ORDER FOR SUPPLIES OR SERVICES

IMPORTANT: Mark all packages and papers with contract and/or order numbers.

PAGE 1 OF 7 PAGES

Field	Entry
1. DATE OF ORDER	2/5/98
2. CONTRACT NO. (If any)	NAS5-97251
3. ORDER NO.	003
4. REQUISITION/REFERENCE NO.	
5. ISSUING OFFICE (Address correspondence to)	NASA Goddard Space Flight Ctr., Code 210
6. SHIP TO: a. NAME OF CONSIGNEE	n/a
b. STREET ADDRESS	
c. CITY	
d. STATE	
e. ZIP CODE	
f. SHIP VIA	

7. TO:

Field	Entry
a. NAME OF CONTRACTOR	Ball Aerospace and Technologies Corp.
b. COMPANY NAME	
c. STREET ADDRESS	1600 Commerce Street
d. CITY	Boulder
e. STATE	
f. ZIP CODE	80306-1062

8. TYPE OF ORDER

☐ a. PURCHASE
REF YOUR: ____
Please furnish the following on the terms and conditions specified on both sides of this order and on the attached sheet, if any, including delivery as indicated.

X b. DELIVERY – Except for billing instructions on the reverse, this delivery order is subject to instructions contained on this side only of this form and is issued subject to the terms and conditions of the above-numbered contract.

9. ACCOUNTING AND APPROPRIATION DATA: See Continuation Pages

10. REQUISITIONING OFFICE: LAM Project Office

11. BUSINESS CLASSIFICATION (Check appropriate box(es))
☐ a. SMALL X b. OTHER THAN SMALL ☐ c. DISADVANTAGED ☐ d. WOMEN-OWNED

12. F.O.B. POINT	14. GOVERNMENT B/L NO.	15. DELIVER TO F.O.B. POINT ON OR BEFORE (Date)	16. DISCOUNT TERMS
Destination			

13. PLACE OF

a. INSPECTION	b. ACCEPTANCE
	On-orbit

17. SCHEDULE *(See reverse for Rejections)*

ITEM NO. (a)	SUPPLIES OR SERVICES (b)	QUANTITY ORDERED (c)	UNIT (d)	UNIT PRICE (e)	AMOUNT (f)	QUANTITY ACCEPTED (g)
1	Core System Spacecraft & associated hardware, software & documentation for the ICESAT (LAM) Mission	1	ea		[redacted]	
2	Battery Open Cell Bypass Protection Option	1	ea		[redacted]	
3	Misison Specific Modifications	1	ea		[redacted]	
5	Flight Software & Source Code as required by SOW and the Delivery Order Requirements	1	ea		[redacted]	
6	CDRL Documentation as required by the contract and this delivery order	1	ea		[redacted]	
	Launch Date: July 1, 2001					

SEE BILLING INSTRUCTIONS ON REVERSE

18. SHIPPING POINT	19. GROSS SHIPPING WEIGHT	20. INVOICE NO.

17(h) TOT. *(Cont. pages)*

21. MAIL INVOICE TO:

Field	Entry
a. NAME	NASA Goddard Space Flight Center, Financial Management Division
b. STREET ADDRESS (or P.O. Box)	Accounts Payable Section, Code 151.3A
c. CITY	Greenbelt
d. STATE	MD
e. ZIP CODE	20771

[redacted] 17(i) GRAND TOTAL

22. UNITED STATES OF AMERICA BY (Signature) *Sharon M. Collignon*

23. NAME (Typed) Sharon M. Collignon
TITLE: CONTRACTING/ORDERING OFFICER

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OPTIONAL FORM 347 (REV. 6/95)
Prescribed by GSA/FAR 48 CFR 53.213(e)

Contractor's Agreement

The contractor agrees to furnish and deliver all items or perform all the services set forth or otherwise identified in this delivery order for the consideration stated herein. The rights and obligations of the parties to this delivery order shall be subject to and governed by the following documents:, (a) the basic contract, (b) this delivery order, (c) the solicitation, if any, and (d) such provisions, representations, certifications and specifications, as are attached or incorporated by reference herein.

(The Contractor is required to sign this document and return five originals to the issuing office.)

E. L Vande Noord
Executive Vice President and General Manager
Ball Aerospace Systems Division

Name and Title of Signer (*Type or Print*)

E L Vande Noord 2/5/98

Signature of Person Authorized to Sign Date

1. All terms and conditions of Master Contract NAS5-97251 apply to this delivery order (D.O.) for the ICESAT (LAM) Mission except as noted below:

B.4, PERFORMANCE-BASED EVENTS AND COMPLETION CRITERIA, is revised for this D.O. to incorporate the Performance Based Payment Events as specified in Attachment C to this D.O.

H.2, LIMITATION OF FUNDS (FIXED-PRICE CONTRACT) (18-52.232-77) (MAR 1989), applies to this D.O.

(a) Of the total price of items 1, 2, 3, 5 & 6, the sum [redacted]s presently available for payment and allotted to this contract. It is anticipated that from time to time additional funds will be allocated to the contract in accordance with the following schedule, until the total price of said item is allotted:

SCHEDULE FOR ALLOTMENT OF FUNDS

Date	Amounts
August 1998	[redacted]
FY 1999	[redacted]
FY 2000	[redacted]
FY 2001	[redacted]

(b) The Contractor agrees to perform or have performed work on the items specified in paragraph (a) above up to the point at which, if this contract is terminated pursuant to the Termination for Convenience of the Government clause of this contract, the total amount payable by the Government (including amounts payable for subcontracts and settlement costs) pursuant to paragraphs (f) and (g) if that clause would, in the exercise of reasonable judgment by the Contractor, approximate the total amount at the time allotted to the contract. The Contractor is not obligated to continue performance of the work beyond that point. The Government is not obligated in any event to pay or reimburse the Contractor more than the amount from time to time allotted to the contract, anything to the contrary in the Termination for Convenience of the Government clause notwithstanding.

(c) (1) It is contemplated that funds presently allotted to this contract will cover the work to be performed until August 31, 1998.

(2) If funds allotted are considered by the Contractor to be inadequate to cover the work to be performed until that date, or an agreed date substituted for it, the Contractor shall notify the Contracting Officer in writing when within the next 60 days the work will reach a point at which, if the contract is terminated pursuant to the Termination for Convenience of the Government clause of this contract, the total amount payable by the Government (including amounts payable for subcontracts and settlement costs) pursuant to paragraphs (f) and (g) of that clause will approximate 75 percent of the total amount then allotted to the contract.

(3) (i) The notice shall state the estimated date when the point referred to in subparagraph (2) above will be reached and the estimated amount of additional funds required to continue performance to the date specified in subparagraph (1) above, or an agreed date substituted for it.

(ii) The Contractor shall, 60 days in advance of the date specified in subparagraph (1) above, or an agreed date substituted for it, advise the Contracting Officer in writing as to the estimated amount of additional funds required for the timely performance of the contract for a further period as may be specified in the contract or otherwise agreed to by the parties.

(4) If, after the notification referred to in subdivision (3)(ii) above, additional funds are not allotted by the date specified in subparagraph (1) above, or an agreed date substituted for it, the Contracting Officer shall, upon the Contractor's written request, terminate this contract on that date or on the date set forth in the request, whichever is later, pursuant to the Termination for Convenience of the Government clause.

(d) When additional funds are allotted from time to time for continued performance of the work under this contract, the parties shall agree on the applicable period of contract performance to be covered by these funds. The provisions of paragraphs (b) and (c) above shall apply to these additional allotted funds and substituted date pertaining to them, and the contract shall be modified accordingly.

(e) If, solely by reason of the Government's failure to allot additional funds in amounts sufficient for the timely performance of this contract, the Contractor incurs additional costs or is delayed in the performance of the work under this contract, and if additional funds are allotted, an equitable adjustment shall be made in the price or prices (including appropriate target, billing, and ceiling prices where applicable) of the items to be delivered, or in the time of delivery or both.

(f) The Government may at any time before termination, and, with the consent of the Contractor, after notice of termination, allot additional funds for this contract.

(g) The provisions of this clause with respect to termination shall in no way be deemed to limit the rights of the Government under the Default clause of this contract. The provisions of this Limitation of Funds clause are limited to the work on and allotment of funds for the items set forth in paragraph (a) above. This clause shall become inoperative upon the allotment of funds for the total price of said work except for rights and obligations then existing under this clause.

(h) Nothing in this clause shall affect the right of the Government to terminate this contract pursuant to the Termination for Convenience of the Government clause of this contract.

(End of clause)

I.1, LIST OF SECTION I CLAUSES INCORPORATED BY REFERENCE, is revised to delete from this D.O. (52.230-2) Cost Accounting Standards (Apr 1996) and (52.230-6) Administration of Cost Accounting Standard (Apr 1996).

J.1, LIST OF ATTACHMENTS, Attachment B(a), Performance Specification, is replaced with the attached ICESAT (LAM) Performance Specification (DO Attachment B) for this D.O.

J.1, LIST OF ATTACHMENTS, Attachment B(b), Mission Implementation Specification, is replaced with the attached ICESAT (LAM) Mission Implementation Specification (DO Attachment A) for this D.O.

J.1, LIST OF ATTACHMENTS, Attachment B(c), Interim Performance Based Payment Events & Completion Criteria, is replaced with the attached ICESAT (LAM) Interim Performance Based Payment Events & Completion Criteria (DO Attachment C) for this D.O.

J.1, LIST OF ATTACHMENTS, Attachment D, Contract Data Requirements List (CDRL), is supplmented with the attached CDRL 18 (DO Attachment E).

2. Additional ICESAT (LAM) Requirements that apply to this DO are as follows:

Taurus XL Launch Vehicle Accommodation

In the event the Government exercises the Taurus XL Launch Vehicle Accommodation option, the line item price set forth below represents the price for the Taurus accommodation option. The Government may order the Taurus Accommodation option by issuing a modification to this delivery order prior to September 30, 1998.

The price for the Taurus Launch Vehicle Accommodation option [redacted]

(End of Clause)

LMLV-2 Launch Vehicle Accommodation

In the event the Government exercises the LMLV-2 Launch Vehicle Accommodation option, the line item price set forth below represents the price for the LMLV-2 Accommodation option. The Government may order the LMLV-2 Accommodation option by issuing a modification to this delivery order prior to September 30, 1998.

The price for the LMLV-2 Launch Vehicle Accommodation option is [redacted]

Payment for the LMLV-2 Launch Vehicle Accommodation option, if exercised, shall be payable following mutual agreement between the Contractor and the Government that the Contractor has shown observatory compatibility with the LMLV-2 launch environment, 92 inch fairing, and payload attach fitting.

(End of Clause)

Contracting Office Delegation

The administration of this D.O. is transferred to:

NASA Goddard Space Flight Center
Code 214.3, EOS/ESSP/RSDO Office
Attn: Ms. Linda Kelley
Greenbelt, MD 20771
Phone: 301-286-2094 FAX: 301-286-0383

The above office will administer all changes, funding requirements, and payment requirements and will ensure that the terms and conditions of the delivery order are met by the contractor and the Government.

(End of Clause)

Contracting Officer's Technical Representative Delegation

The Contracting Officer's Technical Representative (COTR) for the purposes of monitoring and coordinating the technical requirements of this delivery order is Mr. William Anselm.

