channel downlink with increased transmit power (3 dB), and the GOES-i S&R subsystem (i.e., with no position determination capability). Also allocated was 100kbps for the downlinking of attitude control system data, a conservative estimate that can be refined when control system requirements are better defined.

On the assumption that the SOCC will have an MDL demodulator and receive the MDL, the lightning mapper and attitude control system data were included on the MDL. This was thought to be more efficient than the alternative of multiplexing these data on the SDL and relaying them to SOCC via the GVAR link. The project also included the on-orbit telemetry data on the MDL, eliminating the CDA telemetry transmitters on the spacecraft. Not included in the analysis, because the requirement was not discovered until late in the study, was the need for two-station ranging to provide the orbit determination accuracy required by the proposed control system.

The frequency band allocated for these links is 20MHz between the top of the radio astronomy band at 1670MHz and WEFAX at 1691MHz. The sum of the MDL, SDL, and PDR data rates shown in Table 11-5.4 is about 16.5Mbps, largely driven by the large sounder data rate. To operate in the allocated 20MHz band, a combination of higher rate/more spectrum-efficient modulation techniques and imager and sounder data compression need to be considered. The performance of the MDL, SDL, and GVAR links with QPSK modulation and using GOES-I worst case performance parameters is given in Table 11.5-5. In all three cases, suitable solid state power amplifiers are available at S-band.

TABLE 11.5-4
Option II Instrument Link Assignments and Data Rates

INSTRUMENT	LINK DATA RATES (kbps)		
	MDL	SDL	GVAR
Telemetry + Low Rate SEM Instruments	2		
Solar X-Ray Imager	100		
Local Plasma Sensor	32		
Lightning Mapper	64		
Attitude Data	100		
Imager		3200	2300
Sounder		8600	1430
TOTAL	298	11800	4230

TABLE 11.5-5
Option II MDL, SDL, and GVAR Performance

PARAMETER	MDL		SDL		GVAR	
Modulation	QPSK		QPSK		UAQPSK	
Transmit Power (watts)	3		5		40	
E_b/N_o (dB) for P_e=10^{-6} + 2.2 dB Implementation Loss	13.0		13.0		13.0	
Channel	I	Q	I	Q	I	Q
Power Split (dB)	3	3	3	3	1.9	4.6
Data Rate (kbps)*	164	164	4500	4500	2800	1430
Receive C/N_o - BDR (dB)	73.4		-		--	
Margin to BDR (dB)	5.3	5.3	-	-	-	-
Receive C/N_o - CDA (dB)	82.5		84.7		-	
Margin to CDA (dB)	16.5	16.5	2.1	2.1	-	-
Receive C/N_o - DUS (dB)	71.6		-		82.8	
Margin to DUS (dB)	3.5	3.5	-	-	2.9	3.1

* Data rate includes 10 percent multiplexer overhead.

An on-board multiplexer would be required for the MDL to combine the outputs from the five data sources. Because of the sounder's high data rate, balanced QPSK (or 8-PSK) modulation must be used because of bandwidth limitations. A multiplexer is required to combine the imager and sounder data streams so that the I and Q channel data rates can be balanced. Ten percent multiplexer overhead is included in the MDL and SDL data rates, and the SDL data rate includes 1.67 to 1 data compression and Reed-Solomon forward error correction. The coding is added to improve the probability of error from 10^{-6} to about 10^{-8} because errors will have a greater degrading effect on a compressed bit stream than on an uncompressed bit stream. Enough bandwidth is available that UAQPSK can be used for the GVAR link. The resulting bandwidth requirement is about 15MHz, exclusive of guard bands between channels.

11.5.4.4 Option II Modifications

Consolidation of the MDL and SDL was recommended for Option I. Its feasibility hinged on the relatively low Option I instrument data rates. However, because of the much higher data rate of the Option II sounder, consolidation of the SDL and MDL is not viable unless combined with removal of the GVAR link. UAQPSK, which permits ERL to process only the low rate Q channel, cannot be used if there is a GVAR link because of bandwidth limitations. Balanced QPSK would require about 50 watts of transmit power to ERL plus would require the receive system at ERL to demodulate the high data rate signal and then demultiplex the data stream to obtain the SEM instrument data. Although feasible, this approach does not seem worthwhile.

Table 11.5-6 shows the transmit power required for direct downlink to SOCC and ERL of raw imager and sounder data (with compression and coding) on the I channel and MDL data on the Q channel. About 75W of transmit power would be required to provide margins of 2.1dB for the I channel and 10.4dB for the Q channel to SOCC. Two multiplexers would be required on board the spacecraft (one for the I channel and one for the Q channel), two demultiplexers would be required at the DUS, and only one demultiplexer would be required at ERL (assuming there is no interest in the I channel data).

The required transmit power for this consolidated link is about 75W versus a total of 48 watts for separate MDL, SDL, and GVAR links. However, only two power amplifiers (perhaps three if double redundancy is desired) would be required rather than six. In addition, the GVAR transmit equipment at the CDA would no longer be needed.

11.5.4.5 Option III

The added Option III instruments are the SVM and the Auxiliary Imager. The Option III imager and sounder generate the same data rates as their Option II counterparts. Table 11.5-7 shows the Option III instruments, their data rates, and their link assignments. A ½ km resolution imager with a raw data rate of 9.8 Mbps was also considered for Option III. However, it was decided to leave this imager for an additional option (IIIA) to be studied later.

TABLE 11.5-6
Option II Consolidated MDL and SDL Link

PARAMETER		
Modulation	UAQPSK	
Transmit Power (w)	75	
E_b/N_o (dB) for $P_e=10^{-6}$ + 2.2 dB Implementation Loss	13.0	
Channel	I	Q
Power Split (dB)	1	7
Data Rate (kbps)*	8900	328
Receive C/N_o - BDR (dB)	87.4	
Margin to BDR (dB)	3.9	12.2
Receive C/N_o - DUS (dB)	85.6	
Margin to DUS (dB)	2.1	10.4

* Data rate includes 10 percent multiplexer overhead.

TABLE 11.5-7
Option III Instrument Link Assignments and Data Rates

INSTRUMENT	LINK DATA RATES (kbps)		
	MDL	SDL	GVAR
Telemetry + Low Rate SEM Instruments	2		
Solar X-Ray Imager	100		
Local Plasma Sensor	32		
Lightning Mapper		64	64
Attitude Data		100	100
Solar Magnetograph	150		
Auxiliary Imager		1750	1500
Imager		3200	2800
Sounder		8600	1430
TOTAL	284	13714	5894

Excluding multiplexer overhead, the total data rate of these three links is about 19.8Mbps. Thus, compression of the imager, Auxiliary Imager, and sounder data and use of 8-PSK modulation will be required to operate within the allocated 20MHz band. With 1.67 to 1 data compression, Reed-Solomon coding, and a 10 percent multiplexer overhead, the SDL data rate reduces from 13.7Mbps to about 11.5Mbps. Use of 8-PSK modulation on the SDL results in a bandwidth requirement of about 7.6MHz compared to 11.5MHz for balanced QPSK modulation. With balanced QPSK modulation on the MDL and GVAR links, the total bandwidth requirement is about 14.5MHz, or about the same as for Option II. The penalty for using 8-PSK is that the E_b/N_o required for a 10^{-6} bit error rate probability is about 3.5dB higher than it is for QPSK. Table 11.5-8 shows the performance of the MDL, SDL, and GVAR links using worst case GOES-I performance parameters.

As for the other communication subsystems, the three additional WEFAX channels are included in Option III, the S&R subsystem remains the same as in GOES-I, and the DCS is the same as in GOES-I with an increase in downlink EIRP of 150 milliwatts (3dB) for the DCP Report channel.

TABLE 11.5-8
Option III MDL, SDL, and GVAR Performance

PARAMETER	MDL		SDL	GVAR	
Modulation	QPSK		8-PSK	QPSK	
Transmit Power (w)	2		20	40	
E_b/N_o (dB) for $P_e=10^{-6}$ + 2.2 dB Implementation Loss	13.0		16.5	13.0	
Channel	I	Q	-	I	Q
Power Split (dB)	3	3	-	3	3
Data Rate (kbps)*	146	146	11385	3250	3250
Receive C/N_o - BDR (dB)	69.8		-	-	
Margin to BDR (dB)	2.2	2.2	-	-	-
Receive C/N_o - CDA (dB)	-		90.7	-	
Margin to CDA (dB)	-	-	3.6	-	-
Receive C/N_o - DUS (dB)	-		-	83.8	
Margin to DUS (dB)	-	-	-	2.0	2.0

* Data rate includes 10 percent multiplexer overhead.