Specific duties and responsibilities of the COTR are those delegated in the Contracting Officer's Technical Representative Delegation Letter (NASA Form 1634) for this delivery order.

(End of Clause)

Delivery Schedule

Item	Description	Number of Months
1	Core System Spacecraft & all associated hardware, software & documentation for the ICESAT (LAM) mission	Launch Date July 1, 2001
2	Battery Open Cell Bypass Protection	As Required
3	Mission Specific Modifications	As Required
5	Flight Software & Source Code as required by SOW and the Delivery Order Requirements	As Required
6	CDRL Documentation	As Required

(End of Clause)

Period of Performance

The period of performance of this delivery order shall be from the effective date of the delivery order through final acceptance.

(End of Clause)

Accounting and Appropriation Data

PCN: 401-52061 (1C) Suffix C
JON: 401-227-63-10-87
APP: 808/90110(98)
OC: 40-2550
BLI: A701
AMT [redacted]
B/NC: 02
PPC: BX

3. The following attachments constitute part of this delivery order:

Attachment	Description
A	ICESAT (LAM) Mission Implementation Specification
B	ICESAT (LAM) Performance Specification
C	ICESAT (LAM) Interim Performance Based Payment Events and Completion Criteria
D	ICESAT (LAM) Payment Schedule
E	ICESAT (LAM) Contract Data Requirements List Supplement

END OF DELIVERY ORDER

ATTACHMENT A
NAS5-97251, Delivery Order #3
ICESAT (LAM)

ICESAT (LAM)
Mission Implementation Specification

Section 2. EOS/ICESat Mission Implementation Specification

1. Scope

This specification provides a concise and comprehensive description of Ball's management approach, tools, techniques, capabilities, and processes for the implementation activities associated with the Ice, Cloud and land Elevation Satellite (ICESat) as listed below:

- Program Management
- System Engineering
- Contamination Control
- Mission Performance Verification
- Core System Integration and Test
- Observatory Integration and Test
- Storage, Transportation, and Handling
- Observatory Launch Site and Operations
- Operational Software Maintenance
- Operations Support and Transition
- Miscellaneous

The Taurus XL and LMLV-2 launch vehicle options are addressed in the EOS/ICESat Performance Specification.

2. Reference Documents

The following documents are referenced in this specification.

Government Documents

1. Rapid Spacecraft Procurement Request for Proposal (RFP 5-02816/001) Rapid Spacecraft Acquisition
2. Rapid Spacecraft Procurement Statement of Work, Section J Attachment A, Sept. 22, 1997.
3. ANSI/ISO/ASQC Q9001 - 1994 (IS09001)
4. Rapid Spacecraft Request for Offer (RFO) #3, Laser Altimetry Mission, dated 11/12/97

Commercial Documents

1. BATC ISO 9000 Compliance Plan, Volume IV of this proposal.

3. Program Management

Ball will provide a dedicated and experienced program manager who will be responsible for successful implementation of the specific mission effort. He will lead the program management effort and provide to the Government reporting and real-time insight into program status, technical, programmatic performance for all activities performed under the delivery order. He will have full responsibility and authority for the management of the following SOW items:

1) CORE SYSTEM — Spacecraft development, implementation, test and delivery for instrument integration (also includes item 3 below)
2) MISSION SPECIFIC MODIFICATIONS — All core system or implementation modifications required to meet unique requirements necessary for a specific mission
3) OBSERVATORY SYSTEM — Instrument integration, environmental test, performance test, launch support and operations support through acceptance
4) STANDARD SERVICES — Program and quality management, documentation, reviews, Government insight and audits, and system engineering
5) NON-STANDARD SERVICES — Both mission specific and non-mission specific analyses and studies as ordered by the contract

The RSA program will be managed using an Integrated Product Team (IPT) approach, departing from many traditional ways to achieve efficiency with an emphasis on "value-added" processes. The approach to decision-making is to delegate this responsibility to the lowest practical level to achieve cost-effectiveness and program efficiency. The IPT managers will be given full responsibility for technical, schedule, and cost performance of their mission element. They will use the management tools described later in this section to ensure their performance meets all schedule and cost constraints. Staffing and facilities support for all SOW areas will be provided as discussed in Section 3.9.

All hardware and software products and services delivered by Ball under this contract will include accurate processing of the date and date-related data, providing compatibility prior to and including the year 2000 and beyond without human intervention. This date and date-related data bidirectional time capability is supported by Ball's recently implemented CostPoint system for all business accounting related data. All systems delivered under this contract will be compatible with the year 2000.

3.1 Mission-Specific Delivery Order Management (Special Studies)

Ball has extensive experience and capabilities with the performance and management of special studies on two recent missions: Radarsat and Multi-Spectral Thermal Imager (MTI) Spacecraft. Special studies will be managed by the program manager and shall be performed "fixed-price" as they were on the above contracts.

The program manager will have access to all the necessary technical and business staff resources to perform necessary mission-specific and non-mission-specific delivery orders. An example of the MTI special studies implementation form is provided in Section 13.

Studies approved by the Government will be performed during the first year of the delivery order. Study topics may include but are not limited to:

- Suggested GLAS Footprint and Mounting
- GPS Multipath Effects
- Coupled Loads
- Observatory POD Factors
- S-Band TDRS Link
- GLAS Data Generation and Interface
- Accomplishing Programmed Track Slew in Pitch and Roll Axes
- Additional Studies:
  - EOSDIS Interface Compatibility
  - GLAS/RS2000 Shared Sensors

3.2 Scheduling and Program Control

The following set of existing tools will support managers in their monitoring and analysis of cost and schedule status. All of the tools have been tailored to satisfy the unique requirements of a cost and schedule constrained program.

3.2.1 Cost/Schedule Performance System

Ball's Earned Value Measurement System (EVMS) provides sound cost and schedule performance data without being an unnecessary burden to the project's technical and management staff. It has evolved and has been enhanced through use on many spacecraft and instrument programs. The system uses MicroFrame Project Manager (MPM), a performance measurement (earned value) software tool to assess program performance. This software maintains the performance measurement baseline and provides total integration of the program organization, schedule, and work breakdown structure (WBS). It reports time-phased budgeted cost of work performed (BCWP), and actual cost of work performed (ACWP) at the work order level. MPM also identifies variances (cost and schedule) at the work order level. It calculates performance indices used to evaluate program trends and make independent estimates at completion, based on performance formulas. It produces the reports used for internal and external reporting. Cost and schedule variances are identified based on the earned value (BCWP), providing an accurate picture of true accomplishment compared to the baseline plan. Since this contract is fixed-price, this system will be primarily for internal use. Schedule status data will be available to the Government. This system will be compliant with date 2000 and beyond.

We will use Microsoft Project for scheduling. It is integrated with MPM for both the baseline and the current status. This tool will generate the detailed internal schedules (both Gantt and network) and the upper-level schedules for internal and external reporting.

Ball will provide bimonthly status progress reports to GSFC. The data in these reports, and any other issues, will be discussed in the weekly teleconference. The progress report will include programmatics, technical status, and subcontract status. The master schedule will indicate current status against the baseline plan with critical path indicated. Our performance measurement system will produce an earned value report at Level 3 of the WBS, which identifies cost and schedule variances as well as the current cost estimate at completion for internal management and reporting. Milestone and schedule status will be provided to the Government.

3.2.2 Scheduling Development System

Project schedules were generated (utilizing the Microsoft Project scheduling tool) at the subsystem level (WBS level 3) during the proposal effort. They were constructed around major project milestone dates, for example, design reviews, and the launch readiness review. These schedules were iterated to identify critical paths, schedule slack and critical planning milestones, and to remove inconsistencies. The proposed baseline master schedule for the mission is provided in Section 3.10. The mission's master schedule will be used to monitor all project activities to ensure the project is progressing according to plan.

3.3 Quality Management

The Quality Manual previously submitted presents the approach for ICESat.

3.4 Documentation Systems

The following CDRLs will be delivered and maintained as specified in Reference 2:

1. Mission Performance Verification Plan**
2. External Interfaces, Models, and Analysis
3. Instrument Interface Control Document
4. Launch Vehicle Documentation
5. Ground System Interface Control Document (GS-ICD)
6. Spacecraft and Observatory Integration and Test (I&T) Plan**
7. As-Built Bus Configured Item List
8. Spacecraft Operations Description Manual
9. Telemetry and Command Requirements Document
10. Flight Operations Support Plan (Draft)**
11. Observatory Launch Site Operations and Test Plans
12. Observatory Launch Site Operations and Test Procedures
13. Missile System Prelaunch Data Package (MSPDP)

14. Transportation and Handling Plan**
15. Engineering Change Proposals (ECP), Deviations, and Waivers
16. Failure Mode and Effects Analysis (FMEA) and Critical Items List
17. Contamination/Cleanliness Control Plan**
18. Mission Requirements Document*

*** (provided with offer)*

**(DID provided in Section 13.3)*

Ball has added one CDRL item to the RFP list entitled Mission Requirements Document which would formally list and track all mission requirements. This would be delivered initially at the System Requirements Review with an update at the Mission Design Review.

The following additional documents will also be provided per Reference 2:

1. Problem Failure Reports
2. System Safety Plan
3. Payload Hazard Report
4. Performance Specification (provided with proposal)
5. Mission Implementation Specification (provided with proposal)
6. On-orbit Performance Report
7. Bus and observatory-reduced finite element models
8. Pointing and alignment budgets
9. Bus and observatory thermal analysis
10. Flight software documentation for maintenance
11. Software Development and Verification Plan

All other documentation formal or informal, necessary to fulfill the delivery order will be made available to the Government upon request.

3.5 Reviews and Audits

Regularly scheduled programmatic and technical reviews provide a disciplined evaluation and control of all activities involved in the performance of any program. Program reviews will not only include those required by the SOW but also various internal reviews held throughout the program in compliance with Ball policy. These internal reviews include monthly program reviews to monitor cost, schedule, and performance status, as well as internal technical reviews to ensure all requirements are considered and implemented. Participants in internal reviews include key program personnel and other Ball managers and engineers selected for their expertise in the particular aspect of the program being reviewed. A Review Management Plan will be generated for each program as required by Ball policy.

Formal/informal Government audits will be supported as ordered through a separate task order.

3.5.1 Peer Reviews

Ball will use working level (peer) reviews to identify and resolve concerns before these issues reach the formal, high-level system reviews discussed in Section 3.5.2. Peer review participants include, but are not limited to, Ball functional departments and senior management, performance assurance, and systems engineering. The Government and its support contractors are invited to attend.

Peer reviews for the program will be conducted for hardware designs, major subsystems, and contamination control. The primary intent of the reviews is to ensure each element meets requirements prior to fabrication or implementation, and to convey information to team members.

[redacted]

3.5.2 Formal Reviews

Ball will support all of the formal reviews as defined in Section 4.3.1.3 of the SOW.

Figure 3-1 provides the planned duration of each planned review.

Planned Reviews	Duration (days)
Bimonthly Reviews	1x20
System Requirements Review	1
GLAS/Spacecraft ICD Sign-off	2
Mission Design Review (MDR)	3
Mission Operations Review (MOR)	2
Instrument Integration Readiness Review (IIRR)	2
GLAS Preship Review	1
Pre-Environmental Review (PER)	2
Flight Operations Review (FOR)	2
Pre-Ship Review (PSR)	3
Launch Readiness Review (LRR)	1
Spacecraft Acceptance	1
Total	40

***Figure 3-1.** Planned Duration of Each Review*

The proposed baseline schedule for these reviews is as shown in Section 3.10.

3.5.3 Audits

Though no audits are planned, Ball will support any issued through a separate task order.

3.6 Government Insight

All contractor and subcontractor internal data, reviews, audits, meetings and other activities pertinent to the execution of a delivery order shall be open to the Government and/or its support contractors. Timely notification will be provided to facilitate Government attendance. Ball will also support a program status teleconference on either a weekly or biweekly basis. Ball will provide office, telephone and data fax facilities for one on-site Government representative.

3.7 Contract/Subcontract Management

3.7.1 Contract Management

BASD's contracts department is led by T.H. Lapotosky, director, Contracts & Government Compliance. Mr. Lapotosky reports to R.G. Bemis, vice president, Business Management. [redacted]

Ball assigns a contract manager who will work with the program team from the marketing/business development phase and on through the proposal, fact finding, and negotiations process, so that when the contract is executed and administered, there is historical continuity and coherence. The independence is maintained yet the contract manager knows the customer and members of the IPT, understands the technology and programmatic objectives, and works closely with the team to ensure that the terms of the contract are met within the cost and schedule parameters.

3.7.2 Subcontract Management

The Quality Assurance program for BASD-procured articles ensures that all applicable contract, design, reliability, quality, and specification requirements are incorporated into the completed articles. These requirements are transmitted to suppliers and subcontractors by drawings, procurement specifications, purchase orders, and SOWS.

3.7.2.1 Selection of Procurement Sources

BASD's selection of procurement sources is based on an extensive evaluation program that allows selection of those suppliers who have demonstrated ability to furnish high quality material, or who have successfully demonstrated, by a quality survey, capability of supplying materials that meet all the applicable requirements. These evaluations are conducted by QA personnel who have the experience, training, and ability to evaluate quality systems. The "best value supplier" will be chosen. This determination will be made on the basis of cost, schedule, quality, and past history.

BASD maintains a supplier rating system, and evaluations of supplier performance data are made on a quarterly basis. A QA-approved supplier's list is provided to the procurement organization and appropriate QA personnel. Quality Assurance Directive (QAD 150) provides a list of qualified suppliers for 16 categories of outside manufacturing, processing, and inspection/testing. Subcontractors and vendors shall be approved by the quality engineer prior to placing purchase orders with them.

Training and/or technical assistance may be provided by BASD to ensure required quality if a supplier is otherwise acceptable.

When commercial or off-the-shelf items less than an agreed upon dollar value are procured, a survey will not be required. However, a tabulation of incoming results serves as a history for the supplier and is used as a basis for future RS2000 business with that supplier.

3.7.2.2 Procurement

The procurement team consists of the purchasing officer, Product Assurance Manager (PAM), and responsible engineer. This group evaluates and consults on the supplier's acceptability and is responsible for management of the subcontract and subsequent testing and delivery of the hardware. Generally, contract award audits of the subcontractor will be done.

The subcontractor's system, including quality, management, and production will be used wherever possible. Ball-directed procedural changes and modifications to the subcontractor system will be minimized to the extent necessary to receive acceptable material. Copies of the subcontractor's PA plans are maintained at the subcontractor's facilities.

Vendor nonconformance control by Ball will begin at the start of end item test at the vendors. The supplier's quality organization shall be expected to handle other nonconformances per their written plan. Any end-item test failure requires notification of the PAM or subcontracts manager within 24 hours of occurrence. Notification can be by phone if previously agreed upon. Specification or contract nonconformances require BASD-approved waivers/deviations. The BASD PAM and the responsible engineer or systems engineer (if appropriate) shall have approval authority for waivers/deviations.

End-item acceptance testing shall be accomplished to BASD's approved test procedure(s). The BASD Quality department imposes the right to witness final acceptance tests.

Audits will be performed at the subcontractor's facility at least once during performance of the contract. These audits shall be conducted in a formal manner and will assess conformance to the supplier's written plans and examine hardware quality. The customer, with advance notification and agreement, may accompany BASD on these visits.

The PAM ensures that applicable quality requirements are imposed on suppliers and that hardware routing and inspection criteria coding are properly identified on procurement documents.

3.8 Risk Management

Cost, schedule, and technical risk management and mitigation is a responsibility shared by all members of the mission team. There are three types of risk — risk of performance degradation or failure (technical risk), risk of missing schedule, and risk of cost growth. Performance risks are dealt with through design actions and schedule and cost risks are addressed by programmatic actions. Section 1.1.4 of Volume 1 lists specific risk areas identified to date for a generic mission and our approach to mitigating each one.

Figure 3-2 illustrates the disciplined, structured risk management process the Ball team will use to identify risk areas, assess their impact, develop mitigation methods, and, ultimately, direct personnel and cost resources to minimize the impact of each risk area. Risk management is a dynamic process. We quantitatively combine the effects of risk impact (cost, schedule, and performance) and probability of occurrence to determine risk priorities. [redacted] The results of our on-going risk analysis process will be reported on a bimonthly basis as part of the project's status review.

[redacted]

3.9 Resource Management (Staffing, Facilities, etc.)

3.9.1 Staffing

Ball is a program-focused organization. Line management, shown in **Figure 3-3**, is responsible for providing the program team with the people and resources necessary to efficiently execute the program. The ICESat program manager, Zubin Emsley, reports directly to Dick Novaria, Director of Civil Space Systems programs, who is responsible for ensuring the program receives proper support from the line organizations.

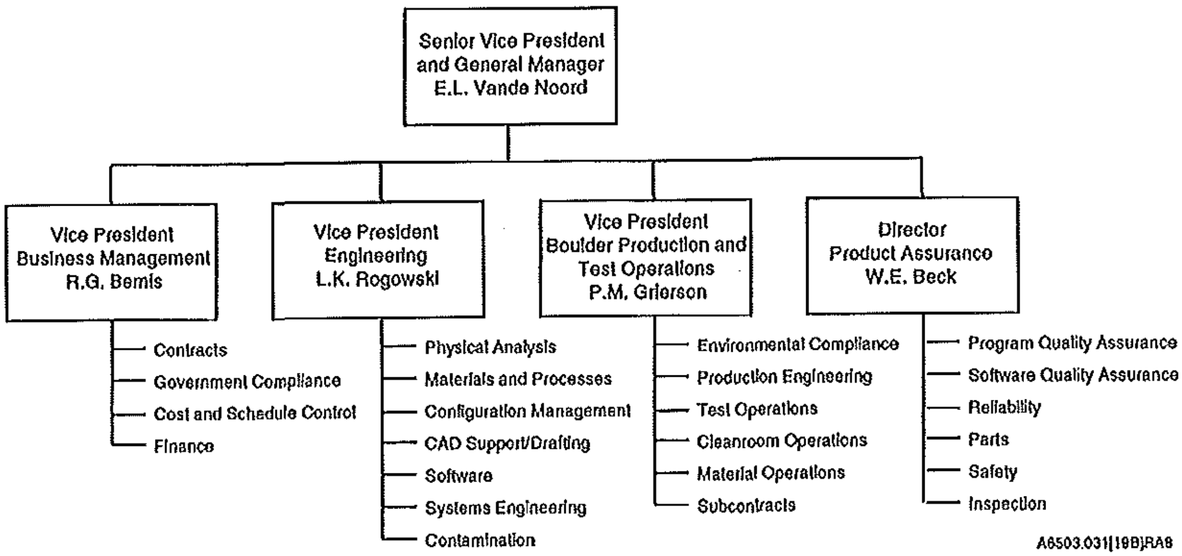

Figure 3-3. Ball's line organizations will provide all needed support to the RSA program

3.9.2 Facilities

Ball owns extensive manufacturing, integration, and test facilities to provide space hardware. The facilities required for each program are scheduled immediately following the program's award. Ownership and scheduling control of facilities ensures we are able to maintain schedule and provides the program with flexibility. Section 1.2.2 of the Performance Specification has a facilities/capabilities summary.

At the beginning of each project, production and test facility needs are identified using the Resource Scheduling System (RSS) for the duration of the project. This includes machine shop and support shop (metal finish, cleaning lab, etc.) hours, as well as, system test facilities (vibration, thermal, EMI/EMC, etc.) needs. The RSS is then used to identify near-term facility usage conflicts and to forecast long-term facility growth to meet the needs of all programs. Facility schedules are monitored daily by the facility resource managers, weekly by the projects, and on a monthly basis, long-term forecast are reviewed by senior managers. This system provides an effective planning tool that allows Ball to take full advantage of our assets while maximizing the return to our customers.

3.10 Implementation Schedule

A baseline ICESat implementation schedule is presented in **Figure 3-4** [provided below in its revised form] based on BATC mission experience tailored for a 3½-year program. All program reviews are shown as well as the key program phases. Key features of this schedule are:

- Schedule flexibility — [redacted]
- Spacecraft delivery — [redacted]
- Payload delivery — [redacted]
- Mission schedule — 41 months to launch

Figure 3-4, Baseline Implementation Schedule [revised], goes here

4. System Engineering Role

A system engineering (SE) manager will be dedicated to the program for the entire contract duration. The SE will transition to project engineering functions after the MDR and will be a key contributor during verification. The system engineer reports to the program manager and is supported by specialists as required. In addition to the requirements flowdown process described below, the system engineer:

- Serves as the primary customer technical contact
- Develops and maintains bus Interface Control Documents (ICD) for the payload and ground segment
- Supports development of the launch vehicle ICD
- Performs risk identification and abatement
- Analyzes mission-specific issues that may affect system performance
- Serves as a catalyst to foster formal and informal communication throughout the program, including both internal and external meetings
- Monitors the entire design to ensure that performance margins are sufficient, yet not excessive
- Performs or supports system- or bus-level trade studies if required before MDR
- Manages specialty engineering disciplines

4.1 Requirements Analysis

During the period before MDR, the system engineering staff works with the customer technical team, to establish the detailed requirements for the bus and its impact on the other elements of the system. Ball's SE effort will contribute to the goal of firming up the lowest risk overall mission implementation. In support of this, Ball will analyze the impact on the modified core system of variations to requirements that are suggested by the customer. These include issues such as: operation time histories, payload interfaces, testing schedules and procedures, orbit parameters, and ground station utilization.

4.1.1 Requirements Flowdown

The requirements flowdown process is performed by system engineering and is done with a good understanding of the intent of requirements. These requirements are collected in the Mission Requirements Document (MRD) CDRL-18 and flowed down to the subsystem-level allocation of requirements. SE, design, and test personnel ensure that requirements are verifiable by test, analysis, similarity, or inspection. Requirement allocation culminates in an "allocated baseline" at MDR as detailed in the Mission Requirements Document (CDRL). A verification matrix of the above requirements is included in CDRL-1, Mission Performance Verification Plan, which is provided as part of the mini-proposal. The verification matrix will be updated at MDR with freezing of the baseline.