11.5.4.6 Option III Modifications

The recommended Option III communications subsystem configuration is the same as that discussed under Option II, (i.e., consolidate the SDL and MDL links and eliminate the GVAR link.) Table 11.5-9 shows the performance of the consolidated link in which the imager and sounder are multiplexed on the I channel and the SEM instruments, telemetry, and the lightning mapper and auxiliary imager are multiplexed on the Q channel. The required transmit power is about 75W, compared to about 63W for the case of separate MDL, SDL, and GVAR links. However, only two power amplifiers (perhaps three if double redundancy is desired) would be required rather than six (two per link). In addition, the GVAR transmitters at the CDA would no longer be needed. Two multiplexers would be required on-board the spacecraft, two demultiplexers at the DUS, and one demultiplexer at ERL (assuming there is no interest in the I channel data).

11.5.5 Conclusions and Recommendations

There are two basic approaches to satisfying the communication subsystem requirements for the GOES-N spacecraft. One is to follow the GOES I-M architecture of providing separate downlinks for the SEM instruments (MDL), the imager and sounder (SDL), the on-orbit telemetry, the GVAR uplink and downlink, and the WEFAX, the DCS, and the S&R subsystems

TABLE 11.5-9
Option III Consolidated MDL and SDL Link

PARAMETER		
Modulation	UAQPSK	
Transmit Power (w)	75	
E_b/N_o (dB) for $P_e=10^{-6}$ + 2.2 dB Implementation Loss	13.0	
Channel	I	Q
Power Split (dB)	1.1	6.6
Data Rate (kbps)*	9000	2500
Receive C/N_o - BDR (dB)	87.4	
Margin to BDR (dB)	3.8	3.8
Receive C/N_o - DUS (dB)	85.6	
Margin to DUS (dB)	2.0	2.0

* Data rate includes 10 percent multiplexer overhead.

The other approach is to consolidate some of these links to reduce the number of transmitters required on board the spacecraft. Such simplification would reduce weight, spacecraft manufacturing and testing time, and schedule risks.

As detailed in the survey reports, the incorporation of a position location capability is not recommended for either the S&R or the DCS. The three additional WEFAX channels could be provided via a single transmitter or separate transmitters for each channel. A single transmitter seems preferable from both a weight and spacecraft complexity standpoint, but the selection should probably be left as an option for the spacecraft manufacturer. Additional downlink EIRP should be provided on the DCP Report downlink to provide additional margin for 1200bps platforms, the recommendation is to increase the transmit power to 300mw. It would also appear advantageous to combine the DCP Report channel with a saturating WEFAX carrier in one transmitter, with the carriers appropriately spaced, to reduce the effect of intermodulation products within the DCP Report channel bandwidth as well as eliminating the DCPR transmitters on-board the spacecraft. This recommendation applies whether a single or separate transmitters are used for the four WEFAX channels. Another possibility that warrants further study is to provide a separate frequency band for 3kHz channels for the 1200bps DCPs.

If possible the GVAR link should be eliminated, with raw imager and sounder data received directly at the SOCC. GVAR processing would then be performed at the DUS. Current GVAR users could either transition to remapped products distributed via AWIPS, they could receive the raw data and process it themselves, or arrangements could be made to distribute GVAR data via the AWIPS or non-real-time via magnetic tape. On-orbit telemetry could be combined with SEM instrument data on the MDL, eliminating the two CDA telemetry transmitters. The imager and sounder data link could be combined with the MDL to produce one downlink carrier. This is recommended for Option I. This is also recommended for Options II and III if the GVAR link can be eliminated.

11.5.6 Recommendations for Additional Studies

As the survey progressed, it became apparent that some of the survey requirements could not be completed. In particular, analysis of the ground system and operations was severely hampered by the fact that the GOES I-M spacecraft have not been launched. One of the purposes of the survey was to determine deficiencies in the GOES I-M ground system and propose solutions for incorporation in GOES-N. In addition, the state of knowledge of the new imager and sounder was such that a study of ground processing requirements for these instruments was not possible during this portion of the study effort. For the same reason, new telemetry and command subsystem requirements could not be generated.

The ACS being proposed for Options II and III requires a two-station ranging capability to provide sufficient orbit determination accuracy. This requirement was not stated until the end of the study effort and, as a result, was not studied. A study is needed to develop alternative ranging system configurations and their cost.

It was commented at the Fourth Quarterly Review that the GOES program may have to move from its present S-band allocation to X-band (7 to 10GHz), as the TIROS program appears to be doing. If serious consideration is being given to such a move, it is critical that the implications be analyzed.