4.2 Interface Definition and Maintenance

Ball applies the interface management approach to ICESat that proved successful in managing internal and external interfaces on satellite programs such as ERBS, RME, CRRES, LOSAT-X, Radarsat, DARPASAT, and GFO.

Interfaces are identified, defined, and controlled by the system engineering part of Ball's team. Each interface is documented in a separate ICD. ICDs detail the interfacing functions and requirements, and Ball is accountable for their development and maintenance.

CDRL 2, External Interfaces, Models, and Analysis, will be the controlling document for all interface definitions. Ball will provide the following ICESat/GLAS interface simulators/templates per the schedule in Figure 3-4:

1. Certified high-fidelity drill template for the GLAS mounting bracket which defines the size and location of the mounting bolts as well as the instrument alignment.
2. Spacecraft-to-GLAS Data Simulator which duplicates the GLAS electrical interface with the spacecraft in terms of primary and keep-alive power, primary power feeds, data protocols, and clocking. The simulator will be used to verify the interface electrical performance with the Spacecraft prior to instrument delivery.
3. Spacecraft-to-Ground Data Simulator which duplicates the uplink and downlink content with the ground segment in terms of telemetry framing, GPS solutions channel, CCSDS protocol

and formats, housekeeping data, etc. The simulator will be used to verify the data interface performance with the EOSDIS.

Section 5, Appendix A of the Performance Specification, and the Launch Vehicle and Ground Station ICDs from QuickBird or GFO will be modified, if necessary, during the baselining of the design before MDR. Preliminary ICDs for all the interfaces will be available 30 days prior to MDR, where they will be presented to the customer for final approval.

Integration of the observatory to the launch vehicle will be controlled by and maintained in the launch vehicle documents, written and controlled by the government. Ball will provide all needed supporting information in CDRL 4. Ball will also produce the Missile System Prelaunch Data Package defining integration and test procedures which conform to range safety. Launch site compatibility testing, interface hardware and software verification, final mating, and integrated checkout, which ensure spacecraft compatibility with the launch vehicle, are detailed in this document. During the processing cycle, launch site communication link verification with the spacecraft C&DH system and range safety testing will be performed. Each step of the integration to the launch vehicle is controlled by procedures and checklists to ensure configuration control. Ball and LV personnel will both participate in prelaunch, launch, and postlaunch activities to ensure a successful launch.

4.3 Reliability Analysis

Ball will update the existing analysis of the RS2000 reliability and report the results at the MDR, highlighting any potential reliability concerns. The analysis will be revised if design changes occur after this review. The performance of the reliability analyses is structured to: (1) ensure adequate safety margin between part stress ratings and the application and usage stress, and (2) provide the bus reliability prediction. It is assumed that no updates are required for the ICESat mission.

Ball will maintain an integrated and proactive reliability program throughout the contract period that is structured to ensure that performance and reliability objectives are achieved. Key elements of the program include continued application of the parts control program (described in paragraph 2.5 of the Product Assurance Plan), plus a structured set of analyses for new and modified designs (described in paragraphs 2.4.1 through 2.4.4 of the Product Assurance Plan), and a closed-loop failure reporting, analysis, and corrective action system (described in paragraph 2.4.5 of the Product Assurance Plan).

The following subsections identify the analyses being performed.

4.3.1 Parts Stress Analysis

Part level electrical and thermal stress analysis will be performed only for new designs to verify that adequate operating margins are used. Where indicated by the analysis, corrective actions will be implemented or rationale for retention justified.

4.3.2 Worst-Case Circuit Analysis

Worst-case analysis for the ICESat bus will be reported at the MDR. New worst-case analyses will only be performed on critical circuits in new or modified electronics to ensure that they will accomplish all functional requirements, within the performance margins, under the most unfavorable combination of realizable conditions. It is assumed that no new worst-case analysis is required for the generic mission.

4.4 Safety

A system safety program will be implemented to ensure the safety of personnel, flight equipment, facilities, and other equipment. The ICESat dedicated safety engineer will coordinate the safety effort and will have responsibility for the following tasks:

- Preparing a System Safety Program Plan in compliance with EWR 127-1 requirements. The System Safety Program Plan will define safety program responsibilities and authority, program interfaces, safety milestones, safety tasks, and safety task outputs.
- Special safety attention will be given to laser operations during all ground testing activities. These safety plans will be fully described in CDRL 6, Spacecraft and Observatory Integration and Test (I&T) Plan.
- Ball will provide analysis to mitigate orbital debris from launch vehicle release through operations, to the end of the mission and re-entry. See Performance Specification, Section 5.5.

- Identifying applicable safety requirements by completion of a review of the spacecraft systems, GSE, and operations against EWR 127-1, OSHA standards, and other federal, state or local regulations
- Communicating safety requirements to the appropriate program personnel
- Performing analysis to identify hazards associated with flight equipment, GSE, and operations. Hazards analysis will identify hazard causes and assess the risk of mishap associated with each hazard. Hazards will be documented on hazard reports and tracked to resolution by elimination or control that achieves acceptable risk of mishap. Observatory hazards will be documented in the Payload Hazard Report.
- Ensuring that appropriate controls are incorporated through design or procedures for each hazard in compliance with the requirements defined in EWR 127-1, OSHA standards, or other federal, state, or local regulations
- Preparing program safety documentation including the Missile System Prelaunch Safety Package (MSPSP) required by EWR 127-1. The MSPSP will be developed and submitted in accordance with Item 13 of the CDRL.
- Coordinating safety program activities within the program and with external entities including the customer safety organization, payload organizations, the launch vehicle contractor, and the launch site safety organization.

Section 13.2 (Product Assurance Plan) has additional safety-related information.

4.5 Configuration & Data Management (C&DM)

C&DM is accomplished as an element of the program management function with appropriate support and interface with the Ball C&DM organization.

4.5.1 Data Management (DM)

Data is prepared by the project team for all program CDRLs and necessary operating information. Subcontractors support Ball in developing data and provide their own data, as defined in the subcontractor data requirements lists (SDRL), which are incorporated by Ball into the program data system.

The program configuration and data manager is responsible for managing the data system used for preparing and controlling technical and administrative documents. The data system and configuration management systems are performed jointly. Program data will result from the following efforts:

- Contract deliverable data per program CDRL
- Program data
- Supplier-generated data

The program CDRL defines the content and delivery schedule for all formal documents. The configuration and data manager prepares detailed schedules for each document and identifies the personnel responsible for preparing the data. A controlled file is maintained by the configuration and data manager for originals and extra copies. All issues are logged to identify current issue and approval status, when applicable. All changes to documents are clearly identified in the change log accompanying each document as well as the authority or reason for the change.

At the start of the program, the configuration and data manager identifies the various program disciplines, the categories of documents, and the numbering system to be used. The data accession list, lists each document and any revisions. The originals are filed by the configuration and data manager. Typical documents under this category are supplier's SOWs, engineering analyses, and test reports.

The Ball systems engineering report (SER) also falls into this category. The program will use the SER to document engineering studies, calculations, analyses, and other pertinent engineering information throughout the program. The SER is used to disseminate information internally and retains the information until such time that it is recorded in formal program documentation or no longer needed.

Ball flows the data requirements down to suppliers, as necessary, to ensure that sufficient backup information is generated to fulfill the CDRL requirements. All supplier data requirements are detailed in a supplier data requirements list accompanying each SOW.

Ball's data management system prevents the improper dissemination of competition sensitive information identified by the Principal Investigator.

4.5.2 Configuration Management (CM)

Ball uses an efficient configuration management process during detailed design, fabrication, test, delivery, and operations. This process is based on CM approaches of MIL-T-31000, MIL-STD-100E, MIL-STD-490, MIL-STD-973, MIL-STD-498, and NASA Software Development Standards, with appropriate reviews and approvals.

Engineering changes will be classified as Class I or Class II and documented on engineering order (EO) forms. Class I changes are revision to baselined documents such as interface control drawings and will be controlled accordingly. Ball implements an engineering document release tracking system that schedules the need date for each document and tracks its progress toward that date to ensure engineering availability to support procurement, fabrication, and test schedules. Engineering changes are also tracked through this system to ensure timely release.

CDRL 15, Engineering Change Proposals (ECPs), Deviations, and Waivers, will be the controlling document for ECPs as well as any requests for deviations and waivers.

As-designed configuration data is computer accessed by production and quality assurance (QA) to ensure the correct configurations are being fabricated, assembled, and tested. To support testing, a redline drawing control system will be implemented to document and control test procedure changes to correct problems identified during testing. The redlines must be officially incorporated and released before QA acceptance of the tested article. As-built vs. as-designed configurations are verified.

Subcontractor's CM systems are reviewed by Ball to ensure configuration control of procured components.

Software CM activities are controlled by Ball's integrated Software Development and Management Control System. This system covers engineering, configuration management, QA, and test activities. Controls are implemented throughout the software lifecycle. The software development engineer controls the configuration prior to the release of the software. Subsequently the software configuration is controlled within the CM system.

4.6 Instrument and Mission Accommodations

4.6.1 Instrument Accommodations

To ensure instrument needs are met, Ball will assign an instrument accommodations engineer to the ICESat program. In most cases, this person will have experience directly relevant to the mission's instrument. Since Ball realizes that it is the *instrument* that provides the data justifying the mission's expense, the instrument accommodations engineer will serve as a consistent advocate for the instrument developer's needs. This person will support development of the IICD, Spacecraft and Observatory I&T Plan, the Contamination/Cleanliness Control Plan, and External Interfaces Models and Analysis documents.

A Spacecraft Simulator will be provided at the instrument builder's facility that will allow all electrical instrument interfaces to be verified prior to integration into the spacecraft.

A high-fidelity drill template will also be provided per the schedule presented in Figure 3-4.

4.6.2 Mission Accommodations

For ICESat, BATC will supply the spacecraft bus, integrate the instrument, test the observatory, and support the launch campaign. We will support the ICESat Project Office as the lead in allocating requirements among mission elements.

Ball will work closely with NASA flight operations engineers to ensure that this interface is well understood. The system engineer will ensure that key interfaces are implemented, with support from the communications subsystem and flight software lead engineers, and will lead development of a mission-specific Flight Operations Support Plan (CDRL 10) and Spacecraft Operations Description Manual (CDRL 8). Training will be led by a Ball mission operations specialist taking advantage of subsystem procedures used for compatibility and performance testing.

Twenty-four hours of training for NASA flight operations personnel will be provided. These flight operators will receive important training and experience by operating the observatory during thermal-vacuum testing. Two shifts of three operators each are assumed during this testing.

Ball will work closely with launch vehicle engineers from the LV supplier, NASA, and the launch site to ensure this interface is addressed adequately. The system engineer will ensure that key interfaces are agreed upon, with support from the mechanical, power, and propulsion lead engineers. Ball will prepare the LVD (CDRL 4), Observatory Launch Site Ops and Test Plan and Procedures (CDRL 11), MSPSP (CDRL 13), and Transportation and Handling Plan (CDRL 14) assuming a TBR launch from WTR.

4.7 Mission Design and Analysis

The following mission-specific analyses are planned ICESat, reflecting the idiosyncrasies of specific orbits, launch dates, launch vehicles, and ground station locations. Ball program personnel will include a number of multi-discipline engineers who can perform and document these analyses. The analyses we plan to perform are:

- **Radiation Environment** — Specific orbit conditions will be analyzed for radiation dose predictions and single-event upset environments. These analyses will be performed by an experienced analyst available through Ball's engineering directorate, using [redacted] These analyses will be used to justify spot-shielding to protect particular components judged to be susceptible to radiation.
- **Orbit Acquisition/Maintenance** — The mission's specific orbit and configuration will be used to generate predictions for nominal and worst-case ΔV and burn frequency. These analyses will be performed by program personnel supporting related activities, using tools such as [redacted] These analyses will be used to verify the propellant load for the selected operational altitude, and evaluate alternatives to ensure the availability of required fuel throughout the mission's specified duration.
- **Initialization Planning** — The details of how to transition from the as-launched state to a designated benign on-orbit state will be addressed based on launch vehicle, launch site, ground station locations, instrument constraints, and orbit conditions. An initialization timeline will be provided, including key inputs to the at-launch memory load to be used for

detumble and autonomous sun acquisition. These analyses will be performed by program personnel supporting related activities.

- **Normal Operations Planning** — Data contact scenarios and optimization trades will be done in support of the mission design process including safe modes and power-down sequences. A total of [redacted] of support to this customer-lead activity is planned.
- **Structural Analysis** — Finite-element structural model of the bus will be provided. This will be combined with a GFE model of the instrument to yield an observatory model.
  - Structural analysis of the instrument and launch vehicle interfaces as defined in the ICDs
- **Thermal Analysis** — Analysis of the bus and observatory. A simplified GFE instrument model will be incorporated.
- **Ground System Compatibility Analysis** — Verification of telemetry protocols, data rates, and link budgets. A spacecraft-to-ground simulator will be provided to verify the data interface performance with EOSDIS. It will duplicate uplink and downlink content in terms of telemetry framing, GPS solutions channel, CCSDS protocol and formats, housekeeping data, etc. This simulator will be of the same fidelity as provided for the GSFC QUIKScat mission. It is recommended that a special definition study (EOSDIS interface compatibility) be performed early in the program.
- **Product Assurance Analyses** — See Section 4.3
- **Other** — All analyses will be performed as required to satisfy the Data Item Descriptions in Reference 2 for CDRL submittals.

Ball engineers will identify how these mission analyses impact component, subsystem, and flight software performance. The requirements levied through the RFO, ICDs, and other sources will be subjected to classic flowdown to subsystems and components, and to the Mission Performance Verification Plan.

4.8 Failure Modes and Effects Analysis and Critical Items List

The Failure Modes and Effects Analysis (FMEA) for the RS2000 will be updated and documented to identify the failure modes and their effect on the mission. This FMEA is at the component interface subsystem and system levels. The analysis identifies single-point failures that could propagate, inhibit redundancy switching, or cause additional failures. All single-point failure modes are identified. The Critical Items List (CIL) will be updated and maintained based on the results of the FMEA. FMEA results will be presented at the MDR and submitted to GSFC per CDRL 16.

The RS2000 has a predicted probability of success of [redacted] over a 5-year mission duration. Prediction analysis was based on MIL-HDBK-217 and similar equipment techniques. This high level of predicted reliability reflects our emphasis on early "front end" involvement in design, analysis, and parts control/standardization.

Our approach to reliability includes:

- A parts program that stresses high reliability and quality
- Use of proven designs
- Adequate margins verified by worst-case and derating analyses
- Use of redundancy to eliminate most single point failures
- Designs that provide low thermal and radiation environments for electronic parts

The LAM requirement of a minimum probability of success (POS) of [redacted] for a three-year mission is met by the basic ICESat design.

5. Contamination Control and Materials & Processes Control

Contamination Control and Materials and Processes Control approach is included in CDRL 17, Contamination/Cleanliness Control Plan.

6. Mission Performance Verification

We will use an automated approach to tracking verification requirements to provide an effective means to flow down test requirements and immediately report meaningful test results. **Figure 6-1** illustrates the flowdown of verification requirements and associated analytical and test results with the original requirements. The test requirements will be put into a database and are associated with test methods, test levels, test procedures, test equipment and GSE. The output of the database will be used to generate the test matrix, test procedure outlines, and GSE design requirements. As test and analytical results become available, they will be associated with the originating verification requirements, ensuring that all requirements are met. The database can be used as a paperless representation of Verification Plans, Test Requirements Documents, Test Data Summaries, etc. The data may be extracted and printed if any of these documents are desired by the customer.

This system simplifies the flowdown of system requirements to lower level testing. This process allows early verification of system requirements thus reducing overall program risk. The Mission Performance Verification Plan (CDRL No. 1) detailing the I&T and on-orbit verification process is submitted as part of the mini-proposal phase. However, the verification matrix included in this CDRL will only be final at MDR.

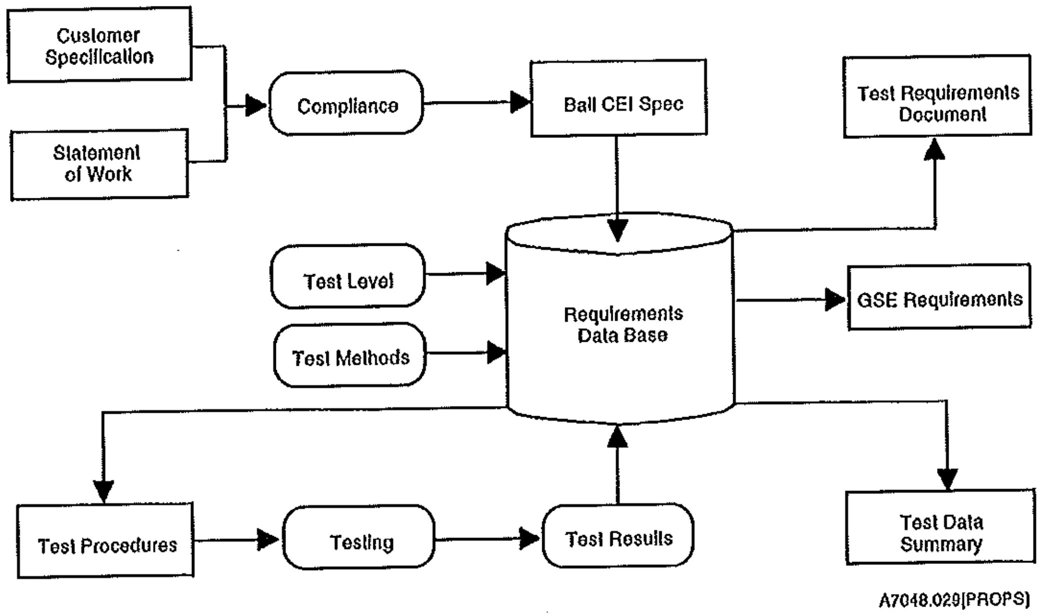

Figure 6-1. Computer-based Test Requirements Tracking and Reporting

6.1 Core System Integration and Test, Observatory Integration andTest

The matrix shown in **Figure 6-2** [revised verification matrix provided below] represents the verification matrix for the ICESat Mission. A similar matrix for the Observatory details the requirements traceability. This matrix shows the methods (analysis, test, demonstration, and inspection), level (component, subsystem, bus, observatory), and location in the bus and observatory I&T flow that the requirements will be verified.

6.2 On-Orbit Verification

Ball will provide on-orbit verification per the checkout plan described in Sections 12.2 and 12.4. The checkout plan will be developed based on the mission-defined performance specifications, test requirements document, spacecraft operations manual, and the flight operations support plan. Results of the on-orbit performance tests will be compared to predicted values and test values and summarized in the 30-day on-orbit performance report.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

7. Core System Integration and Test

The Core System Integration and Test approach is included in CDRL 6, Spacecraft and Observatory Integration and Test Plan.

8. Observatory Integration and Test

The Observatory Integration and Test approach is included in CDRL 6, Spacecraft and Observatory Integration and Test Plan.

9. Storage, Transportation, and Handling

CDRL 14, Transportation and Handling Plan, is provided with this offering. CDRL 17, Contamination and Cleanliness Control Plan, addresses contamination control (Sections 9.1.3 and 9.2.3) and Environmental Controls and Monitoring Equipment (Section 9.1.4).

Movement between facilities at the launch site (addressed in Section 9.2.5) will be launch vehicle and processing facility dependent. The Observatory will be enclosed in a launch vehicle payload can and moved by specialized transports designed specifically for this task. Ball will contract this activity to the launch vehicle manufacturer. Special attention to GLAS handling and cleanliness requirements will be given during this activity. CDRLs 11 and 12 will define the details.

10. Observatory Launch Site and Operations

Ball's launch site processing approach, enabled by years of experience with several different launch vehicles, [redacted]

We will use either the Integrated Processing Facility (Bldg 836) and Hazardous Processing Facility (Bldg 1610) or the Astrotech Payload processing Facility for the observatory launch site checkout, spacecraft propellant loading, and encapsulation operations. After the spacecraft and support equipment are inspected, [redacted] Propellant loading operations will be performed by the Ball team using the Ball propellant loading cart previously used on Radarsat and soon to be used on GFO and QuickBird spacecraft. Following encapsulation with the fairing, the observatory will be ready for transport and integration with the launch vehicle.

All operations will be accomplished using pre-approved processes and procedures. Ball will submit an observatory Launch Site Operations and Test Plan (CDRL 11) to provide a detailed understanding of launch site processing and testing planned for the Observatory. Included in this plan will be activity timelines, facility needs, staffing plans, responsibilities, fueling methods, cleanliness requirements, and any other special needs for operations at the launch site. This plan will be the basis of agreement with the WTR and it will define the needs for launch site test procedures. Preliminary observatory Launch Site Operations and Test Procedures (CDRL No. 12) will be submitted when required by the Launch Vehicle Contractor and Range Safety with the final submittal at the PSR. These procedures are written to provide a complete understanding of all planned activities that are to be carried out at the launch site.

10.1 Schedule

Figure 10-1 shows the planned spacecraft activities leading up to launch. It should be recognized that actual duration will be launch vehicle and observatory dependent. [redacted] Ball will provide 30 days of ICESat on-orbit support at GSFC.

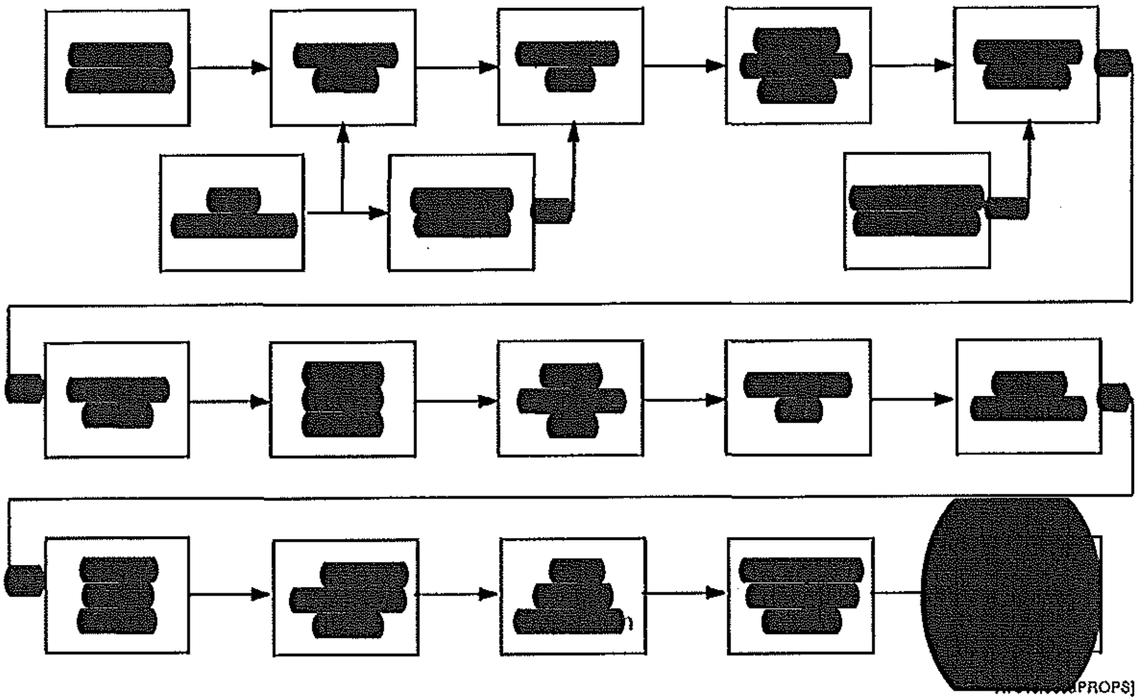

Figure 10-1. Typical Launch Site Operations

10.2 Government-Furnished Facilities and Resources Needed

Ball will use the government facilities provided for payload integration at the Integrated Processing Facility (Bldg 836) and Hazardous Processing Facility (Bldg 1610). Flight and mock-up LV attach fittings are assumed as GFE.

10.3 Planned Fueling Methods

Fueling will be performed by a certified fuel loading team from Ball that has had experience in this operations. Ball has a propellant loading cart that has been used with previous spacecraft. The Ball fuel loading team will arrive at the launch site 1 week prior to the actual loading operation to begin activities associated with it. This starts with the checkout of all GSE and review of the hazardous procedures. Once the spacecraft is ready for fuel loading the highbay will be prepared for hazardous operations. Hydrazine will be delivered and SCAPE operations will commence on day 1. [redacted]

[redacted]

10.4 Cleaning and Cleanliness

CDRL 17, Contamination and Cleanliness Control Plan, is provided with this offering.

10.5 Special Test Equipment

Ball will place the Power Control Console (PCC) on the launch tower or in the blockhouse. [redacted]

10.6 Communications

Ball will conduct end-to-end testing to verify ground station compatibility prior to fairing closeout. The current spacecraft configuration requires S-band and X-band RF links to support this test. Hardline interfaces will also be required between the PCC and STOC during pre-launch activities.

11. Operational Flight Software Maintenance

The Ball Software Engineering Manual (SEM) defines standards and practices that will be used throughout the software development process. These procedures serve as the guideline for the development process and documentation requirements. Software Quality Assurance ensures compliance with the SEM and the Software Development Plan.

11.1 Heritage

The core system flight software will be the [redacted]

11.2 Software Development Process

[redacted]

[redacted]

On-orbit checkout will be performed by verifying that the SCC is processing data from the star trackers, inertial reference unit, coarse sun sensors, and magnetometers to determine spacecraft attitude, performing attitude error correction via actuator commands, and accepting table load and dump operations.

11.3 Documentation

Documentation for the ICESat software includes:

- Software Development and Verification Plan
- CSCI software development folder containing:
  - CSCI requirements
  - CSCI review materials
  - CSCI integration test material
  - CSCI integration test results
  - FQT material
  - FQT results
- CSC software development folder containing:
  - Structure charts
  - CSCI requirements allocated to the CSC
  - CSC structure charts
  - Timing and sizing estimates
  - CSC integration test material
  - CSC integration test results

- CSC review materials

- CSU software development folder containing:
  - CSCI requirements allocated to the CSU
  - CSU structure charts
  - PDL
  - Source code listings
  - Code walkthrough results
  - CSU test materials
  - CSU test results

Documentation produced during the software development effort for ICESat includes:

- ICESat Spacecraft Bus Flight Software Requirements Specification
- ICESat Spacecraft Bus Flight Software Preliminary Design Document
- Software Development Folders containing detailed design for units which required modification of the ICESat mission
- ICESat Flight Software Formal Qualification Test Report

11.4 Rights

Source code will be provided with the delivered core system for the exclusive use on that spacecraft only. The flight software is Ball company proprietary and may not be distributed or used for any other purpose other than the delivered core system.

11.5 Configuration Control

The Software Configuration Management Plan defines use of the Software Change Control System (SCCS) for software configuration control. Following the software requirements review, requirements changes or additions are initiated by a Software Change Request (SCR). The requirement and other affected items (design information, source code, test material, etc.) are updated accordingly. The existence of an SCR for each requirement change facilitates record-keeping as to why a requirement was added or changed. CDRL 15, Engineering Change

Proposals, Deviations, and Waivers, will be the mechanism for documenting all contractual changes, deviations, or waivers.

A source code Software Development Library (SDR) is maintained using the UNIX SCCS software configuration management tool. Computer Software Units (CSU) and all associated unit test material is placed under configuration management following completion of unit test. When a CSU is first placed under configuration management, it is assigned a revision number of 1.1. Subsequent changes to the module result in incrementing the revision number to 1.2, 1.3, etc. Following FQT, the revision number is changed to 2.1. If for any reason FQT is repeated, the leading digit of the revision number is incremented again.

After release of a unit to software configuration management, the following procedure is followed for changes as problems are found or requirements change: [redacted]

11.6 Maintenance and Modifications

Following delivery of the flight software, [redacted] Periodic maintenance will be performed on the software test bench to maintain the operational readiness of the bench. This maintenance will be in the form of a test that exercises the interfaces (sensors and actuators) to the software function properly and verifies the ability to send commands and display telemetry. Maintenance tasks after observatory acceptance will be provided by a dedicated ICESat testbed for the five-year mission as required by special task order.

12. Operations Support and Transition

Details of the Flight Operations and Transition approach is provided in CDRL 10, Flight Operations Support Plan..

13. Miscellaneous

13.1 Special Studies Implementation Forms (Example)

Examples of forms used to implement special studies follow.

13.2 Product Assurance Plan

Ball's Product Assurance Plan is provided in the original RSA proposal.

13.3 Data Item Description (DID)

A DID follows for CDRL 18 entitled Mission Requirements Document.

Table of Contents
Spacecraft Performance Specification

PERFORMANCE SPECIFICATION DEVIATION SUMMARY MATRIX

The Offeror shall show for each numbered section of the Spacecraft Performance Specification whether ICESat text is the SAME as the RSDO contract, MODIFIED, or DELETED.

SECTION HEADING		SAME/MODIFIED/DELETED
1.	SCOPE	Modified
2.	REFERENCE DOCUMENTS	Modified
3.	SPACECRAFT PERFORMANCE CHARACTERISTICS	Same
3.1	Observatory Performance	Same
3.1.1	Launch Vehicle Compatibility	Modified
3.1.2	Orbit Compatibility/Constraints	Modified
3.1.3	Cleanliness Levels Required	Modified
3.1.4	Design Lifetime	Modified
3.2	Spacecraft Performance	Same
3.2.1	Mass Characteristics	Modified
3.2.2	Electrical Payload Power	Modified
3.2.3	Propulsion Performance	Modified
3.2.4	Attitude Control Performance	Modified
3.2.5	Command and Data Handling Performance	Modified
3.2.5.1	Commanding	Modified
3.2.5.2	Telemetry	Modified
3.2.6	Communications Performance	Modified
3.2.7	Thermal Control	Modified
3.2.8	Electrical	Same
3.2.8.1	EMI/EMC Environment	Modified
3.2.8.2	Magnetic Performance	Same
3.2.8.3	ESD Sensitivities	Modified
3.2.9	Radiation Tolerance	Modified
3.2.9.1	Total Dose	Same
3.2.9.2	Single-Event Effects	Same
3.2.10	Safe Modes	Modified
4.	SUBSYSTEM CHARACTERISTICS	Same
4.1	Overall Spacecraft Architecture	Modified
4.1.1	Structural/Mechanical Subsystem	Modified
4.1.2	Power Subsystem	Modified
4.1.3	Propulsion Subsystem	Modified
4.1.4	Attitude Control Subsystem	Modified
4.1.5	C&DH Subsystem	Modified
4.1.6	Communications Subsystem	Modified
4.1.7	Thermal Control Subsystem	Modified
4.1.8	Spacecraft Flight Software	Modified
4.1.9	Spacecraft Ground Support Equipment	Modified
4.1.10	TT&C Ground System Equipment(TT&C)	Same
4.1.10.1	Spacecraft Test and Operations Center	Same
4.1.10.2	Command Modulation Equipment	Modified
4.1.10.3	Telemetry and Data Acquisition	Same
4.1.10.4	Mission Operations Software	Same
4.1.10.5	Spacecraft Event Prediction and Command Management	Same
5.	PAYLOAD ACCOMMODATIONS	Same
5.1	Physical Requirements	Same
5.1.1	Spacecraft Coordinate System	Modified
5.1.2	Available Payload Envelope	Modified
5.1.3	Mass	Modified
5.1.4	Payload Center of Mass	Modified
5.1.5	Moments Of Inertia	Modified
5.1.6	Mechanical Interfaces	Same

SECTION HEADING		SAME/MODIFIED/DELETED
5.1.6.1	Mounting	Modified
5.1.6.2	Alignment	Modified
5.1.6.3	General Structural Design Requirements	Modified
5.1.6.4	Star Tracker Interfaces	Modified
5.1.7	Thermal Interfaces	Modified
5.1.7.1	Thermal Control Hardware	Modified
5.1.7.2	Multilayer Insulation	Same
5.1.7.3	Other Considerations	Same
5.1.7.4	Field of View Constraints (RF, Optical, Thermal)	Modified
5.2	Electrical Power, Data and Command Interface	Same
5.2.1	Data Bus Interface Protocol(s)	Same
5.2.1.1	MIL-STD 1553B Narrow Band Serial Digital Interface	Same
5.2.2	Maximum Payload Data Ingest Rate	Same
5.2.3	Payload/Spacecraft Bus Synchronization	Same
5.2.4	Electrical Power Interface	Same
5.2.4.1	Power Availability	Modified
5.2.4.2	Voltage	Same
5.2.4.3	Ripple	Same
5.2.4.4	Under Voltage	Same
5.2.4.5	No Voltage	Deleted
5.2.4.6	Reverse Voltage Protection	Same
5.2.4.4	Conducted Transient Voltage	Same
5.2.4.8	Raw Input Current	Same
5.2.4.9	Line Impedance Simulation Network	Same
5.2.4.10	Raw Input Application and Removal	Same
5.2.4.11	Payload Heater Power Load Requirements	Deleted
5.2.4.12	Power Control Unit Interface	Same
5.2.4.13	Electrical Grounds, Returns, and References	Same
5.2.5	Solid State Recorder Interface	Modified
5.2.5.1	Performance Summary	Modified
5.2.5.2	Commands	Same
5.2.5.4	Record Data	Same
5.2.5.6	Bit Error Rate	Same
5.2.5.4	Data Capacity	Modified
5.2.5.8	Memory Management	Same
5.2.5.9	SSR Telemetry Outputs and Test Points	Same
5.2.5.10	Wideband Parallel Digital Data Interface	Same
5.2.5.11	Wideband Data Signal Characteristics	Same
5.2.5.12	Data Timing	Same
5.2.5.13	Cross-Strapping of Payload to SSR	Deleted
5.2.6	Low Rate Telemetry Interface	Same
5.2.6.1	Telemetry Signals	Same
5.2.6.2	Analog Telemetry	Same
5.2.6.3	Thermistor Telemetry	Same
5.2.6.4	GPS Handling	New
5.2.6.5	GLAS Data Handling	New
5.2.7	Command Interface	Same
5.2.7.1	Discrete Command Signals	Same
5.2.8	Harnesses	Same
5.2.8.1	Spacecraft-to-Payload Cabling	Same
5.2.8.2	Intrapayload Cabling	Same
5.2.8.3	Spacecraft-to-Payload Connectors	Same
5.2.8.4	Intrapayload Connectors	Same
5.2.8.5	Flight Plugs	Same
5.2.9	EMI/EMC	Same

SECTION HEADING		SAME/MODIFIED/DELETED
5.2.9.1	Electrical Bonding	Same
5.2.9.2	Separation and Shielding of Circuits	Same
5.2.9.3	Emissions and Susceptibility	Same
5.3	Software Applications	Modified
5.4	Payload Environmental Requirements	Modified
5.5	Safety	Modified
5.6	Ground Support Equipment	Modified
5.6.1	Platform Simulator Description	Same
5.6.1.1	Spacecraft Simulation	Same
5.6.1.2	Dynamic Orbit Simulation	Same
5.6.1.3	GSE Command and Telemetry Processing System (CTPS)	Same
5.6.2	Architecture and Ground Support Equipment	New
5.6.3	Handling of GLAS GSE	New
5.7	Operational Factors	Same
5.7.1	Test Scenarios	Same
5.7.2	Commanding	Modified
5.7.3	Telemetry Recovery	Modified
5.7.4	Operational Duty Cycle	Modified
6.	Options to the ICESat Bus	Deleted
6.1	Battery Open Cell Bypass Protection	Deleted
6.2	Changes to ICESat Performance	Deleted
6.3	Description of the Option	Deleted
6.4	Modifications to Payload Interface Description	Deleted
6.5	Deviations to the Mission Implementation Specification	Deleted
7.	System Engineering Reports (SERs) in Support of Changes	New

ATTACHMENT B
NAS5-97251, Delivery Order #3
ICESAT (LAM)

ICESAT (LAM)
Performance Specification

Section 1. ICESat Spacecraft Performance Specification

1. Scope

This specification describes the RS2000 spacecraft bus as applied to the ICESat mission. ← ok?

2. Reference Documents

The following documents support the specifications described in this document.

Government Documents

MIL-STD 461C	Requirements for Control of Electromagnetic Interference Emissions and Susceptibility
MIL-STD 883	Microcircuits
MIL-STD 1246	Product Cleanliness Levels and Contamination Control Program
MIL-STD 1553B	Aircraft Internal Time Division Command/Response Multiplex Data Bus
	GLAS Instrument Description Document (10/24/97)
	ICESat Mission Operations Concept (Draft) (10/22/97)
	TurboRogue Space Receiver Instrument Interface Description (9/17/97)
	CCSDS 100.0-G-1: "Green Book," Issue 1 (12/87)

Commercial Documents

BATC #536971	Environmental Design and Test Specification Document
BATC #536991	Power Control Unit (PCU) Product Functional Specification
BATC #SP0031A-014	Reliability, Parts, and System Safety Handbook
BPS 27.20	Ball Process Spec-Cleanliness for Space Hardware
	Commercial Taurus Payload User's Guide (4/18/96)
	LMLV Mission Planner's Guide (9/97)
	ICESat Mission Performance Verification Plan
	ICESat Spacecraft and Observatory I&T Plan
	ICESat Flight Operations Support Plan (Draft)
	ICESat Transportation and Handling Plan
	ICESat Contamination/Cleanliness Control Plan

3. ICESat Bus Performance Characteristics

This section describes the top-level performance characteristics of the ICESat bus.

3.1 Observatory (Mission) Level Performance

3.1.1 Launch Vehicle Compatibility

The spacecraft has been designed to launch on a Cosmos SL-8 or a Taurus launch vehicle. It is also compatible with the LMLV-2 and Long March. The Taurus configuration uses the 92-in. payload fairing with the 38.81-in. separation system. The Athena-2 configuration uses the Model 92 payload fairing with the Model 47 payload separation system and adapter ring, on a 45° adapter cone. An Observatory cg offset 5.5 cm from the ICESat Z-axis (see Section 5.1.1) will be acceptable. The Government will select between the Taurus XL and Athena-2 no later than six months ARO, providing the adapter and any other required launch vehicle hardware and consumables as GFE.

ICESat is compatible with both the Taurus XL and Athena-2 performance, while supporting the GLAS payload. The Athena-2 allows direct insertion into the ICESat calibration orbit, while the lower-performance Taurus XL requires using a park orbit. From the user's guides, the Athena-2 provides 1080 kg performance to a 600 km, 94° orbit while the Taurus XL provides 980 kg to 400 km, 94°. Given the 300-kg GLAS mass, 780 kg and 680 kg, respectively, can be allocated for ICESat. As described in Section 4.1.1, the ICESat mass is ~~665~~ 670 kg including fuel and growth contingency. Sufficient fuel is carried to allow transfer from the Taurus XL park orbit to the calibration orbit; if an Athena-2 is selected, significantly more fuel will be available for other activities to improve ICESat science return.

3.1.2 Orbit Compatibility/Constraints

The ICESat spacecraft is designed to operate in low earth orbit nominally between 500 and 600 km and at inclinations between 0 deg and approximately 98 deg (sun-synchronous). Other orbits with altitudes as low as 400 km and as high as 900 km can be accommodated. Additional shielding for some electronics units and increased fuel load would be required for these orbits. Orbit eccentricities of up to approximately 0.07 can be accommodated without impacting the bus design. Orbits other than circular earth orbits are possible but would have to be evaluated on a mission specific basis.

ICESat shall support two separate orbits, as listed in Figure 3-0. The calibration orbit has an exact ground repeat every 119 revolutions (8 days), while the mission orbit has an exact ground repeat every 2723 revolutions (183 days). In both cases, perigee is at the northernmost latitude (a frozen orbit). The coordinate system is True-of-Date, Earth equator and equinox.

Element	Calibration Orbit (Mean Values)	Mission Orbit (Mean Values)
Semi-major axis	6971.5 km	6970.0 km
Eccentricity	0.0013	0.0013
Inclination	94°	94°
Argument of perigee	90°	90°
Launch Conditions		
Right ascension of ascending node	105°	
Launch Site	WTR	
Launch Date	7/1/01	

Figure 3-0. ICESat Orbit Elements

Once acquired, the groundtracks of both the calibration and mission orbits will be maintained to an equator crossing accuracy of ~800 m (E and W) of a reference groundtrack (no drag repeat cycle) for the entire mission.

If the Taurus XL is used, ICESat will need to use a park orbit. Pending optimization with the launch vehicle supplier, a 400-km circular park orbit is baselined. This will provide a 9-month drag life to eliminate premature reentry from concern.

After basic checkout, a series of thruster burns will be planned to efficiently transfer from the Taurus XL or Athena-2 injection orbit to the calibration orbit, raising altitude while correcting inclination errors and placing argument of perigee. To acquire the calibration orbit from the injection orbit, up to 30 separate burns will be needed.

The calibration orbit shall be acquired within ten days of launch. 90 days will be spent in the calibration orbit, with groundtrack trim burns occurring twice a week. No yaw transitions need be performed during the 90-day calibration orbit; alternatively, the last 8-day cycle can be accomplished without array articulation or maintenance burns (TBR). At the end of this interval, a pair of thruster burns will transfer down to the operational orbit.

Groundtrack maintenance burns will occur up to twice a week for the entire mission to compensate for the effects of atmospheric drag. Acceleration shall be ~0.005 m/s2, depending on the fuel tank's current pressure. Groundtrack maintenance burns will last from ~0.2 sec (impulse predictability limit) to ~400 sec (orbital efficiency limit), and shall provide a command range of 0.1 - 200 cm/sec per burn. A typical burn will require 5 cm/sec. Using atmospheric density predictions calculated from the Marshall Engineering Thermosphere model, density predictions vary from 0.36 g/km3 (+2σ in July 2001) to 0.012 g/km3 (-2σ in July 2006).

Groundtrack maintenance planning will avoid platform disturbances during critical science-gathering periods. At least 3 1/2 days will elapse between groundtrack maintenance burns; these will be largest and most frequent early in the mission when solar activity is highest. Groundtrack maintenance burns shall allow simultaneous correction of one or more of the following parameters:

- Semi-major axis
- Inclination
- Argument of perigee
- Eccentricity

Due to required off-pointing, GLAS data may be rendered invalid during groundtrack maintenance burns. All activities required for these burns (including off-pointing, burn execution, re-pointing, and full stabilization) shall be completed within 30 minutes. Groundtrack maintenance burns will be planned so that data recovery over Antarctica and Greenland is not compromised. These requirements will be waived if required for safety reasons.

ICESat will reenter within 25 years of mission completion, so a dedicated reentry burn is not required.

The overall delta-v budget calculated for ICESat is included in Figure 3-8.5. ICESat shall provide 152 m/sec of delta-v, satisfying mission requirements. This allocation is tailorable; should additional booster performance be available to achieve a higher park orbit, the fuel saved shall be available to enhance ICESat science return by correcting inclination in the presence of luni-solar perturbations (TBR).

3.1.3 Cleanliness Levels Achieved

Cleanliness, handling, and storage meet the requirements of Ball's internal process specification BPS 27.20 and MIL-STD-1246. ICESat assembly and integration and testing is performed in a Class 100,000 clean room. Payload assembly and integration with the spacecraft bus is performed in a class 10,000 clean room. For ICESat, all integration and test of the spacecraft after payload installation will take place within a Class 10,000 environment.

Before instrument installation the bus is maintained clean to visibly clean level 500C with solvent and aqueous cleaning. All components that interface with the payload are cleaned to a minimum level of 400B. Volatile components are baked out and cleaned at the unit level. Cleaned and vacuum-baked bags and mirror caps are used for all sensitive surfaces. Filtered and dry nitrogen is used to protect payload optical benches from moisture absorption. For shipment to the launch site, a sealed, dry nitrogen purged liner inside the shipping container is used.

A contamination plan is written for each program to specifically address the needs of that particular payload.

Further detail is included in CDRL 17, ICESat Contamination/Cleanliness Control Plan.

3.1.4 Design Lifetime

The ICESat bus' fully redundant architecture provides a 5-year mission life with a probability of success (Ps) of greater than [redacted] Should a shorter mission be desired, the Ps for a 3-year mission and 1-year mission are [redacted] and [redacted] respectively. Storage life is 12 months. There are no credible single point failures.

Figures 3-1 through 3-4 show the redundancy configuration of the major components of the ICESat platform.

[redacted]

[redacted]

Figure 3-2. [redacted]

[redacted]

The ICESat bus' expendable materials shall support a five years mission lifetime; it is likely to last twice as long. The bus expendables are:

- **Fuel.** The fuel budget shows over five years' worth of margin beyond ICESat's five-year design life. Although long-term atmospheric density predictions are notoriously difficult, the GSFC/Ball ERBS demonstrates that little fuel is required to offset atmospheric drag at ICESat's 600-km altitude.
- **Battery cycles.** The ICESat NiH_2 battery is qualified for 40,000 cycles at 40% depth-of-discharge (DOD). Further, the battery temperature is controlled between [redacted] to enhance its cycle life. For ICESat, only 80% of the orbits have eclipses so only 4,300 cycles per year are required. Although worst-case eclipses require a 37% DOD, the average eclipse requires a DOD <30%. Therefore, it is likely that the battery will provide at least five years additional performance beyond its five-year design life.
- **Solar array degradation.** The ICESat solar array may degrade up to 5% per year. This degradation will allow nominal ICESat operation for the required five-year mission. ~~Operational workarounds have been identified to reduce bus power consumption in years 4 and 5.~~ An additional five years of full operation can be provided by performing twice-an-orbit yaw steering at unfavorable orbit beta angles in the out years, and Ball's experience with LEO spacecraft (including ERBS) is that out-year solar array degradation is not severe.
- **MLI blankets.** MLI will degrade over the years, but not severely. At 600 km, ICESat is high enough to avoid significant blanket degradation due to atomic oxygen. Using SME's 8+ years on-orbit as an example, the ICESat MLI blankets will continue to allow effective thermal control for years past ICESat's design lifetime.
- **On-orbit contamination.** ~~ICESat's orbit (600 km, 94°) is nearly worst-case from the standpoint of optics contamination. If not considered, the combination of spacecraft charging and atomic oxygen could lead to unacceptable deposition on the cool GLAS receiver telescope, particularly with its relatively short, unscarfed, shroud.~~ ICESat's legacy is from a remote sensing bus; by design, it uses clean materials, is well grounded, and maintained at a relatively cool temperature. These factors all mitigate contamination concerns, minimizing GLAS degradation.

The only moving parts on ICESat are solar array drives, reaction wheels, and thrusters. All have qualified lifetimes well in excess of ICESat's five-year requirement.

3.2 ICESat Bus Performance

3.2.1 Mass Characteristics

The ICESat structure provides a stable and rigid platform sufficient to carry precision optical and similar payloads through all phases of development and flight. Payload capacity for the ICESat bus is [redacted] Higher payload masses may be accommodated with minor structural modifications. Combined mass and center of gravity constraints are given in Section 5. The ICESat bus mass, including fuel, the launch vehicle adapter, and growth contingency, is ~~665~~ 670 kg.

The first lateral bending mode occurs at [redacted] and the first axial mode occurs at [redacted] These mode frequencies are well above the Taurus XL minimum requirements of 20 Hz and 35 Hz, and the Athena-2 minimum requirements of 12 Hz and 30 Hz, respectively.

Figure 3-5 shows the worst case line of LOS jitter magnitude anticipated in the ICESat bus. It is based upon the maximum disturbance magnitude expected at each frequency. Without articulating the solar panels, the maximum expected disturbance out of all the sources is less than [redacted] for all frequencies. The figure shows the jitter for the cases with and without solar panel articulation during steady-state pointing.

The only deployable is the solar array. The solar array is composed of two wings, each having a six-point attachment to the bus. [redacted] The array deployment sequence is shown in **Figure 3-8**. In the deployed position a single-axis drive mechanism of the spacecraft can maintain the arrays normal to the sun line for any given pointing direction.

[redacted]

[redacted]

The location of the ICESat cg along the GLAS Z-axis shall ~~remain constant~~ be predictable to within 0.5 cm. After orbit raise, fuel depletion shall migrate the ICESat cg location no more than [redacted] along the GLAS X or Y axes over the five-year mission life. A simple algorithm shall be supplied to convert telemetered ~~hydrazine tank~~ pressure readings into corrections for cg location~~, essentially a linear migration along the Observatory centerline.~~ ~~Solar array articulation shall produce negligible cg shifts. No other sources shall alter the location of the RS2000 cg.~~

3.2.2 Electrical Payload Power

ICESat uses a [redacted] power system architecture to provide continuous power to all subsystems during all phases of the launch and mission for all candidate orbits. [redacted]

[redacted] provides power during eclipse. The bus voltage is 28 +6/-4 Vdc.

The power system is single-fault tolerant in that no single part failure in the subsystem will result in loss of the mission. Under-voltage protection results in [redacted] After any zero bus voltage condition, [redacted] assuming that environmental survival conditions have not been exceeded.

ICESat uses a pair of solar array wings with single-axis articulation. To allow adequate insulation, the spacecraft bus will occasionally perform yaw maneuvers. During periods of low orbit beta angle, the spacecraft yaw orientation will align the GLAS +X direction along the velocity (or anti-velocity -- TBR) direction. During periods of high orbit beta angle, the GLAS +X direction will be aligned along the orbit normal or anti-normal, away from the Sun. The transition from one yaw orientation to the other will occur when orbit beta angle is ~32°; several months will elapse between yaw transitions.

To enhance platform stability, [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

If these groundrules are adopted, [redacted]

The combination of ICESat's beta angle variation, [redacted] reduces the available power. ~~This may require modifying ICESat operations during years 4 and 5.~~ Total solar array output is affected by several mission-specific factors:

- End-of-life solar array degradation -23%

- Worst-case orbit-average cosine loss -27%
- Worst-case orbit-average self-shadowing loss -14%
- [redacted]
- Daylit orbit fraction +58%

These items do not stack up simultaneously. ~~Worst-case Observatory orbit-average power availability shall exceed~~ [redacted] ~~W for the first 3 5 years, and~~ [redacted] ~~W at 5 years. ICESat orbit-average power consumption shall not exceed~~ [redacted] ~~W for the first 3 years, dropping to~~ [redacted] ~~W at 5 years. Bus power conservation~~ [redacted] ~~may be needed during periods of unfavorable beta angle (~25—40°) during years 4 and 5, occurring in four separate 1-3 week intervals. This shall be achieved by reducing battery heater power or some other measure(s).~~

During science operations, ICESat shall provide ~~300~~ 350 W orbit-average, ~~350~~ 400 W (TBR) peak, for primary payload power for the entire five-year mission life. ~~After completing the baseline 5-year mission, twice-an-orbit yaw steering may be necessary. These maneuvers shall adhere to the same constraints as for array articulation (above).~~

3.2.3 Propulsion Performance

The propulsion subsystem is a mono propellant blowdown system that delivers thrust for orbit acquisition, orbit maintenance, and three axis attitude control. Nominally, the ICESat propulsion system is used for insertion error correction, drag make-up, attitude maneuvers, [redacted] The baselined tank configurations provide 164,000 N-s of impulse.

The placement of the thrusters has been designed to minimize contamination of optical surfaces caused by thruster plume impingement. Positive indication of thruster drive operation is provided when signals are generated to fire orbital control thrusters. [redacted]

The ICESat propulsion system will provide for orbit raising and injection orbit correction, attaining the calibration and mission orbits, and groundtrack maintenance for the five-year ICESat lifetime. Groundtrack maintenance will be consistent with Section 3.1.2. A delta-v of 152 m/sec shall be provided, with baselined usage summarized in Figure 3-8.5.

#	Item	Taurus XL Insertion Value	Taurus XL Insertion Δv (m/s)	Athena-2 Insertion Value	Athena-2 Insertion Δv (m/s)
1	Transfer from park orbit	200 km	111	not req'd	0
2	Transfer from calibration orbit	1.5 km	1	1.5 km	1
3	Drag makeup	nominal	15	nominal	15
4	Deorbit	not req'd	0	not req'd	0
5	Additional science allocation	not req'd	0	baselined	100
6	**Nominal (sum #1 - 5)**		127		118
7	Perigee insertion error	20 km	6	20 km	6
8	Apogee insertion error	40 km	11	40 km	11
9	Inclination insertion error	0.1°	1	0.1°	13
10	Additional drag makeup	+2σ	22	+2σ	22
11	**Dispersion (RSS #7 - 10)**		25		28
12	Requirement (#6 + #11)		152		146
13	Available		187		187
14	**Margin**	(23%)	35	(28%)	41

***Figure 3.8-5.** ICESat Delta-V Budget*

The thruster configuration shall keep the entire GLAS payload outside the thrusters' Prandtl-Meyer expansion cones, precluding plume impingement on the GLAS optics. Ultra-pure hydrazine shall be used to minimize contamination.

3.2.4 Attitude Control Performance

The ICESat attitude control and determination subsystem uses a star tracker, sun sensors and magnetometers for attitude determination. Four reaction wheels, three torque rods with redundant windings and drivers, and four hydrazine thrusters are used for control.

ICESat can handle all pointing orientations. Sun exclusion requirements are payload specific. [redacted]

The maximum momentum storage capacity about the pitch, roll, and yaw axes is 9 N-m-s. The settling time ~~to achieve the above steady state pointing accuracy is~~ [redacted] following a large <u>angle</u> maneuver [redacted] ~~Immediately a~~<u>A</u>fter a maneuver, [redacted] pointing knowledge and [redacted] are available. [redacted]

[redacted] For Earth-looking payloads the FOV limitations for slewing are [redacted] deg about the pitch and roll axes. For pointing orientation other than nadir, thermal issues, tracker intrusions, and wideband antenna pointing need to be examined on a mission specific basis.

The GPS time is also provided to the Spacecraft Control Computer (SCC). It can also be made available to other subsystems. [redacted] ~~All relevant ACS telemetry information is time-tagged using the GPS time reference to support 15 m geolocation requirements.~~

ICESat shall provide real-time attitude control and knowledge consistent with GLAS requirements. Safe-hold modes shall be provided for autonomous action in response to various mission-threatening faults (see Section 4.1.4).

Ball assumes star tracker performance comparable to that of a Ball CT-601 and IRU performance comparable to Litton HRG predictions, and that the interfaces used are electrically identical to and functionally ~~identical to~~ compatible with those used on the RS2000's CT-601 and Allied RLG. Ball assumes the onboard star catalogue is updated every [redacted] Uploaded ephemeris may also be required (TBR). On-orbit calibration will occur by using procedures developed for ICESat or through customer-provided procedures yielding comparable fidelity. These assumptions are inherent in the following performance specifications.

During science operations, attitude knowledge about all axes shall be less than 50 μrad (1σ) using the bus-only attitude determination suite and less than 20 μrad (1σ) when the GLAS star tracker and IRU are available.

The ICESat bus star tracker shall be mounted to the spacecraft bus. It shall be oriented ~20° from the GLAS -X axis, in the XZ plane. This orientation shall preclude:

- Sun outages of the bus star tracker simultaneous with those of the GLAS star tracker
- Earth outages for all attitudes with the GLAS +Z within 5° of nadir

[redacted]